Postural Control in Patients with a History of Diabetic Foot Ulcers: A Pilot Study

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Introduction

Diabetic peripheral neuropathy reduces somatosensory input from the feet and can impair postural control. When plantar sensation and proprioceptive information are reduced, greater reliance on visual input may be required to maintain balance. Previous work has shown increased postural sway in people with diabetic neuropathy, with particularly marked instability reported in those with a history of foot ulceration (Katoulis et al., 1997). People at high risk of recurrent diabetic foot ulceration are also commonly prescribed pressure-relieving footwear and insoles. These interventions are designed primarily to redistribute plantar loading, but their influence on postural control is less clear. Insole design can alter centre-of-pressure behaviour during standing, while other studies suggest that therapeutic footwear does not necessarily compromise dynamic stability (Malki et al., 2024; Paton et al., 2016). These pilot data form part of a wider prospective study examining biomechanical characteristics in people in remission following diabetic foot ulceration and their relationship with time in remission. The present analysis examines **visual dependency during dynamic and static postural control and whether this response is influenced by the footwear–insole condition**.

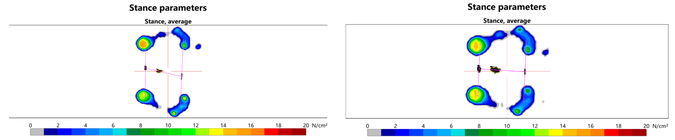
Methods

Ten adults with diabetes and a diabetic foot ulcer healed within the previous year were included (**age 61.6 ± 10.1 years; diabetes duration 16.1 ± 12.5 years; 6 male, 4 female**).
Dynamic postural stability was assessed using the **Biodex Balance System Fall Risk Test**. **Quiet-standing postural control** was assessed using the **Zebris FDM pressure platform**.
Measurements were performed under four conditions:

- barefoot, eyes open;
- barefoot, eyes closed;
- standard accommodative diabetic footwear Lucro (Schein) with DiabetiX insoles (TalarMade), eyes open; and the same footwear–insole condition, eyes closed.

Biodex Stability Index (SI) was averaged across three trials for each participant and condition. Zebris outcomes included the **95% confidence ellipse sway area, CoP path length, CoP velocity and plantar load distribution**.
The effects of **vision (eyes open/closed)** and **condition (barefoot/footwear–insole)** were examined using a 2 × 2 repeated-measures ANOVA, including the vision × condition interaction.

Figure 1. Representative Zebris quiet-standing output illustrating the increase in postural sway following removal of visual input.



Results

Dynamic postural stability (Biodex)
Closing the eyes produced a marked increase in Stability Index in both conditions:
Barefoot: 7.07 ± 4.86 → 13.24 ± 3.24 ; **Footwear–insole:** 8.43 ± 3.49 → 14.80 ± 2.07
There was a strong overall effect of **vision** on dynamic postural stability (**F(1,9)=37.05, p<0.001**). There was no significant overall effect of the footwear–insole condition (**p=0.115**) and, importantly, no vision × condition interaction (**p=0.807**). The increase in SI following eye closure was therefore similar in the barefoot and footwear–insole conditions.
Quiet-standing postural control (Zebris)
Sway area increased following eye closure:
Barefoot: 244.1 ± 152.4 → 551.6 ± 327.4 mm^2; **Footwear–insole:** 494.2 ± 402.2 → 640.3 ± 324.6 mm^2
There was a significant overall effect of **vision** on sway area (**F(1,9)=14.86, p=0.004**).
Sway area was also greater overall in the footwear–insole condition (**p=0.021**), but there was no significant vision × condition interaction (**p=0.212**). CoP path length and CoP velocity showed the same strong effect of eye closure (**p=0.003 for both**), without significant footwear–insole or interaction effects.

Outcome	Barefoot EO	Barefoot EC	Footwear + insole EO	Footwear + insole EC
Biodex Stability Index	7.07 ± 4.86	13.24 ± 3.24	8.43 ± 3.49	14.80 ± 2.07
Sway area (mm^2)	244.1 ± 152.4	551.6 ± 327.4	494.2 ± 402.2	640.3 ± 324.6
CoP path (mm)	385.6 ± 163.8	872.1 ± 436.3	505.5 ± 204.9	982.1 ± 424.3
CoP velocity (mm/s)	13.0 ± 5.6	29.0 ± 14.5	16.9 ± 6.7	32.7 ± 14.4

2 × 2 repeated-measures analysis

Outcome	Vision	Footwear–insole	Interaction
Biodex Stability Index	**<0.001**	0.115	0.807
Sway area	**0.004**	**0.021**	0.212
CoP path	**0.003**	0.106	0.929
CoP velocity	**0.003**	0.107	0.956

Figure 2A: Change in Biodex Stability Index after eye closure

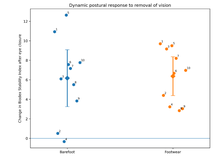
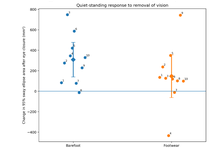


Figure 2B: Change in Zebris 95% sway ellipse area after eye closure



Discussion

The clearest finding was the **marked effect of visual deprivation on postural control**. Closing the eyes increased instability during both the dynamically challenging Biodex assessment and quiet standing on the Zebris platform. This is consistent with previous evidence that people with diabetic neuropathy rely more heavily on vision to compensate for reduced somatosensory information from the feet (Katoulis et al., 1997; van Geffen et al., 2007). The presence of a significant visual effect across two different assessment approaches is important. Biodex challenges the ability to maintain balance on an unstable support surface, whereas Zebris measures spontaneous sway during quiet standing on a stable surface. The findings therefore suggest that visual dependency is evident across different aspects of postural control rather than being restricted to a single test. The footwear–insole condition did **not significantly modify the effect of eye closure** on either Biodex Stability Index or Zebris sway. This is consistent with evidence that therapeutic footwear and insoles do not necessarily impair dynamic stability, although individual insole characteristics can alter static CoP behaviour (Malki et al., 2024; Paton et al., 2016). Zebris sway area was greater overall in the footwear–insole condition. However, corresponding footwear effects were not evident for CoP path, CoP velocity or Biodex Stability Index. This is therefore better considered a **condition-specific change in quiet-standing sway rather than evidence of an overall deterioration in balance**.

Interpretation

- **Removal of visual input consistently challenged postural control**, with significant effects across dynamic balance, sway area, CoP path and CoP velocity.
- The footwear–insole condition **did not significantly alter the degree of visual dependency**.
- Dynamic balance and quiet-standing assessment provide complementary information and may help identify different postural-control strategies in people with a history of diabetic foot ulceration.
- Individual responses were variable, supporting further investigation beyond group-average measures.

Clinical relevance

Visual dependency may be an important component of postural control in people with a history of diabetic foot ulceration.

People in remission following diabetic foot ulceration may rely substantially on visual information to maintain postural control.

Balance assessment in this population may therefore benefit from including **conditions in which visual input is reduced**, rather than relying solely on eyes-open testing.

Pressure-relieving footwear and insoles should also be considered in relation to **balance and functional movement**, alongside their established role in pressure redistribution.

Future work

These findings form part of an ongoing prospective study of people in remission following diabetic foot ulceration. The larger study will provide a more detailed characterisation of postural control and movement following ulcer healing and allow us to examine whether these biomechanical characteristics are associated with **time in remission and subsequent clinical outcomes**.

Further work will: (1) examine these findings in a larger cohort; (2) investigate individual patterns of visual dependency; (3) incorporate comprehensive movement and gait analysis; (4) examine the relationship between static and dynamic postural-control measures; (5) investigate the specific contribution of footwear and insole characteristics; and (6) determine whether baseline postural-control characteristics change during follow-up or relate to longer-term outcomes.

References:

(1) Katoulis EC, Ebdon-Parry M, et al., (1997). Postural instability in diabetic neuropathic patients at risk of foot ulceration. *Diabet Med.*, *14*(4), 296–300. (2) Malki, A., Baltasar Badaya, M., et al., (2024). Effects of individually optimised rocker midsoles and self-adjusting insoles on dynamic stability in persons with diabetes mellitus and neuropathy. *Gait and Posture*, *112*, 154–158. (3) Paton, J., Glasser, S., et al., (2016). Getting the right balance: insole design alters the static balance of people with diabetes and neuropathy. *Journal of Foot and Ankle Research*, *9*(1):40. (4) van Geffen, J. A., Dijkstra, P. U., et al., (2007). Effect of flat insoles with different Shore A values on posture stability in diabetic neuropathy. *Prosthetics and Orthotics International*, *31*(3), 228–235.

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