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# The effect of a balance training programme on centre of pressure excursion in one-leg stance

Evert Verhagen [a], Maarten Bobbert [b], Melanie Inklaar [b], Marike van Kalken [b], Allard van der Beek [a,c], Lex Bouter [a], Willem van Mechelen [a,c,*]

[a] *Department of Public and Occupational Health, Institute for Research in Extramural Medicine, VU University Medical Center, Amsterdam, The Netherlands*
[b] *Faculty of Human Movement Sciences, Vrije Universiteit, Amsterdam, The Netherlands*
[c] *Body@Work Research Center for Physical Activity, Work and Health, TNO VUmc, Amsterdam, The Netherlands*

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**Abstract**

*Background.* Balance training is widely used in the rehabilitation after an ankle sprain and is thought to have a decreasing effect on postural sway. The present study investigated whether a 5.5-week balance training programme leads to a decreased postural sway showing in a reduced range of centre of pressure excursion.

*Methods.* Thirty university students participated in this study. Twenty-two untrained subjects were randomly assigned to either an intervention group ($n = 11$) or a control group ($n = 11$). The remaining eight subjects were participants in an organized volleyball competition and were assigned to an additional volleyball group ($n = 8$). All subjects of the intervention group and the volleyball group received a 5.5-week balance training programme, while subjects of the control group received no training. Centre of pressure of the ground reaction force was measured as a proxy measure of postural sway, using a force platform. Measurements took place before and after the 5.5-week training programme for standing on one leg (both for right and for left leg) of single leg stance, both for the eyes-open and eyes-closed situation. From these measurements centre of pressure excursion in the anterior–posterior and the medial–lateral direction was calculated. A linear regression analysis was performed to check for differences in centre of pressure excursion between any of the groups over the training period.

*Findings.* No differences in changes of centre of pressure excursion were found between any of the groups over the 5.5-week training period.

*Interpretation.* Balance training does not lead to a reduction in centre of pressure excursion in a general population consisting of non-injured and previously injured subjects.


*Keywords:* Centre of pressure; Balance training; Ankle stability; Prevention; Postural sway; Proprioception

## 1. Introduction

The ankle is at high risk for sports injuries. About a quarter of all injuries for a wide range of sports affect the ankle (Boruta et al., 1990; Jerosch and Bischof, 1996). Between 90% and 95% of all ankle injuries are acute ankle ligament injuries, i.e. ankle sprains, causing a partial or complete rupture of the anterior talofibular ligament and in some cases also the calcaneofibular ligament (Tropp et al., 1984). Freeman (1965) stated that trauma to mechanoreceptors of the ankle ligaments after an ankle sprain can produce a proprioceptive impairment in the ankle. This might explain the increased risk of

* Corresponding author. Address: EMGO-Institute, VU University Medical Center, Van der Boechorststraat 7, NL-1081 BT, Amsterdam, The Netherlands.
*E-mail address:* w.vanmechelen@vumc.nl (W. van Mechelen).

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re-injury within one year after an ankle sprain (Brand et al., 1977; Ekstrand and Gillquist, 1983; Tropp and Odenrick, 1988).

Since the publication of the study of Freeman (1965), a deterioration of the ability to maintain balance in single limb stance after an ankle sprain has been well documented (Hertel, 2000). Many balance parameters are altered, of which an increased area of postural sway during single limb stance is the most commonly described. Postural sway is defined as the deviation from the mean centre of pressure (CoP) of the foot (Guskiewicz and Perrin, 1996).

Balance training is designed for the rehabilitation after an ankle sprain and is thought to have a positive effect on postural sway (i.e. a decrease of postural sway). Previous studies have tried to establish an association between balance training and a decrease in postural sway in a variety of populations, of which populations with chronic ankle instability are the most common (De Carlo and Talbot, 1986; Garn and Newton, 1988; Hertel, 2000; Sahlstrand et al., 1978). However, a recent review concluded that the number of studies reporting alterations in postural control due to such a programme matches the number of studies failing to show such alterations (Riemann, 2002).

A (suggested) preventive effect of proprioceptive balance training on the risk of re-injury after an initial ankle sprain has been shown multiple studies (Bahr et al., 1997; Stasinopoulos, 2004; Tropp et al., 1985; Verhagen et al., 2004; Wedderkopp et al., 1999; Wedderkopp et al., 2003). Although these intervention studies did not measure chronic ankle instability, it is unlikely that a preventive effect only exists for athletes with chronic ankle instability. Therefore, from a societal perspective balance training should be advocated to all athletes with previous injury. One problem that arises in achieving this goal is that compliance with such preventive programmes is generally low. Adherence to a preventive balance programme could be improved if there is evidence that balance training improves other sports related factors as well. Therefore, the purpose of our study was to investigate whether a balance-training programme leads to a smaller postural sway in a general population, showing in a decreased CoP excursion.

## 2. Methods

### 2.1. Subjects

Thirty university students (5 male and 25 female) participated voluntarily in this study. Written informed consent was obtained after the purpose, nature and potential risks were explained to all subjects. Twenty-two untrained subjects who did not participate in an organized volleyball competition were randomly assigned to either an intervention group ($n = 11$) or a control group ($n = 11$). The remaining eight subjects participated in an organized volleyball competition and trained at least two times each week. Volleyball is a fast paced game with a high jump rate. Therefore, it was believed that the subjects of the volleyball group had a smaller baseline postural sway due to their volleyball background. Consequently, in this group a smaller effect of a balance training programme was expected. All subjects of the intervention group and the volleyball group received balance training, while subjects of the control group received no training. At baseline, all subjects completed a questionnaire on demographic variables, previous ankle sprains, and time since previous ankle sprains. Subjects that reported a previous ankle sprain more than 12 months ago were categorised as having no previous ankle sprain, since the increased risk for a residual injury is present during one year (Bahr, 1997). Subject characteristics are given in Table 1. The study was approved by the Medical Ethics Committee of the VU Medical Center.

### 2.2. Balance programme

Subjects of the intervention group and the volleyball group were given a balance training programme two times a week during a period of 5.5-weeks. The training programme was designed in association with sports physicians of the Dutch Volleyball Association (NeVoBo) and the Dutch National Olympic Committee (NOC*NSF), and was previously used in a prospective controlled trial in a population of second and third division volleyball players to assess its preventive effectiveness (Verhagen et al., 2004).

Table 1
Characteristics of the study population

| | *n* | | | Age | Previous ankle sprain | |
|---|---|---|---|---|---|---|
| | Total | Male | Female | Mean (SD) | No | Yes |
| Control | 11 | 3 | 8 | 25.5 (7.8) | 5 | 6 |
| Intervention | 10 | 2 | 8 | 22.5 (2.4) | 8 | 2 |
| Volleyball | 8 | 0 | 8 | 23.6 (3.2) | 5 | 3 |

Control: no volleyball participants and did not receive balance board programme.
Intervention: no volleyball participants and received balance board programme.
Volleyball: volleyball participants and received balance board programme.

The training programme consisted of 14 basic exercises on and off a balance board (diameter 45 cm, height 6 cm, maximum tilt 20°), with variations on each exercise (Table 2). All subjects of the intervention group followed the same training programme during the training period (Table 3). During each training session three different exercises of similar difficulty and intensity were carried out, with a gradual increase in difficulty and

Table 2
The exercises of the 5.5-week balance board training programme

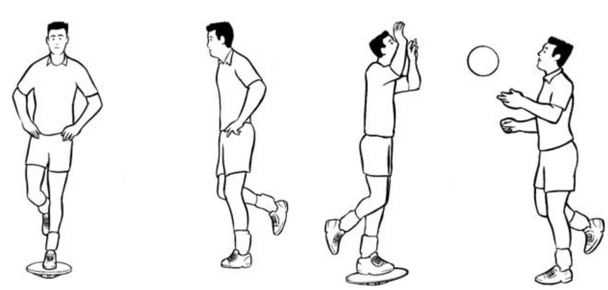
| No material | Ball | Balance board | Ball and balance board |
|---|---|---|---|
| *Exercise 1*<br>One legged stance with the knee flexed. Step-out on the other leg with the knee flexed and keep balance for 5 s. Continue this exercise for a duration of 5 min | *Exercise 3*<br>One legged stance with the knee flexed. Throw and/or catch a ball over a distance of 5 m while maintaining balance. Continue this exercise for a duration of 5 min | *Exercise 5*<br>One legged stance on the balance board with the knee flexed. Maintain balance for 30 s and change stance leg. Repeat four times for both legs | *Exercise 7*<br>Both feet on the balance board. Throw and/or catch a ball with one hand over a distance of 5 m while maintaining balance. Continue this exercise for a duration of 5 min |
| *Variations* A B C D | *Variations* A B | *Variations* A B C D | |
| *Exercise 2*<br>One legged stance with the hip and the knee flexed. Step-out on the other leg with the hip and knee flexed, and keep balance for 5 s. Continue this exercise for a duration of 5 min | *Exercise 4*<br>One legged stance with the hip and knee flexed. Throw and/or catch a ball over a distance of 5 m while maintaining balance. Continue this exercise for a duration of 5 min | *Exercise 6*<br>One legged stance on the balance board with the hip and knee flexed. Maintain balance for 30 s and change stance leg. Repeat four times for both legs | *Exercise 8*<br>One legged stance with the knee flexed on the balance board. Throw and/or catch a ball with one hand over a distance of 5 m while maintaining balance. Continue this exercise for a duration of 5 min |
| *Variations* A B C D | *Variations* A B | *Variations* A B C D | *Variations* A B |
|  | | *Exercise 10*<br>Step slowly over the balance board with one foot on the balance board. Maintain the balance board in a horizontal position while stepping over. Repeat 10 times for both legs | *Exercise 9*<br>One legged stance with the hip and knee flexed on the balance board. Throw and/or catch a ball with one hand over a distance of 5 m while maintaining balance. Continue this exercise for a duration of 5 min |
| | | | *Variations* A B |
|  | | *Exercise 11*<br>Stand with both feet on the balance board. Make 10 knee flexions while maintaining balance. Repeat twice with a break of 1 min between the repetitions | *Exercise 13*<br>Both feet on the balance board. Play the ball with an upper hand technique over a distance of 5 m while maintaining balance. Continue this exercise for a duration of 5 min<br>*Variations* E F |
| *Variations on basic exercises:*<br>A the standing leg is stretched<br>B the standing leg is flexed<br>C the standing is stretched and the yes are closed<br>D the standing leg is flexed and the eyes are closed<br>E the standing leg is stretched and upper hand technique<br>F the standing leg is stretched and lower hand technique | | *Exercise 12*<br>One legged stance on the balance board with the knee flexed. Make 10 knee flexions while maintaining balance. Repeat twice for both legs. Repeat twice with a break of 1 min between repetitions | *Exercise 14*<br>One legged stance with the knee flexed on the balance board. Play the ball with an upper hand technique over a distance of 5 m while maintaining balance. Continue this exercise for a duration of 5 min |
| | | | *Variations* E F |

Table 3
The 5.5-week proprioceptive balance board training programme

| Session | First exercise | Second exercise | Third exercise |
|---|---|---|---|
| Week 1 session 1 | 1A | 3A | 5A |
| Week 1 session 2 | 2A | 4A | 6A |
| Week 2 session 1 | 1B | 3B | 5B |
| Week 2 session 2 | 2B | 4B | 6B |
| Week 3 session 1 | 1C | 7 | 10 |
| Week 3 session 2 | 2C | 5C | 8A |
| Week 4 session 1 | 1D | 6C | 9A |
| Week 4 session 2 | 2D | 11 | 13A |
| Week 5 session 1 | 5D | 12 | 8B |
| Week 5 session 2 | 6D | 9B | 14A |
| Week 6 session 1 | 12 | 13B | 14B |

Numbers of exercises correspond with the exercises described in Table 2.

intensity during the 5.5-week training period (Table 3). The total duration of one training session, in which both legs were equally trained, was approximately fifteen minutes.

### 2.3. Measurements

Leg dominance was determined through the implementation of three functional tests: ball kick test, step-up test and balance recovery test (Hoffman and Payne, 1995). For the ball kick test, the leg used to kick a ball was identified as the dominant leg. For the step-up test, the leg used to step on a bench was considered to be dominant. Finally, for the balance recovery test, the leg used to step out for balance recovery after a push from behind was considered dominant. The leg that was recorded dominant in at least two out of the three tests was considered the dominant leg for the study.

Before and after the 5.5-week training period all subjects were measured. Prior to the baseline measurement a footprint was taken of each subject. The footprint was used for reproducible positioning of the subject on a force plate during the course of the study. This was done by placing the intersection of the plantar-dorsi flexion axis and the inversion–eversion axis onto the origin of the force platform, and the inversion–eversion axis onto the $y$-axis of the force platform.

Each force plate measurement consisted of five trials for each leg. In order to minimize variations of CoP excursion measurements between different trials and testing days, for each trial subjects successively (1) stood beside the force platform for 10 s, (2) placed one foot for 10 s on the footprint that was placed on the centre of the platform, (3) stood in single limb stance on the platform with the eyes open for 15 s, and (4) stood in single limb stance on the platform with the eyes closed for 20 s. These last 20 s with the eyes closed were included in the protocol to rule out any visual cues that aid postural control, since CoP excursion not only depends on proprioceptive information but also on vestibular and visual cues.

### 2.4. Data analysis

Centre of pressure excursions (CoP) were measured as a proxy measure of postural sway, using a Kistler force platform (Kistler, Piezo-Messtechnik, type 9281A11, Stuttgart, Germany), in the eyes-open and eyes-closed situation, for both the dominant leg and the non-dominant leg during single limb stance. Sampling occurred at 50 Hz resulting in 750 data points for the eyes-open situation, and 1000 data points for the eyes-closed situation. Each subject's trial consisted of data points for movement in millimetres in both the anterior–posterior direction (sagittal plane; $Y$ parameter), and the mediolateral direction (anterior plane; $X$ parameter). From these data points the location of CoP in the anterior–posterior direction (CPap), and the location of CoP in the medial–lateral direction (CPml) was calculated. CPap and CPml were then converted to a frequency distribution. The difference between the 2.5 percentile and the 97.5 percentile was used as a measure of CoP range (Goldie et al., 1989). For all eight conditions of the outcome measure of each subject (i.e. CPap dominant leg eyes open, CPap dominant leg eyes closed. CPml dominant leg eyes open, CPml dominant leg eyes closed, CPap non-dominant leg eyes open, CPap non-dominant leg eyes closed, CPml non-dominant leg eyes open, CPml non-dominant leg eyes closed) the calculated range of all five trials was averaged to produce eight measures of CoP excursion ($P_{2.5}$–$P_{97.5}$) in millimetres.

### 2.5. Statistical analysis

Differences in baseline $P_{2.5}$–$P_{97.5}$ of CPml and CPml between groups were analyzed using a one-way Analysis of Variance (ANOVA). For each of the eight $P_{2.5}$–$P_{97.5}$ outcome measures a linear regression was performed with the follow-up value as the dependent variable, and the baseline value, group allocation (two dummy variables), and previous injury as the independent variables.

## 3. Results

### 3.1. Subjects

One subject of the intervention group did not complete the training programme due to an acute lateral ankle ligament injury to this leg. It is suggested that an ankle sprain to one leg has an influence on the postural control of the other leg. In order to rule out any effect this dominant sided sprain might have on the measurements of the non-dominant leg, this subject was excluded from all analyses. This resulted in a final sample size of 29. Subject characteristics are given in Table 1. Although the group of subjects comprised more females than males, the three groups were not different at baseline.

Baseline CoP excursion measurements showed no significant differences between groups for any of the $P_{2.5}$–$P_{97.5}$ of CPml and CPap (Table 4). In general, in the eyes-open conditions no remarkable changes in $P_{2.5}$–$P_{97.5}$ were found over 5.5-week period in any of the groups. In contrast, in the eyes-closed situations all groups showed a tendency towards a smaller $P_{2.5}$–$P_{97.5}$, with the volleyball groups showing the smallest decrease and the control group the greatest decrease. The control group showed relatively high values at baseline, while their values were comparable to those of both other groups at follow-up. However, linear regression analysis showed only significant differences between groups for the dominant leg in the CPap eyes-open situation over the 5.5-week period (Table 5).

Table 4
Mean (SD) $P_{2.5}$–$P_{97.5}$ values (millimeters) for centre of pressure excursion in medio-lateral direction and anterior–posterior direction

| | Dominant leg | | Non-dominant leg | |
|---|---|---|---|---|
| | Baseline | Follow-up | Baseline | Follow-up |
| | CPml eyes-open[a] | | CPml eyes-open[a] | |
| Control | 26.7 (5.8) | 27.2 ( 3.9) | 25.9 (5.1) | 29.0 (11.8) |
| Intervention | 26.8 (4.3) | 27.3 (4.9) | 24.8 (2.6) | 27.3 (4.8) |
| Volleyball | 28.7 (5.2) | 27.4 (7.7) | 29.4 (5.9) | 26.1 (3.8) |
| | CPml eyes-closed[a] | | CPml eyes-closed[a] | |
| Control | 55.8 (14.5) | 47.3 (9.1) | 48.8 (16.0) | 43.7 (12.1) |
| Intervention | 49.1 (12.6) | 43.4 (7.5) | 49.3 (10.9) | 42.2 (7.7) |
| Volleyball | 53.1 (12.8) | 46.1 (5.7) | 49.2 (13.8) | 48.6 (9.3) |
| | CPap eyes-open[b] | | CPap eyes-open[b] | |
| Control | 19.5 (4.4) | 22.4 (2.0) | 21.5 (5.7) | 24.1 (8.8) |
| Intervention | 19.8 (2.5) | 19.9 (3.4) | 17.2 (2.6) | 18.4 (2.4) |
| Volleyball | 20.8 (3.4) | 20.4 (3.2) | 18.9 (1.6) | 19.8 (2.6) |
| | CPap eyes-closed[b] | | CPap eyes-closed[b] | |
| Control | 41.3 (3.9) | 36.1 (4.0) | 40.7 (9.8) | 35.8 (6.2) |
| Intervention | 39.0 (7.1) | 35.4 (2.8) | 37.1 (3.0) | 35.7 (5.0) |
| Volleyball | 35.1 (2.6) | 35.5 (4.2) | 34.6 (4.7) | 35.4 (3.3) |

[a] CPml = centre of pressure in medio-lateral direction.
[b] CPap = centre of pressure in anterior–posterior direction.

Table 5
Results of the linear regression analysis (standardized beta's) of all eight $P_{2.5}$–$P_{97.5}$ variables with the follow-up value as the dependent variable

| | Baseline | Group 1[a] | Group 2[b] | Previous injury | Prev inj * group 1 | Prev inj * group 2 |
|---|---|---|---|---|---|---|
| Dominant leg | | | | | | |
| CPml[c] eyes open | 0.608** | −0.003 | −0.054 | 0.150 | 0.146 | −0.183 |
| CPml[c] eyes closed | 0.577* | −0.274 | −0.295 | −0.058 | −0.169 | 0.316 |
| CPap[d] eyes open | 0.469* | −0.544* | −0.609* | −0.175 | 0.170 | 0.399 |
| CPap[d] eyes closed | 0.601* | −0.065 | −0.116 | −0.106 | −0.172 | 0.211 |
| Non-dominant leg | | | | | | |
| CPml[c] eyes open | 0.136 | 0.089 | 0.078 | 0.388 | −0.173 | −0.415 |
| CPml[c] eyes closed | 0.111 | −0.323 | −0.185 | −0.871** | 0.151 | 0.859 |
| CPap[d] eyes open | 0.073 | −0.215 | 0.007 | 0.654* | −0.280 | −0.430 |
| CPap[d] eyes closed | 0.705** | 0.015 | 0.005 | 0.075 | −0.049 | 0.374 |

* $P < 0.05$.
** $P < 0.01$.
[a] Group dummy intervention vs. control.
[b] Group dummy volleyball vs. control.
[c] CPml = centre of pressure in medio-lateral direction.
[d] CPap = centre of pressure in anterior–posterior direction.

## 4. Discussion

We hypothesized that the balance training programme would improve postural sway as shown by a reduced range of CoP excursion. This hypothesis was based on the assumption that ankle (in)stability can be measured through CoP measurements in single limb stance (De Carlo and Talbot, 1986; Garn and Newton, 1988; Guskiewicz and Perrin, 1996; Hertel, 2000; Sahlstrand et al., 1978). However, postural sway was unaffected as a result of the training programme since range of CoP excursion after the 5.5-week balance training programme was not different between the study groups.

Our results are difficult to compare to other similar studies, due to the various CoP excursion assessment methods used in different studies. Furthermore, the majority of studies on the effect of balance training on CoP excursion involved subjects with functional ankle instability and/or did not include a control group in the study design (Bernier and Perrin, 1998; Eils and Rosenbaum, 2001; Gauffin et al., 1988; Holme et al., 1999; Matsusaka et al., 2001; Rozzi et al., 1999). However, the methodology used in our study was similar to the methods previously used by Hoffman and Payne (1995), and to a large extent comparable to a previous study by Chong et al. (2001). The results of our study oppose the findings of Hoffman and Payne (1995), who reported a significant decrease in single limb stance CoP excursion with the eyes-open after a 10-week balance training programme. Hoffman and Payne (1995) studied the effect of a balance training programme on the dominant leg of 15 healthy subjects and compared the CoP excursion scores with 15 healthy controls. In their study CoP excursion was calculated as a standard deviation of all measured data points in both the CPml and CPap directions, which is similar to our calculation. However, Chong et al. (2001), also studying healthy subjects, found no effects of a 4-week balance training programme on CoP excursion. Moreover, a recent review on the association between functional ankle instability and postural control concluded that the number of studies reporting alterations in postural control matches the number of studies failing to show such alterations (Riemann, 2002).

CoP excursion not only depends on proprioceptive information but also on vestibular and visual cues. Therefore, measurements in this study included eyes-open and eyes closed situations, where the eyes closed situations were included to rule out any visual cues that aid postural control. In general, in the eyes-open conditions no remarkable changes were found, while in the eyes-closed situations all groups showed a tendency towards less CoP excursion. This could mean that all groups improved their processing of proprioceptive information during the study. The only significant difference found was in the eyes-open situation in the anterior–posterior direction for the dominant leg, where the control groups showed an increase in CoP excursion. If there would be a general tendency to a true difference between eyes-open and eyes-closed situations, similar results in other parameters would have been found as well. This latter was not the case. This makes the current significant finding most likely a random effect that could be due to a disturbance of the subjects during testing.

Several possible explanations for the lack of CoP excursion reduction found in the present study could be proposed. For example, the present study dealt with previously injured subjects as well as healthy subjects. Basis for this choice of population is the assumption that the impaired parameters after an ankle sprain can be improved in healthy subjects as well. Rehabilitation methods aimed at improving these parameters result in a reduction of ankle sprain recurrences. If it is possible to improve these parameters in healthy subjects, a reduced ankle sprain risk is expected in these individuals as well. Perhaps CoP excursion cannot be reduced in healthy subjects, so that a positive effect of the training programme on previously injured subjects could have been masked by the healthy part of the population.

Another cause of masked results might stem from a learning effect through the repetition of the measurements. In other words, subjects might have gained a decreased CoP excursion due to the measurement instead of the balance training programme. This thought is supported by the fact that the control group shows a decrease in CoP excursion as well. If a learning effect is present this will most likely have an equal effect in the intervention and volleyball group. Although not significant, all groups showed a decrease in CoP excursion over time. Therefore, it could be suggested that all that is found in the present study is a learning effect.

A different explanation could be that the sample size was relatively small ($n = 30$) in the present study. In addition, three groups were incorporated. This could have hampered statistical power resulting in the absence of a significant difference. However, when looking at the data the control group has the highest decrease in CoP excursion. This suggests that a higher power might have led to the control group improving significantly over the other two groups.

Another explanation might be in that the majority of enrolled subjects participated fanatically in one or more sports on a regular basis. This population characteristic could have resulted in all participants having a low baseline CoP excursion due their sports background. If this is the case subjects will have no improvement or only a small improvement in CoP excursion as a result of the training programme. In addition, this could also explain the finding that baseline CoP excursion of the volleyball group is similar to the other groups, which opposes the assumption that the volleyball group had a smaller baseline CoP excursion due to their volleyball background. Although more explanations can be brought up, all remain speculative and are not supported by data.

Since Freeman stated in 1965 that trauma to mechanoreceptors of the ankle ligaments after an ankle sprain can produce a proprioceptive impairment in the ankle, a deterioration of the ability to maintain balance in single limb stance after an ankle sprain has been well documented. Although measurements of CoP excursion (mostly referred to as postural sway) are popular from this viewpoint, CoP excursion is not the only parameter affected following an ankle sprain. As stated by Hertel (2000) ankle instability after an ankle sprain shows for instance in balance deficits, joint position sense deficits, delayed peroneal muscle reaction time, altered common peroneal nerve function, strength deficits, and a decreased dorsiflexion range of motion. Although these parameters are interrelated to a large extent, it is not unlikely that the magnitude of the deficits varies among individuals. Whereas one individual has a great balance deficit after an ankle sprain, another individual might have less balance problems and more joint position sense deficits. This may well be the reason of the various findings between studies.

## 5. Conclusion

The $5\frac{1}{2}$ week balance training programme applied in this study did not reduce CoP excursion in a general population consisting of non-injured and previously injured subjects.

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