Foot placement control can be trained: Older adults learn to walk more stable, when ankle moments are constrained

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Abstract

Falls are a problem, especially for older adults. Placing our feet accurately relative to the center-of-mass helps us to prevent falling during gait. The degree of foot placement control with respect to the center-of mass kinematic state is decreased in older as compared to young adults. Here, we attempted to train foot placement control in healthy older adults. Ten older adults trained by walking on shoes with a narrow ridge underneath (LesSchuh), restricting mediolateral center-of-pressure shifts. As a training effect, we expected improved foot placement control during normal walking. A training session consisted of a normal walking condition, followed by a training condition on LesSchuh and finally an after-effect condition. Participants performed six of such training sessions, spread across three weeks. As a control, before the first training session, we included two similar sessions, but on normal shoes only. We evaluated whether a training effect was observed across sessions and weeks in a repeated-measures design. Whilst walking with LesSchuh, the magnitude of foot placement error reduced half-a-millimeter between sessions within a week (cohen's *d*=0.394). As a training effect in normal walking, the magnitude of foot placement errors was significantly lower compared to the control week, by one millimeter in weeks 2 (cohen's *d*=0.686) and 3 (cohen's *d*=0.780) and by two millimeters in week 4 (cohen's *d*=0.875). Local dynamic stability of normal walking also improved significantly. More precise foot placement may thus have led to improved stability. It remains to be determined whether the training effects were the result of walking on LesSchuh or from repeated treadmill walking itself. Moreover, enhancement of mechanisms beyond the scope of our outcome measures may have improved stability. At the retention test, gait stability returned to similar levels as in the control week. Yet, a reduction in foot placement error persisted.

Introduction

Anyone who sees someone close to them grow older may become concerned about them falling. Indeed, older adults are less stable than young adults (1-3) and at old age a fall can have severe consequences (4). Falls in older adults most commonly occur during walking (5), suggesting that improving gait stability may prevent falls. In young adults, foot placement control with respect to variations in the center-of-mass (CoM) kinematic state is the dominant mechanism to maintain gait stability (6-11). One of the reasons why older adults are at a higher risk of falling may be a compromised control over foot placement (12).

Foot placement control is achieved through modulation of hip muscle activity (8, 13), based on a combination of visual, vestibular and proprioceptive information (12, 14-16). This allows adequate foot placement in relation to the CoM kinematic state. Older adults demonstrated less well coordinated foot placement control, due to impaired (processing of) proprioceptive information, or inability to generate adequate motor responses (12, 17). Perhaps, training older adults, by imposing constraints demanding more accurate foot placement, will help them to relearn how to coordinate their foot placement with respect to the CoM.

The relative variance explained (R^2) by a model predicting foot placement based on the CoM kinematic state (7, 11) describes what proportion of the variance in foot placement is explained by the variance in CoM kinematic state. It can thus be interpreted as a measure quantifying how well foot placement is coordinated with respect to the CoM and we have coined it “the degree of foot placement control” (18).

Constraining ankle moments by walking on the so-called LesSchuh, a shoe with a narrow ridge along the length of the sole, led to an increase in this degree of degree of foot placement control in young adults (19). The reduced ability to correct for foot placement errors, due to constrained ankle moment control (20), may have driven this adaptation, and this suggests a training potential. Still so far, we have been unsuccessful to transfer this adaptation to normal walking (without ankle moment constraints). Despite a trend, no significant after-effect was found in young adults after training with LesSchuh (21). It must be noted, however, that in the latter study participants walked on a split-belt treadmill, for which the effect of ankle moment constraints on foot placement control is different (19). Apart from treadmill interaction effects, the already high degree of foot placement control in young adults may have prevented a training effect. Alternatively, it may require multiple training sessions before a significant improvement in the degree of foot placement control can be detected.

In this study, we investigated whether foot placement control can be improved in older adults, by walking with constrained ankle moments (i.e. by walking on LesSchuh). We expected a greater training potential in older adults due to their lower degree of foot placement control (12). We asked them to train over a training period of three weeks, with two sessions per week. Each week, the ridge of the LesSchuh on which they walked became narrower. We hypothesized that the degree of foot placement control would improve between sessions and weeks. In addition to the degree of foot placement control (relative explained variance), we considered the magnitude of foot placement errors. We also calculated local divergence exponents (22), step width and stride time, to explore changes in stability (control).

Methods

Ten older adults (≥ 65 years old, 7 males & 3 females) participated in this repeated-measures study. All participants filled out an inclusion/exclusion questionnaire (see S4), before they were allowed to participate. If the questionnaire raised any doubt for inclusion, we discussed this with the participant, in the end ensuring that all participants included could sustain the intensity of the training protocol. All included participants signed an informed consent from, and ethical approval for this experiment had been granted by the ethical committee of the faculty of behavioral and movement science of the Vrije Universiteit Amsterdam (VCWE-2020-186R1). All participants completed eight sessions, spread across one control and three training weeks. Eight participants completed the ninth session, the retention test, within the second week after their last training session. Two participants performed the retention test respectively four and nine weeks after the last training session, due to their holidays. Data were collected during all sessions.

The data and code for analysis can be found at : https://surfdrive.surf.nl/files/index.php/s/6fwmnAaH3hfxVCu, and will be published on Zenodo if the manuscript is accepted.

Study design

All participants followed the training protocol as presented in Fig 1. The training protocol comprised four weeks, of which the first week served as a control week. In week one, participants only walked on normal shoes. In weeks two to four, participants still walked on normal shoes in the normal walking and after-effect conditions. In addition, participants trained by walking on the treadmill with LesSchuh in the training conditions (Fig 2). As such, the sessions in week two until four were designed similarly as the single training session of our previous study (21). LesSchuh is a shoe that has a narrow ridge underneath the sole, which allows for anteroposterior roll-off and push-off, but limits mediolateral center-of-pressure shifts. As such, it constrains mediolateral ankle moment control. The width of the ridge was narrowed every training week (weeks two until four) from two centimeter to respectively one-and-a-half and finally one centimeter. If, with the narrower ridge, the participant could no longer perform the training according to our instructions, we allowed them to walk on the ridge with the same width as the preceding week.

Each (training) session consisted of five bouts of treadmill walking, intermitted with opportunities to rest. The first bout (normal walking condition) lasted ten minutes, and bouts two to five lasted five minutes each. Between the last two bouts no rest was offered. In this intermission, we quickly changed the shoes back to normal shoes, to be able to evaluate immediate after-effects (see S3).

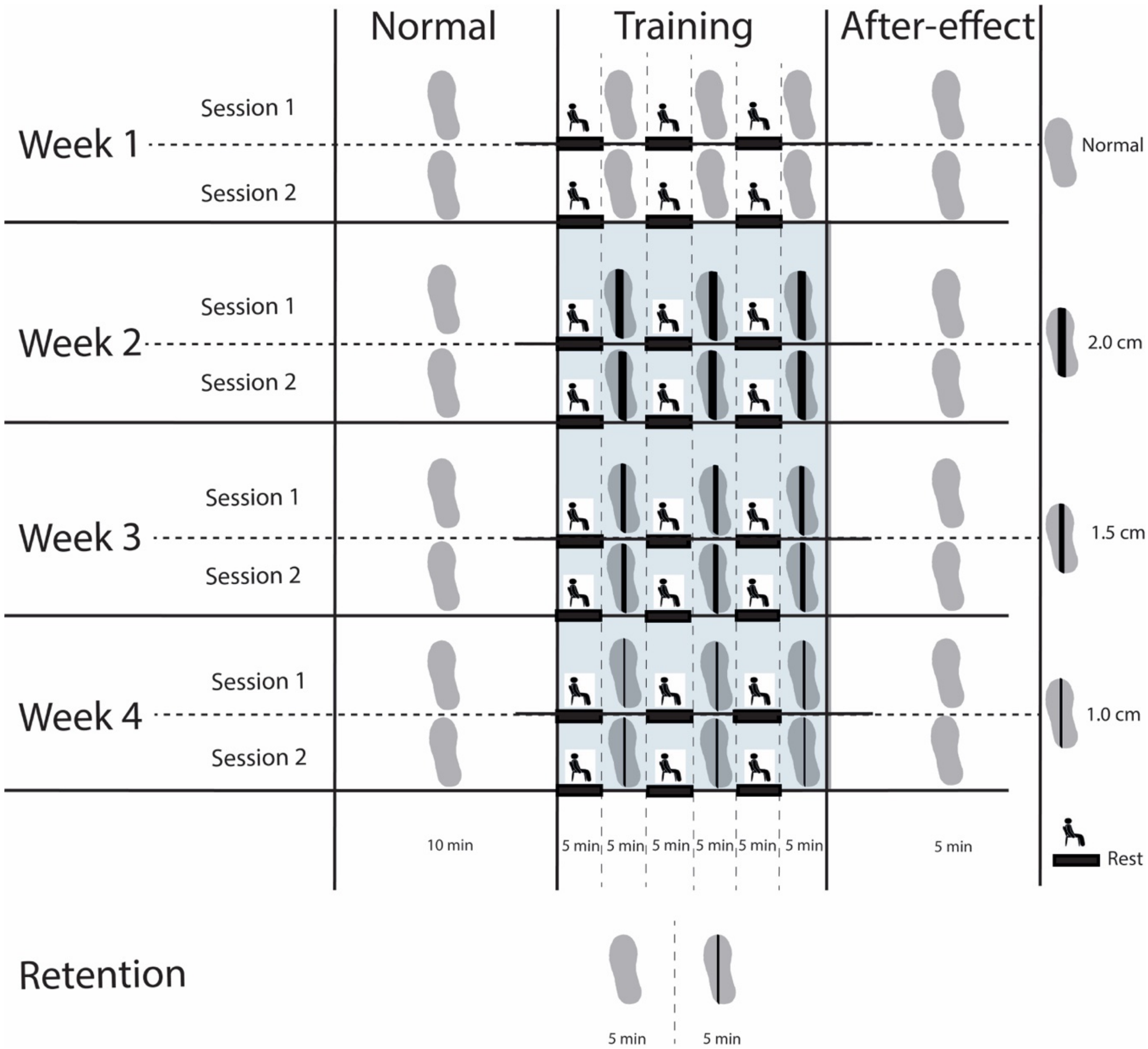

Fig 1. Experimental design. Each week consisted of two (training) sessions. In week 1, participants walked only on normal shoes. In weeks 2-4, they walked on normal shoes in the Normal walking and After-effect conditions, but on LesSchuh (Fig 2) in the Training condition (shaded blue area). In weeks 2-4, the widths of the ridges underneath the shoes were 2.0, 1.5 and 1.0 cm respectively. In week 6, we performed a retention test. We collected data during all sessions.

Fig 2. LesSchuh. The narrow ridge underneath the sole constrains mediolateral shifts in the center-of-pressure. The width of the ridge in the figure is one centimeter.

To conclude the experiment, we conducted a retention test. During the retention test participants walked for five minutes with normal shoes, followed by five minutes on LesSchuh with the same width of the ridge as in their final training session.

General assessment

During the first session, participants were first asked to fill out the Mini Mental State Examination (MMSE), to validate inclusion (MMSE>24). Furthermore, we performed the Short Physical Performance Battery (SPPB) (23), to assess the overall fitness of the older adults. Finally, we assessed their concern of falling by the Falls Efficacy Scale – International (FES-I) (24).

Equipment and safety precautions

To measure the kinematics of the feet and the thorax (as a proxy for the center-of-mass), we tracked three cluster markers (with three single markers each) with two Optotrak cameras sampled at 100 Hz (Northern Digital Inc, Waterloo Ont, Canada). Participants walked at a three-meter long treadmill, wearing a safety harness connected to the ceiling to support the participant in case of a fall (Fig 3).

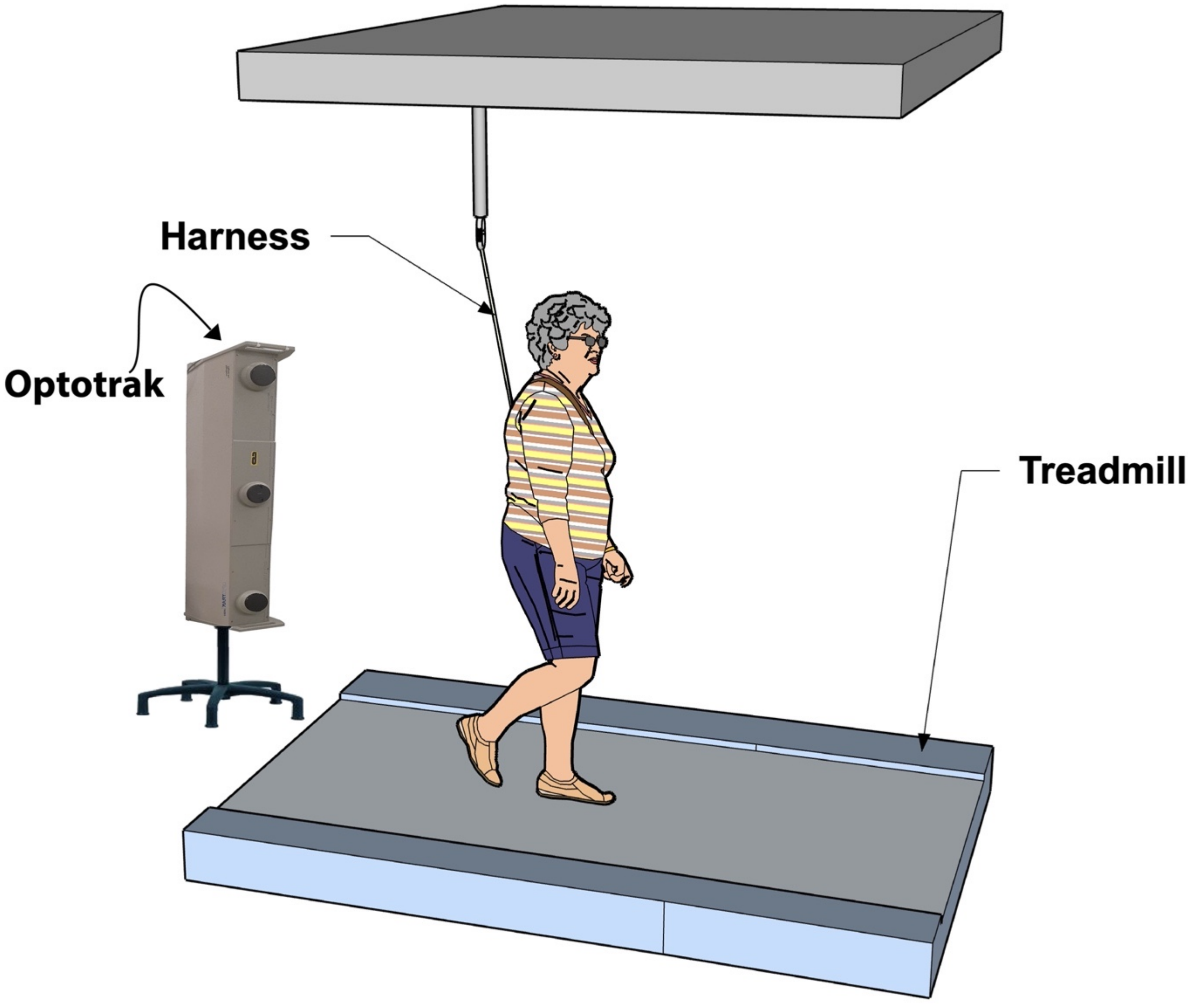

Fig 3. Treadmill with safety harness.

Experimental protocol

We asked participants to wear shoes to which the cluster markers were attached. We invited participants to stand on the treadmill, where we fastened the safety harness. We also attached an elastic band to mount the thorax cluster markers. In the first session, we determined the participant's preferred walking speed on normal shoes, by increasing and decreasing the speed until the participant felt comfortable with the pace. This walking speed was used in all subsequent conditions, sessions and weeks.

While walking on LesSchuh, participants were instructed to only stand on the narrow ridge underneath the sole. Furthermore, we asked them to keep pointing their feet straight ahead (avoiding a toeing-out strategy (25)). If corrections were needed, we gave feedback (e.g. "rotate your left foot more inward", "keep pointing your feet straight ahead", "stay on the ridge") and we kept motivating participants throughout the trial. If it was evident that the participant had a hard time adhering to the instructions, we tried not to push him/her further than trying their best. Whenever feedback distracted the participant, we limited our feedback.

Clinical outcome measures and questionnaire

As clinical outcome measures, baseline SPPB and FES-I scores were obtained from the general assessment at the first experimental session. The walking part of the SPPB was repeated at the end of weeks one, two and three. At the end of week four (after the last training session), the full SPPB and FES-I were re-assessed. We also administered an additional questionnaire, asking participants about their (training) experiences and whether they felt the training had any positive impact (see S4). Finally, at the start of the retention test we repeated the SPPB and FES-I.

Biomechanical outcome measures

Our main outcome measure was "the degree of foot placement control" as assessed by the relative explained variance (R^2) of Model (1), in which FP represents the demeaned mediolateral placement of the swing foot relative to the stance foot (step width), CoM_{pos} the demeaned mediolateral CoM position and CoM_{vel} the demeaned mediolateral CoM velocity at terminal swing. $\beta_{pos,}$, β_{vel} and ε represent respectively the regression coefficients of CoM_{pos} and CoM_{vel}, and the residual (i.e. the foot placement error). FP was determined as the mediolateral distance between the heel markers at midstance. CoM_{pos} and CoM_{vel} were determined with respect to the stance foot.

$$FP = \beta_{pos} \cdot CoM_{pos} + \beta_{vel} \cdot CoM_{vel} + \varepsilon, \quad [1]$$

Complementary to the degree of foot placement control (R^2) we calculated "the magnitude of foot placement error", as the standard deviation of the residual (ε) of Model (1). In our previous work, we referred to this measure as "precision in foot placement control" (21). The degree of foot placement control describes what percentage of foot placement variance can be explained by variations in the CoM kinematic state during the preceding swing phase. However, as it is a relative measure, the R^2's value can be in- or deflated depending on the total variance. It thus does not reflect how precise foot placement is in absolute terms. By considering the magnitude of the foot placement error as an extra outcome measure, we add an absolute measure of foot placement precision.

As secondary outcome variables we evaluated step width, stride time (time between two subsequent heelstrikes of the same leg), and local dynamic stability. For the latter, we computed the local divergence exponent (22, 26-28) of the mediolateral CoM velocity. First, we time-normalized the signal, so that on average each stride was 100 samples in length. Then we constructed a six-dimensional state space based on copies with a 25-samples time delay. Within this state space, for each point, we found the five nearest neighbors (defined as the points that had the smallest Euclidian distance to the original point, while having at least half an average stride time of temporal separation). Subsequently, the divergence with the nearest neighbors was tracked for 1000 samples. We fitted a line (least squares fit) through the first 50 samples (i.e. half a stride on average) of the averaged logarithmic divergence curve. The slope of this line defined the local divergence exponent. The lower the local divergence exponent, the more stable the gait pattern.

The outcome measures as described above were analyzed in a similar way as in (21). Accordingly, we distinguished between "normal" (first 10 minutes of each session), "training" (concatenated 3 x 5 minutes walking on LesSchuh of each session) and "after-effect" (last 5 minutes of each session) conditions. These conditions were split into blocks of 30 strides, and for each block the outcome measures were computed. For our main analysis, to test whether a training effect occurred across sessions and weeks, for the normal walking and training conditions, we averaged each outcome measure over all 30-stride-blocks within each condition. To assess what changes within a single session underlie these training effects (see S3), we used the outcome measures computed from the first 30 strides (i.e. normal walking/training/after-effect start) and the last 30 strides of the condition (i.e. normal walking /training/after-effect end).

Statistics

Clinical outcome measures

For the clinical outcome measures (SPPB and FES-I scores), we used paired samples t-tests to assess changes between the first session of the control week (baseline) and the end of the last training session. In addition, if a significant effect was found, we assessed whether the change in SPPB/FES-I score was retained at the retention test. To this end, we used a paired samples t-test to test the score at retention against the baseline score from the first session of the control week

Biomechanical outcome measures

A repeated-measures ANOVA was used to test whether the degree of foot placement control improved during the normal walking condition, as a function of Week ("1","2","3","4") and Session ("1","2"). We chose to test the normal walking condition to represent normal walking rather than the after-effect condition, to avoid confounding by potential immediate after-effects. By adding both "Week" and "Session", we essentially include two factors that both represent time. However, we found that this two-factor model fitted the data better, since there was a relatively short time between "Sessions" within a week, and a bit longer time between the session at the end of the week and the subsequent session in the new week. If "Week", "Session" or their interaction was significant, we conducted Bonferroni corrected post-hoc analyses to determine which comparisons were significant.

To better understand how potential training effects were elicited, we performed another repeated-measures ANOVA. This ANOVA included the factors Week ("2","3","4") and Session ("1","2"), and tested the outcome measures during the training. Here, we focused specifically on any Session effects, since that would demonstrate changes whilst walking on the same LesSchuh (i.e. 2, 1.5 or 1 cm). If "Session" or the "Session*Week" interaction effect was significant, we performed Bonferroni corrected post-hoc analyses. For those interested, in S3 we zoomed in even further and tested for immediate and after-effects of walking with LesSchuh, as in Hoogstad, van Leeuwen (21).

The same analyses were applied for the magnitude of foot placement error and the secondary outcome measures. In addition, we tested for retention of those outcome measures that had changed as a function of Week during the normal walking condition, and as a function of Session in the training condition. These retention tests were conducted as paired-samples t-tests either between the first session and retention (normal walking) or between the last training session and retention (LesSchuh walking).

Results

All participants completed all training sessions and the retention test. Most participants were able to walk on the one-centimeter ridge in the final training week. For one participant, we decided to use the one-and-a-half-centimeter ridge in the final training session and retention test. For this participant, the first session with the one-centimeter ridge proved too challenging to perform within the boundaries of our instructions (i.e. pointing the feet forward, and only letting the ridge touch the floor, not the other parts of the sole). The tables of the statistical tests can be found in S2.

Participant characteristics

Our participant group consisted of fit older adults (SPPsB, Table 1), with a low concern of falling (FES-I, Table 1).

Table 1. General assessment.*

Participant characteristics		
Age	73.4 (SD = 5.7) years	
Height	179.7 (SD = 8.9) cm	
Weight	74.5 (SD = 8) kg	
Preferred treadmill walking speed	3.2 (SD = 1.0) km/h	
MMSE score	29.2 (SD = 1.1)	Above inclusion threshold
mean SPPB score (baseline)	11.2 (SD = 1.1)	No risk of impaired physical functioning
FES-I score (baseline)	19 (SD = 2.5)	Low concern of falling

MMSE: Mini Mental State Examination
SPPB: short physical performance battery
FES-I: Falls Efficacy Scale International
*An overview of the individual SPPB and FES-I can be found in S1.

The results of the additional questionnaire can be found as S4. Not all participants experienced a subjective training effect, but others were enthusiastic about the training.

Clinical outcome measures – Training effects

Despite a visible increase in Fig 4, the SPPB score at baseline was not significantly different from the SPPB score at the last training session. Neither was there a significant change in the FES-I score between baseline and the last training session (Fig 5) For more insight into the walking test of the SPPB we have added an overview in S1 Fig 1.

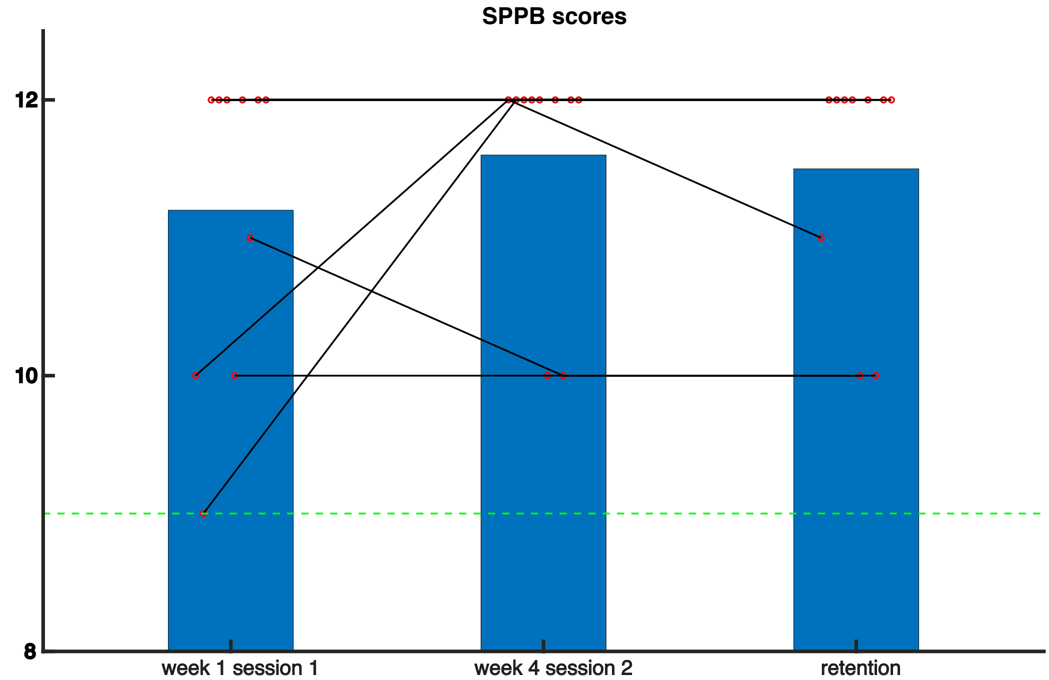

Fig 4. Scores on the Short Physical Performance Battery (SPPB). Higher scores represent better physical performance. Red circles represent individual data points. The green line represents the threshold (9) (29) above which participants are in the safe zone.

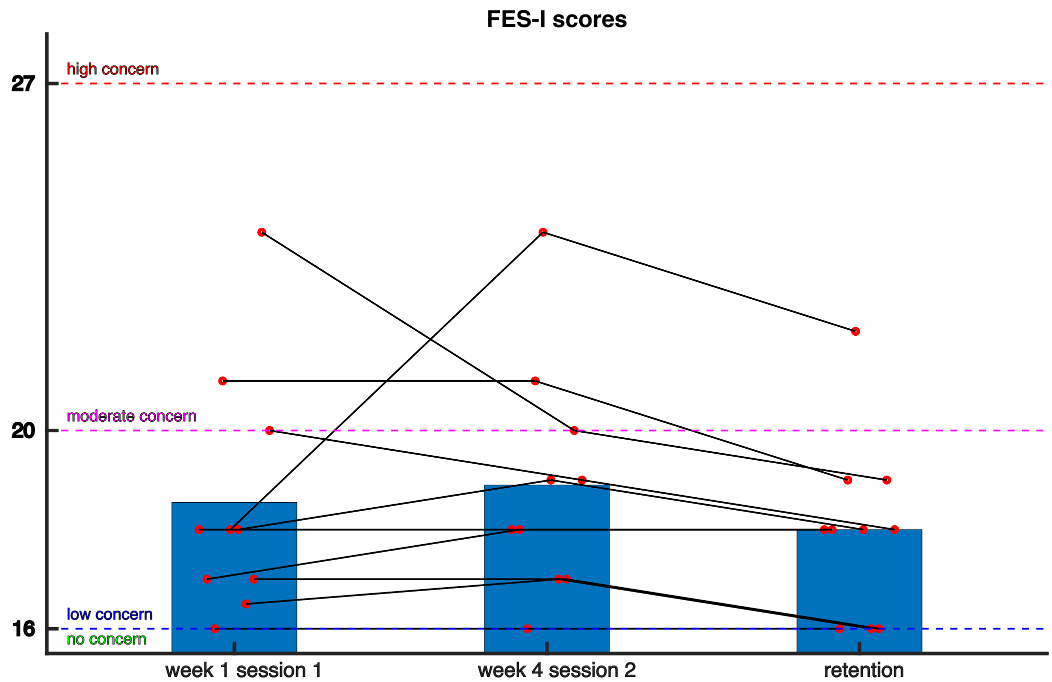

Fig 5. Scores on the Falls Efficacy Scale-International (FES-I). Red circles represent individual data points. Higher scores mean a more serious concern of falling.

Biomechanical outcome measures – Training effects

Degree of foot placement control - Normal walking

The degree of foot placement control during the normal walking condition did not significantly change between Sessions or Weeks. Yet, the Week * Session interaction was significant. However, Bonferroni corrected post hoc analysis of the interaction effect did not yield any significant comparisons (Fig 6a).

Degree of foot placement control - Training condition

The degree of foot placement control during the training condition, was not significantly affected by either Week or Session, nor by their interaction (Fig 6b).

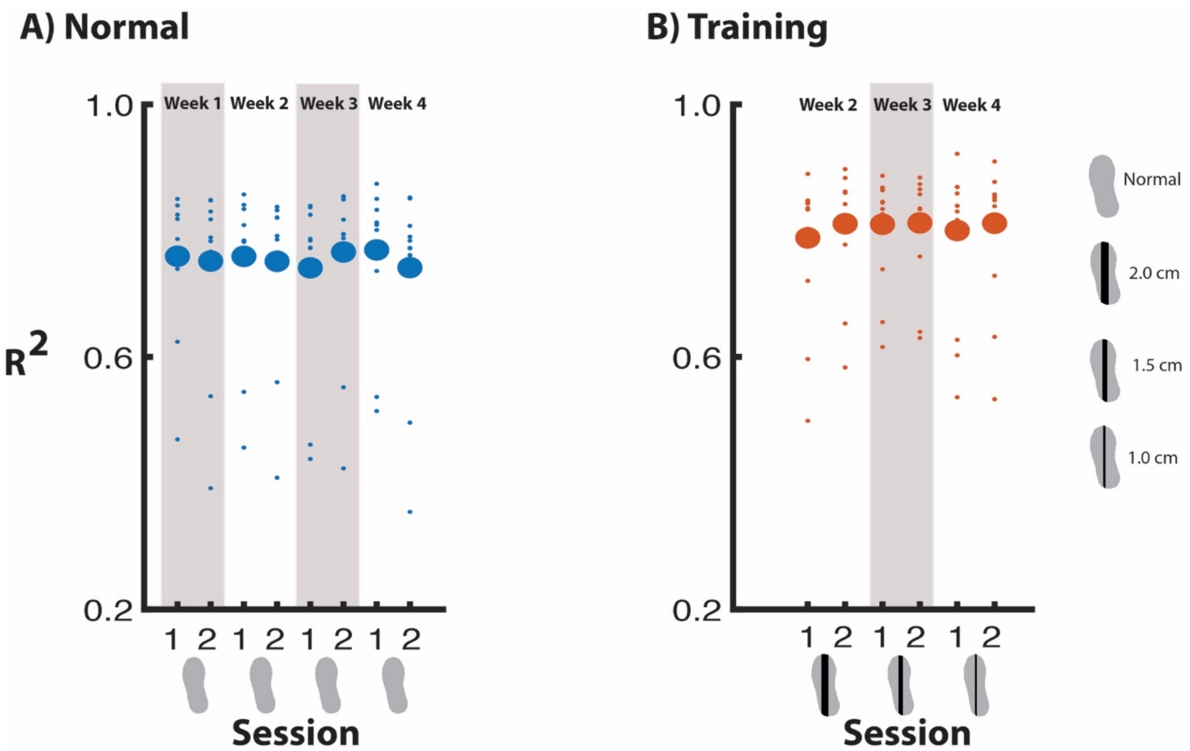

Fig 6. The degree of foot placement control across measurement sessions.

Magnitude of foot placement error - Normal walking

For the normal walking condition, we found a significant effect of Week on the foot placement error. This effect denoted that from week 2 onwards, the foot placement error was smaller than in week 1 (Fig 7a).

Magnitude of foot placement error - Training condition

For the foot placement error during training, we found a significant effect of Session. This signifies that every second time participants trained with the same shoe (respectively 2, 1.5 or 1 cm), the foot placement error was smaller (Fig 7b).

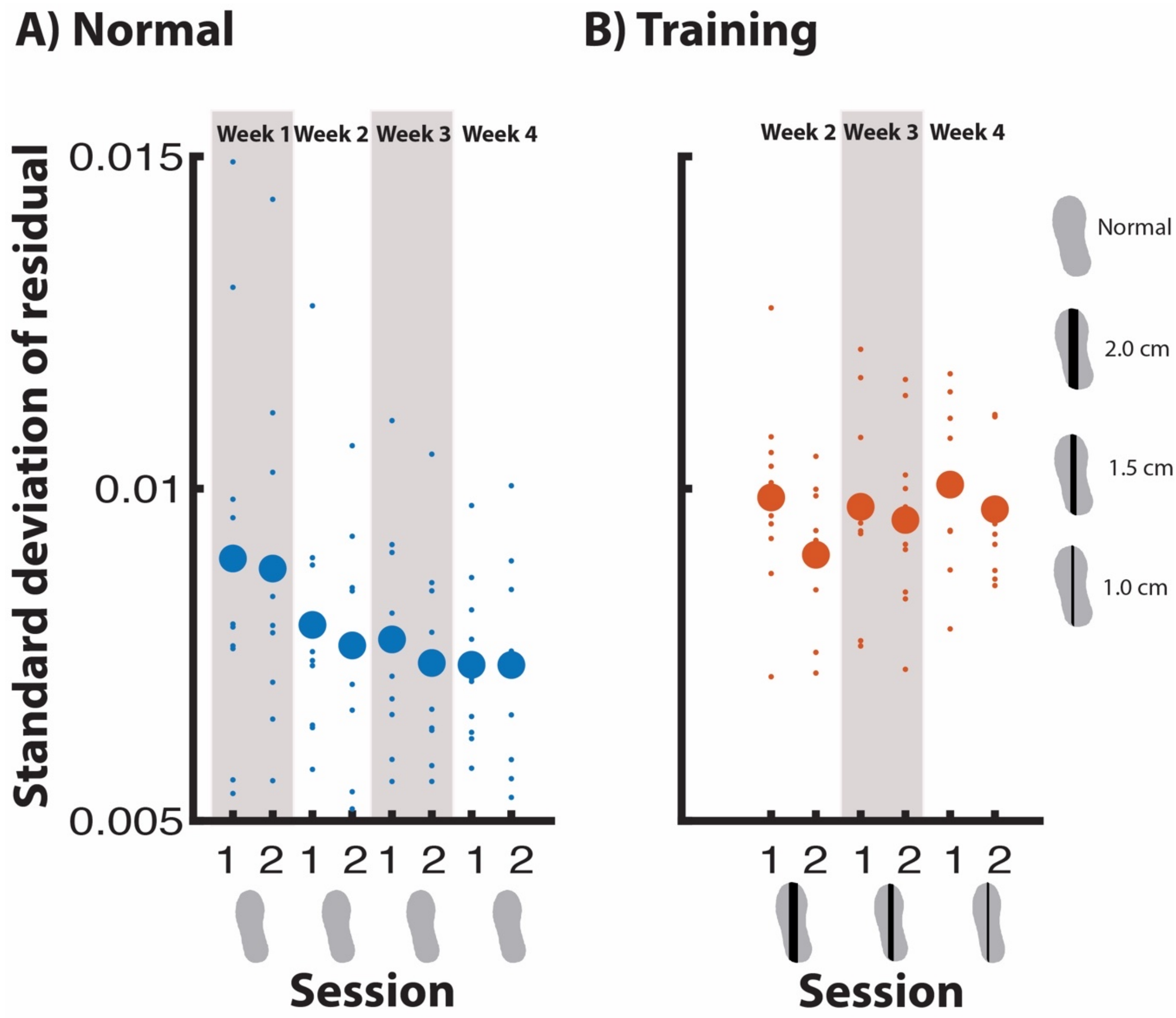

Fig 7. Magnitude of foot placement error (i.e. standard deviation of residual) in meters across measurement sessions.

Gait stability - Normal walking

In the normal walking condition, gait stability was significantly affected by Week and Session ($p<0.05$). Post-hoc comparisons for Week showed that from week 3 onwards, participants walked more stable than in week 1. The effect of Session revealed that in every second session, participants walked more stable than in the first session that week (Fig 8a).

Gait stability - Training condition

For the training condition, we did not find a significant effect of Week, nor of Session (Fig 8b).

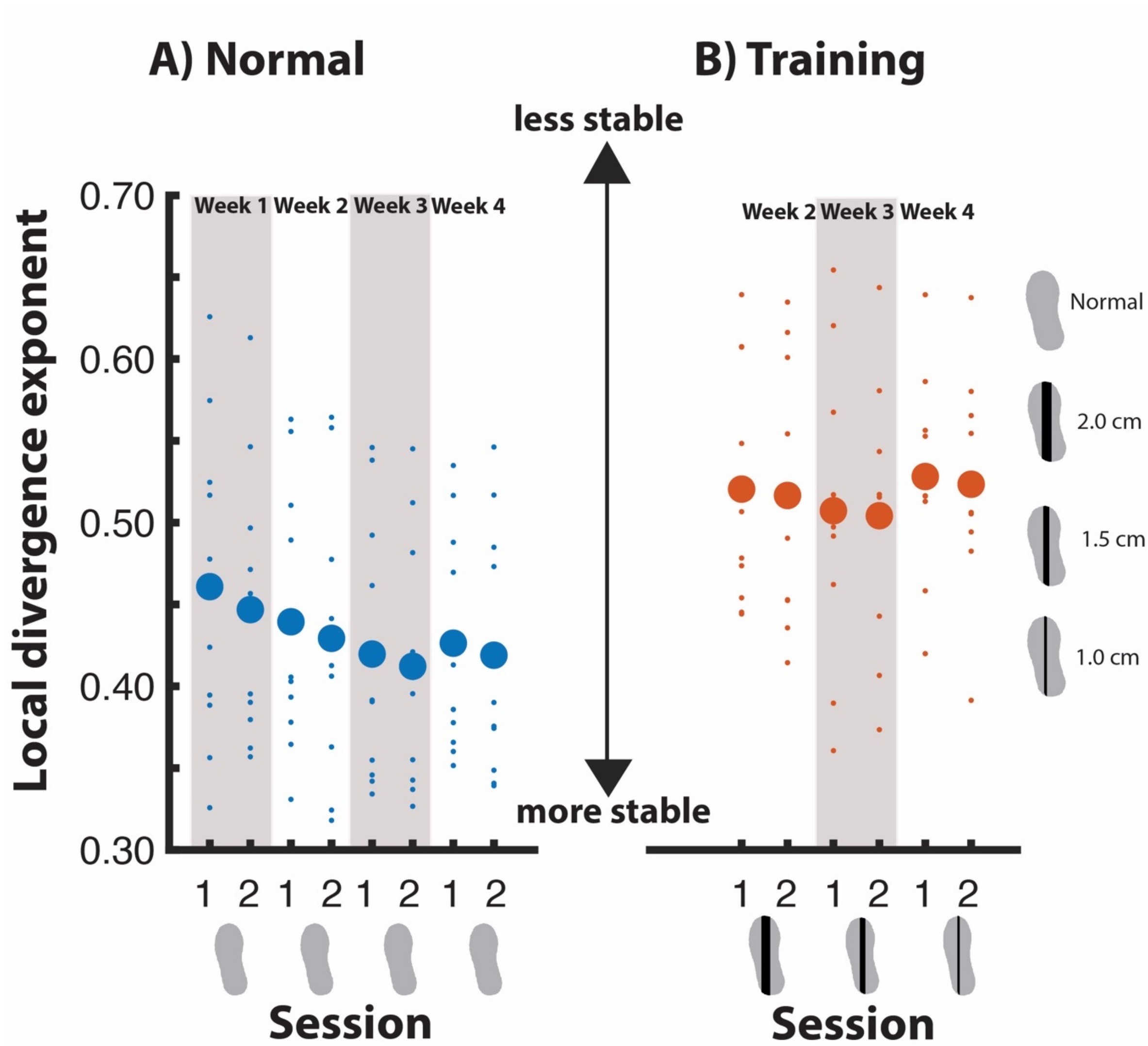

Fig 8. Gait stability across measurement sessions.

Step width - Normal walking

In the normal walking condition, step width was significantly affected by Week. Post-hoc analysis revealed that only week two differed significantly from week one, with a smaller step width in week 2 (Fig 9a).

Step width - Training condition

During training, step width did not significantly change across Week and Sessions (Fig 9b).

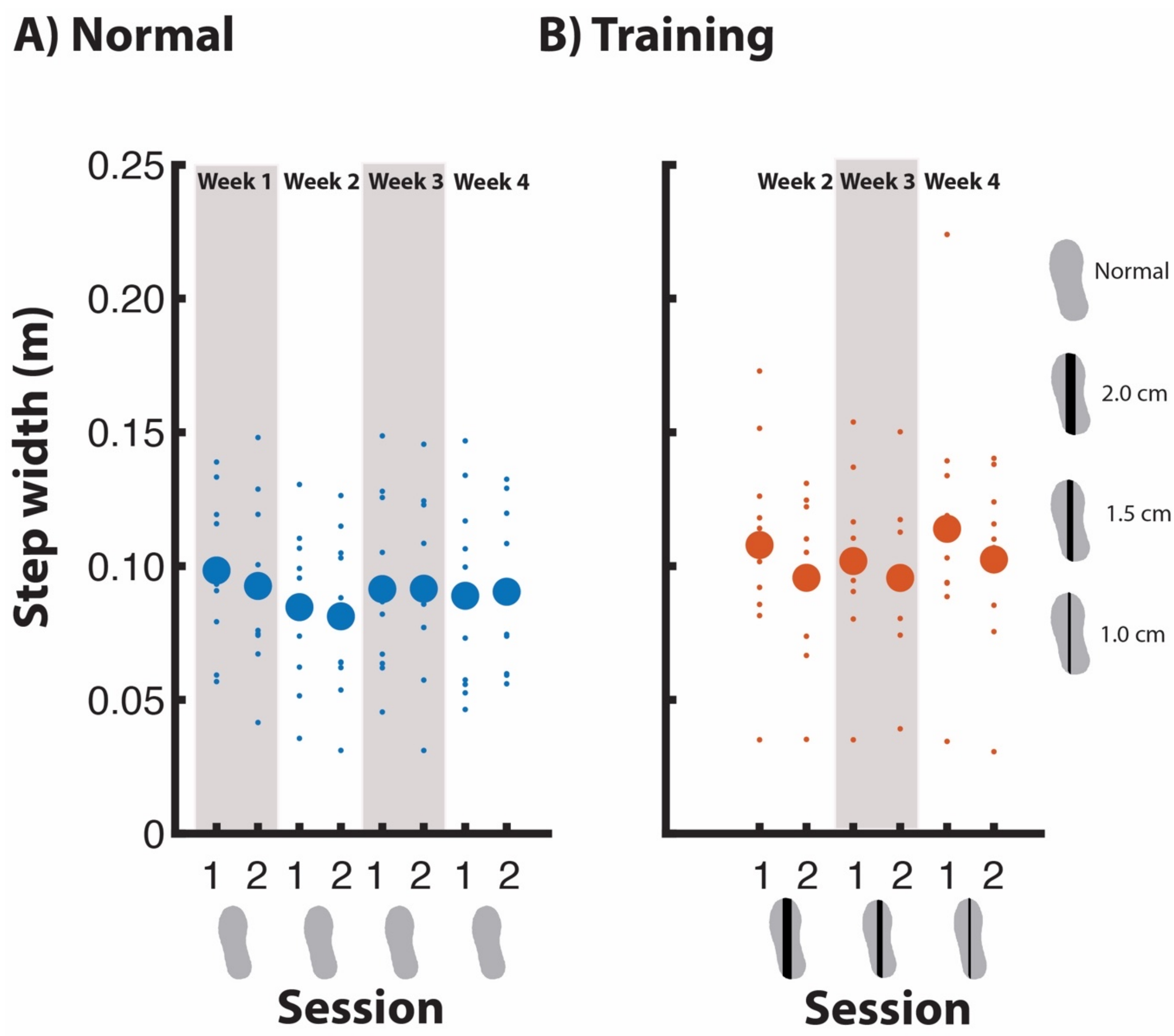

Fig 9. Step width across measurement sessions.

Stride time - Normal walking

During normal walking, there was no significant effect of Week nor Session on stride time (Fig 10a).

Stride time - Training condition

For the training condition no significant effects were found for Week nor Session on stride time (Fig 10b).

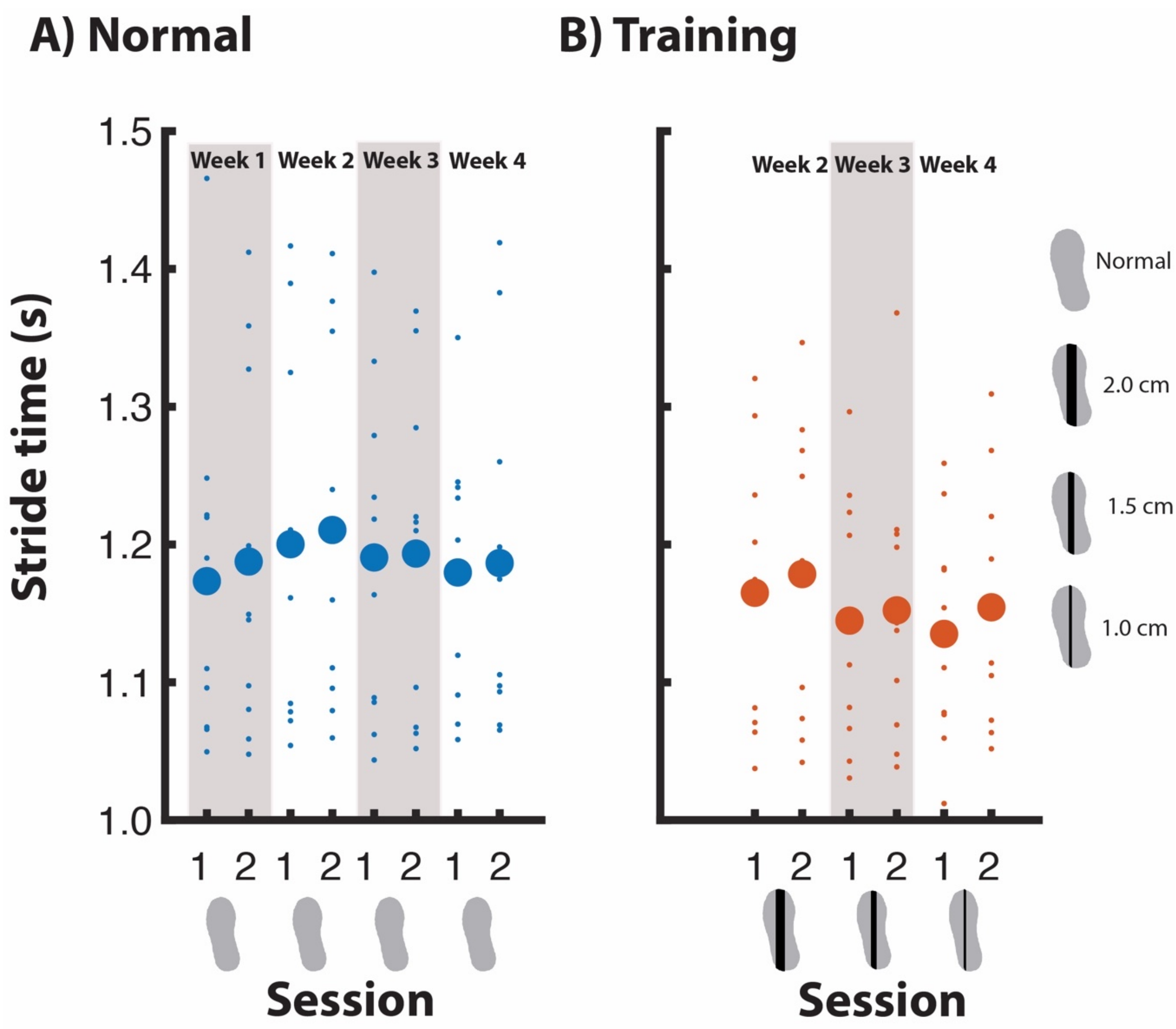

Fig 10. Stride time across measurement sessions.

Retention

For the retention test we only statistically tested outcome measure that had changed significantly between Weeks (for the normal walking condition) or Sessions (for the training condition).

Magnitude of foot placement error

Foot placement error in the normal walking condition remained significantly smaller during retention as compared to the normal walking condition in week 1. Moreover, when comparing the retention training condition to the training condition of the last training session, foot placement error seemed to have further decreased when walking with LesSchuh (Fig 11), but this was not a significant decrease.

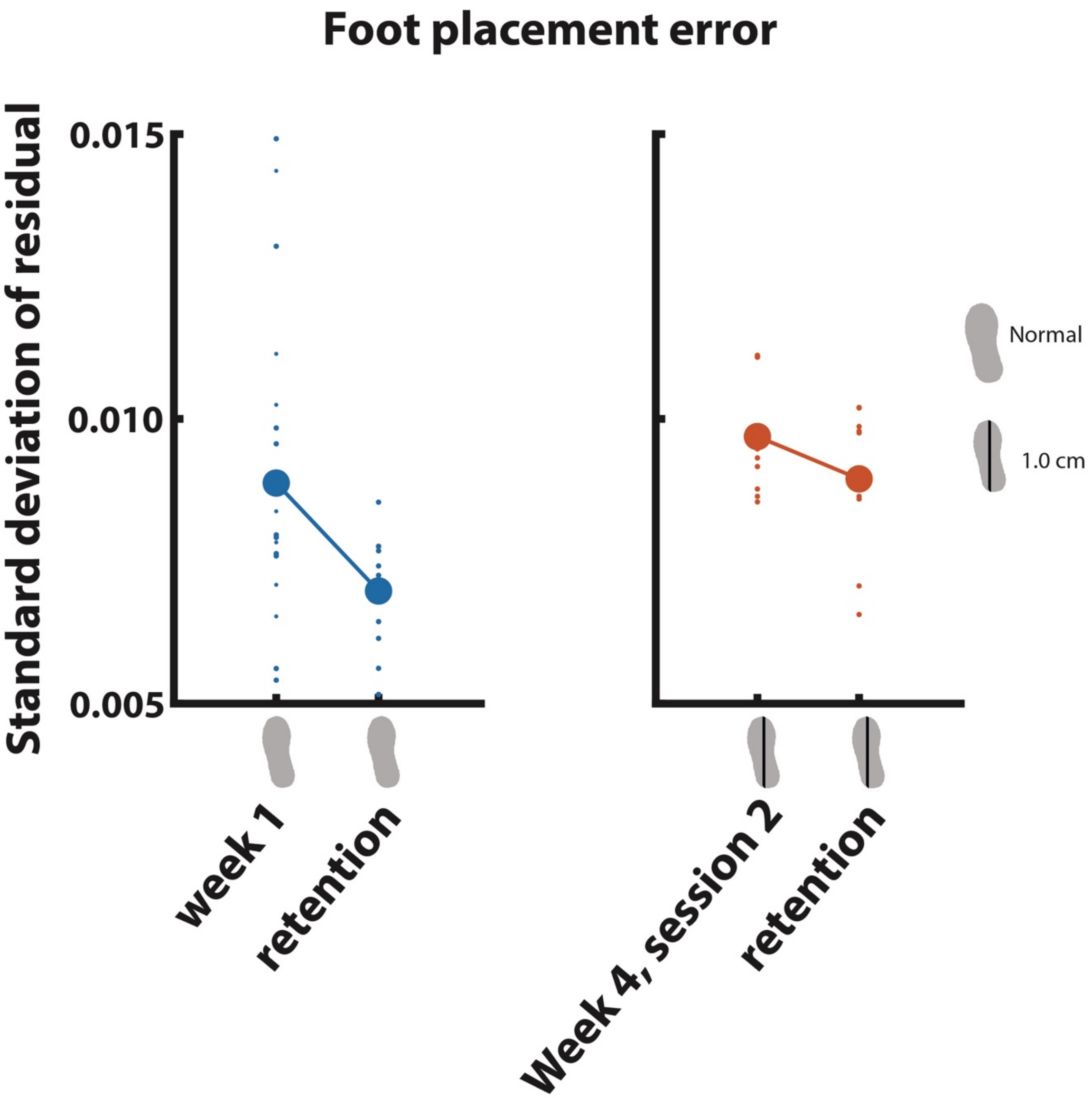

Fig 11. Magnitude of foot pacement placement error in meters retention.

Gait stability

During the normal walking condition of the retention session, gait stability was no longer significantly improved compared to the normal walking condition in week 1 (Fig 12).

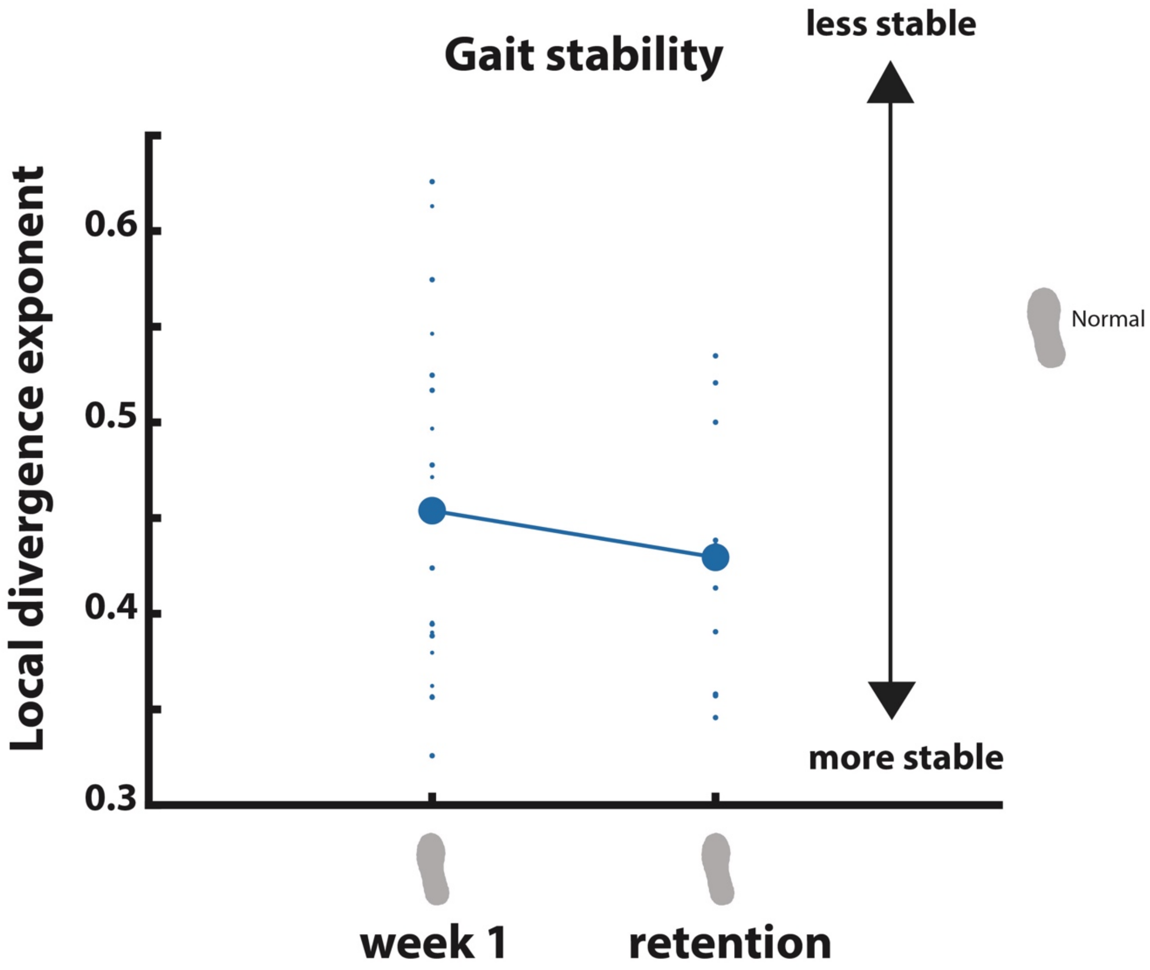

Fig 12. Gait stability retention.

Discussion

Maintaining mediolateral gait stability requires accurate coordination between the center-of-mass (CoM) and foot placement. Here we tried to train foot placement control in older adults, to improve their mediolateral gait stability. We expected that walking with constrained ankle moments would enforce participants to increase their degree of foot placement control, as they could no longer rely on ankle moment control to compensate for errors in foot placement. Although we did not find the hypothesized changes in the degree of foot placement control, foot placement errors decreased. Moreover, gait stability improved across training sessions and weeks, albeit without retention. Below we will discuss possible explanations as to why the ankle moment constraints did not induce changes in the degree of foot placement control, and how other mechanisms may have contributed to their improved gait stability.

Task compliance

LesSchuh's main function is to limit center-of-pressure (CoP) adjustments, after the foot is placed. As such, errors in foot placement can no longer be corrected for by ankle moment control, as occurs in unconstrained steady-state walking (20). Unlike the young adults from our previous study (21), as a group, the older adults complied with our instructions to keep their feet pointing straight ahead (see S3). As such, they avoided compensation through a toeing-out strategy (25). Thus, despite failing to walk only on the ridge from time to time, corrected by our feedback, the participants managed to walk in such a way that overall ankle moment control was constrained. Non-compliance with the instructions is therefore not a likely explanation for the absent change in the degree of foot placement control.

Training effects

Although we did not find a training effect for the degree of foot placement control, the older adults demonstrated other training effects across sessions and weeks. Most of these effects were found during normal walking, rather than while walking on LesSchuh.

Foot placement error during the normal walking condition was decreased relative to week 1 from week 2 onwards, but did not show any further significant reduction over the weeks that followed. From Fig 7, it seems that part of the reduction can be attributed to treadmill walking in itself (large drop between week 1 session 2 and week 2 session 1), possibly reflecting familiarization (30). However, LesSchuh may have played a role in this training effect as well. In Fig 7, we can see that for the normal walking condition, the largest decrease in foot placement error was found between the last session of the control week and the start of the first training week. However, within the first training week (week 2), a further reduction in foot placement error is observable. As we found significant reductions in foot placement error across sessions during the training condition, one may speculate that these changes during the training were, to some extent, transferred to normal walking. That we do not find a decrease in foot placement error during training across weeks, may be explained by the fact that the ridge underneath the shoe became narrower in each training week. This increased task difficulty, which would explain why in the first session of each training week the foot placement error was increased, while it was decreased again in the second session (Fig 7).

For step width and stride time (Figs 9 and 10), we also noticed an increase in the training condition of the week's first session, followed by a decrease in the second session. This could reflect compensation for the ankle moment constraints, and a lesser need for compensation in the second training session with the same shoe, as foot placement error decreased. In previous studies, increased step width and decreased stride time were found to be used to compensate for the constrained ankle moments (18, 21). However, in the current study such compensations (see "Immediate effect of walking with ankle moment constraints", S3) were not significant, nor was there a significant effect of Session on step width and stride time. The use of a single-belt treadmill in the current study, rather than a split-belt, may have diminished the need for such compensatory strategies (19).

Another training-effect was found for gait stability. We defined gait stability as a local divergence exponent, which has previously been shown to be able to distinguish fall-prone from healthy older adults (31). During the normal walking condition, gait stability consistently improved between sessions, and from week 3 onwards participants walked more stable as compared to the control week. Since week 3 was the second training week, it is likely that part of the improvement in gait stability can be attributed to the LesSchuh training, rather than just familiarization.

Stabilizing strategy

From our outcome measures, the reduction in foot placement error is the most likely candidate to underlie the enhanced gait stability. Since none of our outcome measures exactly mirrored the changes in stability, it is likely that other strategies outside the scope of our outcome measures, such as an angular momenum strategy (9, 32), contributed to the improved gait stability.

The fact that the decreased foot placement error did not coincide with a higher degree of foot placement control, can be accounted for by a similar reduction in the absolute explained variance of the foot placement model (which we have earlier (21) referred to as "the foot placement contribution"). Possibly, this reduction in absolute variance is caused by the more precise foot placement. More precise foot placement in a given step would need less foot placement adjustment on the next step to accommodate for variations in CoM kinematic state. As such, a lower absolute (explained) foot placement variance could result from reducing foot placement errors. Alternatively, other stability control mechanisms may have contributed, allowing for lower foot placement variance.

It should be noted that for our participants it was quite challenging to support themselves on the narrow ridge underneath the shoe. This was not necessarily only related to the limited CoP shift, but, based on their feedback, also on the muscle activity and strength required to keep their feet in the required orientation. This additional challenge may have enhanced their general coordination and muscle strength. As such, it may have facilitated stability control in general, as opposed to a specific adaptation to the lack of a compensatory mechanism for errors in foot placement.

Retention

During normal walking in the retention test, the foot placement error remained smaller compared to the control week. Despite a retained reduction in the magnitude of foot placement error, stability had returned to the control week level in the retention test. It seems that participants needed to keep training/walking on the treadmill to retain improved stability.

Training potential

Although this study included a fit group of older adults (based on the SPBB), the training proved quite strenuous for some participants. Compared to young adults, the older adults needed more intensive feedback when walking on LesSchuh. Since for this fit and physically active group it was already a challenge to stay on the ridge, often resulting in muscle soreness on subsequent days, the applicability may be limited. Yet, overall our participants expressed positive feelings regarding the training, and one participant even took LesSchuh home to continue the training. If LesSchuh can effectively enhance stability, the fact that they can easily be made using low-cost materials and the ability to train at home promote the potential as a training tool. As such, LesSchuh could be suitable as a training tool for relatively fit older adults. However, for frail older adults more controlled training methods, such as assistive force fields (33, 34) or augmented proprioceptive feedback (35), may be preferred in terms of effort and feasibility.

Study limitations

We only included a small sample size with relatively fit older adults. At baseline, on average the group had “No risk of impaired physical functioning” (SPPB) and had a “Low concern of falling” (FES-I). Perhaps the high scores on both tests at baseline, prevented a significant improvement on these tests. A larger, more diverse group, in terms of SPPB and FES-I levels, may have given more insight into a potential effect of LesSchuh on these clinical measures. Another limitation of this study is, that it is not a randomized control trial, and therefore it cannot be concluded whether the training effects should be attributed to training on LesSchuh, or to treadmill walking in itself. We did have the control week, theoretically as a control for within week (Session) effects. During normal walking, stability did not only improve across sessions in the training weeks, but also in the control week, likely reflecting treadmill familiarization (30). This makes it hard to distinguish true LesSchuh training effects on stability. A randomized controlled trial, with normal treadmill walking as a control intervention would be needed to verify the presumed effects of LesSchuh. Moreover, although this study showed training effects in normal treadmill walking, it remains to be elucidated whether such training effects translate to overground walking.

Lastly, future studies are recommended to collect full body kinematics, center-of-pressure data and energy cost data to be able to investigate whether apart from desired changes in foot placement and stability control, no maladaptive changes are found in the gait pattern, following training with LesSchuh. A potential maladaptive change can be related to potential stiffening of the ankle joint in order to support oneself only on the narrow ridge. Increasing ankle stiffness is a part of ageing (36), and may not only be detrimental to gait stability, but also to an energetically inefficient push-off mechanism (37). In future studies, it should be monitored whether LesSchuh teaches a gait pattern in which even less ankle range of motion is used, and whether this pattern is transferred to normal walking, as such undesired effects should be avoided. From an optimistic perspective, the stiffening of the ankle and the effort exerted to stay on the ridge may instead have a positive effect on ankle functionality, as muscle strength exercises are recommended to combat ankle stiffness, in combination with stretching exercises (Vandervoort, 1999). Perhaps combining LesSchuh training with stretching exercises will prevent maladaptive changes related to ankle stiffness.

Conclusion

Older adults have a lesser degree of foot placement control than young adults (12), which can be detrimental to mediolateral gait stability (6). Therefore, we set out to train their degree of foot placement control by constraining ankle moments. Their degree of foot placement control remained unchanged, yet foot placement errors decreased and gait stability increased. We conclude that LesSchuh may be useful to improve the precision in foot placement.

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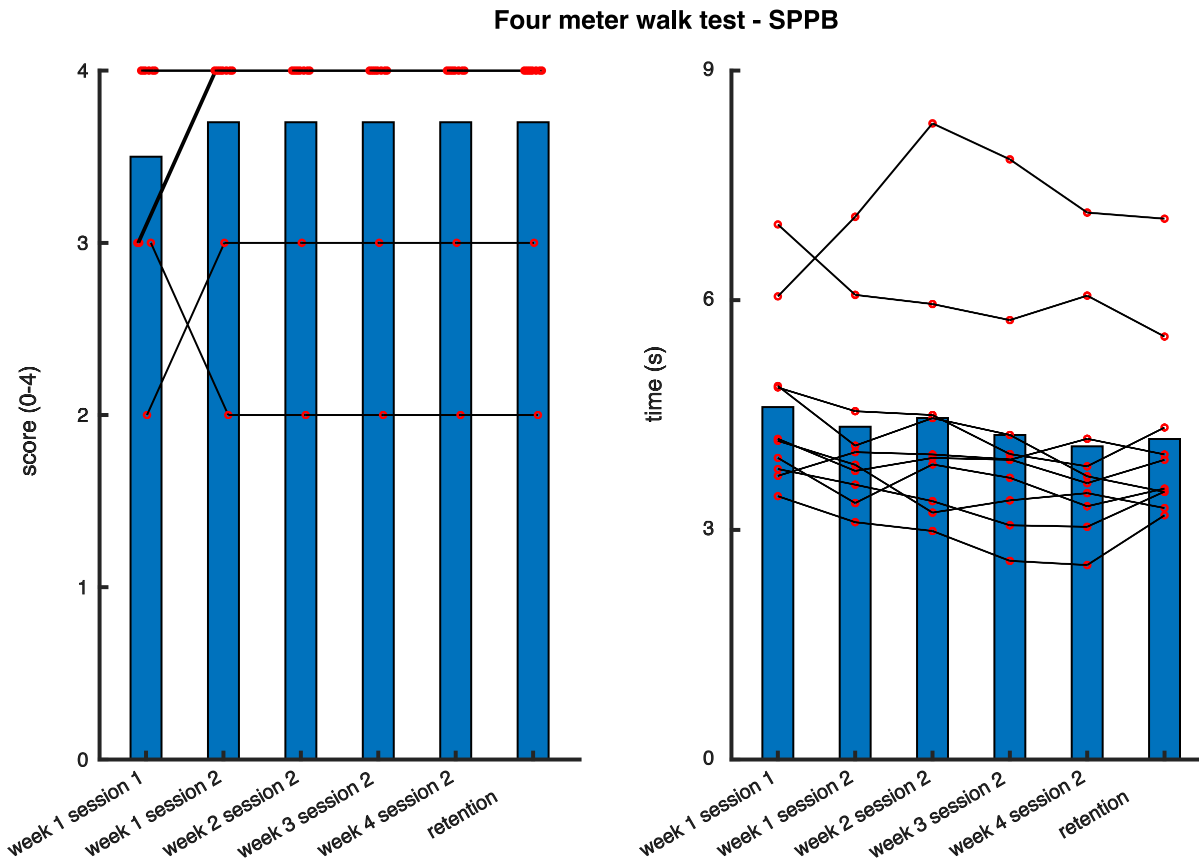
Supplementary material

S1 SPPB Four meter walk test



S1 Fig 1. Four-meter walking test of the Short Physical Performance Battery (SPPB). SPPB scores (left panel) and time in seconds (right panel) have been depicted. Red circles represent individual data points.

S2 Tables main analysis statistical tests

In supplementary material 2, we report the tables from the statistical tests computed in JASP, for our clinical and biomechanical outcome measures. **Significant effects** have been printed in **bold**.

Clinical outcome measures – Training effect

SPPB

Paired Samples T-Test

Measure 1		Measure 2	t	df	p
baseline	-	last training session	-1.078	9	0.309

Note. Student's t-test.

Descriptives

Descriptives

	N	Mean	SD	SE
baseline	10	11.200	1.135	0.359
last training session	10	11.600	0.843	0.267

FES-I

Paired Samples T-Test

Measure 1		Measure 2	t	df	p
baseline	-	last training session	-0.452	9	0.662

Note. Student's t-test.

Descriptives

Descriptives

	N	Mean	SD	SE
baseline	10	18.550	2.455	0.776
last training session	10	18.900	2.331	0.737

Biomechanical outcome measures – Training effect

Degree of foot placement control - Normal walking

Repeated Measures ANOVA
Within Subjects Effects

Cases	Sum of Squares	df	Mean Square	F	p
Week	0.001	3	4.620e-4	0.099	0.960
Residuals	0.126	27	0.005		
Session	0.006	1	0.006	0.423	0.532
Residuals	0.127	9	0.014		
Week ✻ Session	0.067	3	0.022	5.112	**0.006**
Residuals	0.118	27	0.004		

Note. Type III Sum of Squares

Post Hoc Tests
Post Hoc Comparisons - Week ✻ Session

		Mean Difference	SE	t	Cohen's d	p_{bonf}
1, 1	2, 1	0.005	0.030	0.182	0.016	1.000
	3, 1	0.060	0.030	1.991	0.171	1.000
	4, 1	-0.023	0.030	-0.756	-0.065	1.000
	1, 2	0.028	0.037	0.762	0.080	1.000
	2, 2	0.027	0.037	0.736	0.078	1.000
	3, 2	-0.012	0.037	-0.312	-0.033	1.000
	4, 2	0.068	0.037	1.818	0.194	1.000
2, 1	3, 1	0.054	0.030	1.810	0.155	1.000
	4, 1	-0.028	0.030	-0.937	-0.080	1.000
	1, 2	0.023	0.037	0.607	0.065	1.000
	2, 2	0.022	0.037	0.596	0.063	1.000
	3, 2	-0.017	0.037	-0.458	-0.049	1.000
	4, 2	0.062	0.037	1.672	0.178	1.000
3, 1	4, 1	-0.082	0.030	-2.747	-0.236	0.228
	1, 2	-0.032	0.037	-0.852	-0.091	1.000
	2, 2	-0.032	0.037	-0.869	-0.092	1.000
	3, 2	-0.071	0.037	-1.938	-0.204	1.000
	4, 2	0.008	0.037	0.214	0.023	1.000
4, 1	1, 2	0.051	0.037	1.362	0.145	1.000
	2, 2	0.050	0.037	1.345	0.143	1.000
	3, 2	0.011	0.037	0.297	0.032	1.000
	4, 2	0.090	0.037	2.455	0.258	0.591
1, 2	2, 2	-6.343e-4	0.030	-0.021	-0.002	1.000
	3, 2	-0.040	0.030	-1.321	-0.113	1.000
	4, 2	0.040	0.030	1.322	0.113	1.000
2, 2	3, 2	-0.039	0.030	-1.300	-0.112	1.000
	4, 2	0.040	0.030	1.343	0.115	1.000

Post Hoc Comparisons - Week ✻ Session

	Mean Difference	SE	t	Cohen's d	p_{bonf}
3, 2 4, 2	0.079	0.030	2.643	0.227	0.300

Note. P-value adjusted for comparing a family of 28

Degree of foot placement control – Training condition

Repeated Measures ANOVA
Within Subjects Effects

Cases	Sum of Squares	df	Mean Square	F	p
Week	0.011	2	0.005	0.278	0.760
Residuals	0.350	18	0.019		
Session	0.019	1	0.019	3.221	0.106
Residuals	0.054	9	0.006		
Week ✻ Session	0.015	2	0.008	1.489	0.252
Residuals	0.093	18	0.005		

Magnitude of foot placement error - Normal walking

Repeated Measures ANOVA
Within Subjects Effects

Cases	Sum of Squares	df	Mean Square	F	p
Week	3.226e-5 [a]	3 [a]	1.075e-5 [a]	6.969 [a]	**0.001** [a]
Residuals	4.166e-5	27	1.543e-6		
Session	1.198e-6	1	1.198e-6	3.828	0.082
Residuals	2.817e-6	9	3.130e-7		
Week ✻ Session	5.080e-7	3	1.693e-7	0.706	0.557
Residuals	6.479e-6	27	2.400e-7		

Note. Type III Sum of Squares

[a] Mauchly's test of sphericity indicates that the assumption of sphericity is violated ($p < .05$).

Post Hoc Tests

Post Hoc Comparisons - Week

		Mean Difference	SE	t	Cohen's d	p_{bonf}
1	2	0.001	3.928e-4	3.222	0.686	**0.020**
	3	0.001	3.928e-4	3.661	0.780	**0.006**
	4	0.002	3.928e-4	4.106	0.875	**0.002**
2	3	1.723e-4	3.928e-4	0.439	0.093	1.000
	4	3.470e-4	3.928e-4	0.883	0.188	1.000
3	4	1.747e-4	3.928e-4	0.445	0.095	1.000

Note. P-value adjusted for comparing a family of 6

Note. Results are averaged over the levels of: Session

Magnitude of foot placement error – Training condition

Repeated Measures ANOVA
Within Subjects Effects

Cases	Sum of Squares	df	Mean Square	F	p
Week	2.144e-6	2	1.072e-6	1.120	0.348
Residuals	1.723e-5	18	9.570e-7		
Session	3.827e-6	1	3.827e-6	5.545	**0.043**
Residuals	6.211e-6	9	6.901e-7		
Week ✻ Session	1.458e-6	2	7.288e-7	2.926	0.079
Residuals	4.484e-6	18	2.491e-7		

Note. Type III Sum of Squares

Post Hoc Tests
Post Hoc Comparisons - Session

		Mean Difference	SE	t	Cohen's d	p_{bonf}
1	2	5.051e-4	2.145e-4	2.355	0.394	**0.043**

Note. Results are averaged over the levels of: Week

Gait stability - Normal walking

Repeated Measures ANOVA
Within Subjects Effects

Cases	Sum of Squares	df	Mean Square	F	p
Week	0.018	3	0.006	6.624	**0.002**
Residuals	0.024	27	8.835e-4		
Session	0.002	1	0.002	6.293	**0.033**
Residuals	0.003	9	3.120e-4		
Week ✻ Session	1.399e-4	3	4.664e-5	0.087	0.967
Residuals	0.015	27	5.378e-4		

Note. Type III Sum of Squares

Post Hoc Tests
Post Hoc Comparisons - Week

		Mean Difference	SE	t	Cohen's d	p_{bonf}
1	2	0.021	0.009	2.216	0.250	0.212
	3	0.039	0.009	4.123	0.466	**0.002**
	4	0.033	0.009	3.490	0.394	**0.010**
2	3	0.018	0.009	1.906	0.215	0.404
	4	0.012	0.009	1.273	0.144	1.000
3	4	-0.006	0.009	-0.633	-0.072	1.000

Note. P-value adjusted for comparing a family of 6
Note. Results are averaged over the levels of: Session

Post Hoc Comparisons - Session

	Mean Difference	SE	t	Cohen's d	p_{bonf}
1 2	0.010	0.004	2.509	0.119	**0.033**

Note. Results are averaged over the levels of: Week

Gait stability – Training condition

Repeated Measures ANOVA
Within Subjects Effects

Cases	Sum of Squares	df	Mean Square	F	p
Week	0.005	2	0.002	1.052	0.370
Residuals	0.039	18	0.002		
Session	1.965e-4	1	1.965e-4	0.337	0.576
Residuals	0.005	9	5.838e-4		
Week ✻ Session	9.777e-6	2	4.888e-6	0.014	0.986
Residuals	0.006	18	3.543e-4		

Note. Type III Sum of Squares

Step width - Normal walking

Repeated Measures ANOVA
Within Subjects Effects

Cases	Sum of Squares	df	Mean Square	F	p
Week	0.002	3	6.089e-4	5.319	**0.005**
Residuals	0.003	27	1.145e-4		
Session	8.588e-5	1	8.588e-5	0.615	0.453
Residuals	0.001	9	1.396e-4		
Week ✻ Session	1.615e-4	3	5.385e-5	0.517	0.674
Residuals	0.003	27	1.041e-4		

Note. Type III Sum of Squares

Post Hoc Tests
Post Hoc Comparisons - Week

		Mean Difference	SE	t	Cohen's d	p_{bonf}
1	2	0.013	0.003	3.893	0.410	**0.004**
	3	0.004	0.003	1.189	0.125	1.000
	4	0.006	0.003	1.847	0.195	0.455
2	3	-0.009	0.003	-2.704	-0.285	0.070
	4	-0.007	0.003	-2.046	-0.216	0.304
3	4	0.002	0.003	0.658	0.069	1.000

Note. P-value adjusted for comparing a family of 6
Note. Results are averaged over the levels of: Session

Step width – Training condition

Repeated Measures ANOVA

Within Subjects Effects

Cases	Sum of Squares	df	Mean Square	F	p
Week	8.954e-4 [a]	2 [a]	4.477e-4 [a]	1.355 [a]	0.283 [a]
Residuals	0.006	18	3.305e-4		
Session	0.002	1	0.002	3.936	0.079
Residuals	0.004	9	4.138e-4		
Week ∗ Session	1.222e-4	2	6.109e-5	0.540	0.592
Residuals	0.002	18	1.132e-4		

Note. Type III Sum of Squares
[a] Mauchly's test of sphericity indicates that the assumption of sphericity is violated ($p < .05$).

Stride time - Normal walking

Repeated Measures ANOVA
Within Subjects Effects

Cases	Sum of Squares	df	Mean Square	F	p
Week	0.010 [a]	3 [a]	0.003 [a]	0.589 [a]	0.627 [a]
Residuals	0.145	27	0.005		
Session	0.002	1	0.002	1.087	0.324
Residuals	0.018	9	0.002		
Week ∗ Session	5.297e-4 [a]	3 [a]	1.766e-4 [a]	0.123 [a]	0.946 [a]
Residuals	0.039	27	0.001		

Note. Type III Sum of Squares
[a] Mauchly's test of sphericity indicates that the assumption of sphericity is violated ($p < .05$).

Stride time – Training condition

Repeated Measures ANOVA
Within Subjects Effects

Cases	Sum of Squares	df	Mean Square	F	p
Week	0.008	2	0.004	2.809	0.087
Residuals	0.027	18	0.001		
Session	0.003	1	0.003	2.966	0.119
Residuals	0.009	9	0.001		
Week ∗ Session	3.846e-4	2	1.923e-4	0.410	0.669
Residuals	0.008	18	4.685e-4		

Note. Type III Sum of Squares

Retention

Magnitude of foot placement error

Paired Samples T-Test

Measure 1		Measure 2	t	df	p	Cohen's d
w1_s1_baseline	-	retention_normal	2.700	9	**0.024**	0.854
w4_s2_training	-	retention_LesSchuh	2.124	9	0.063	0.672

Note. Student's t-test.

Gait stability

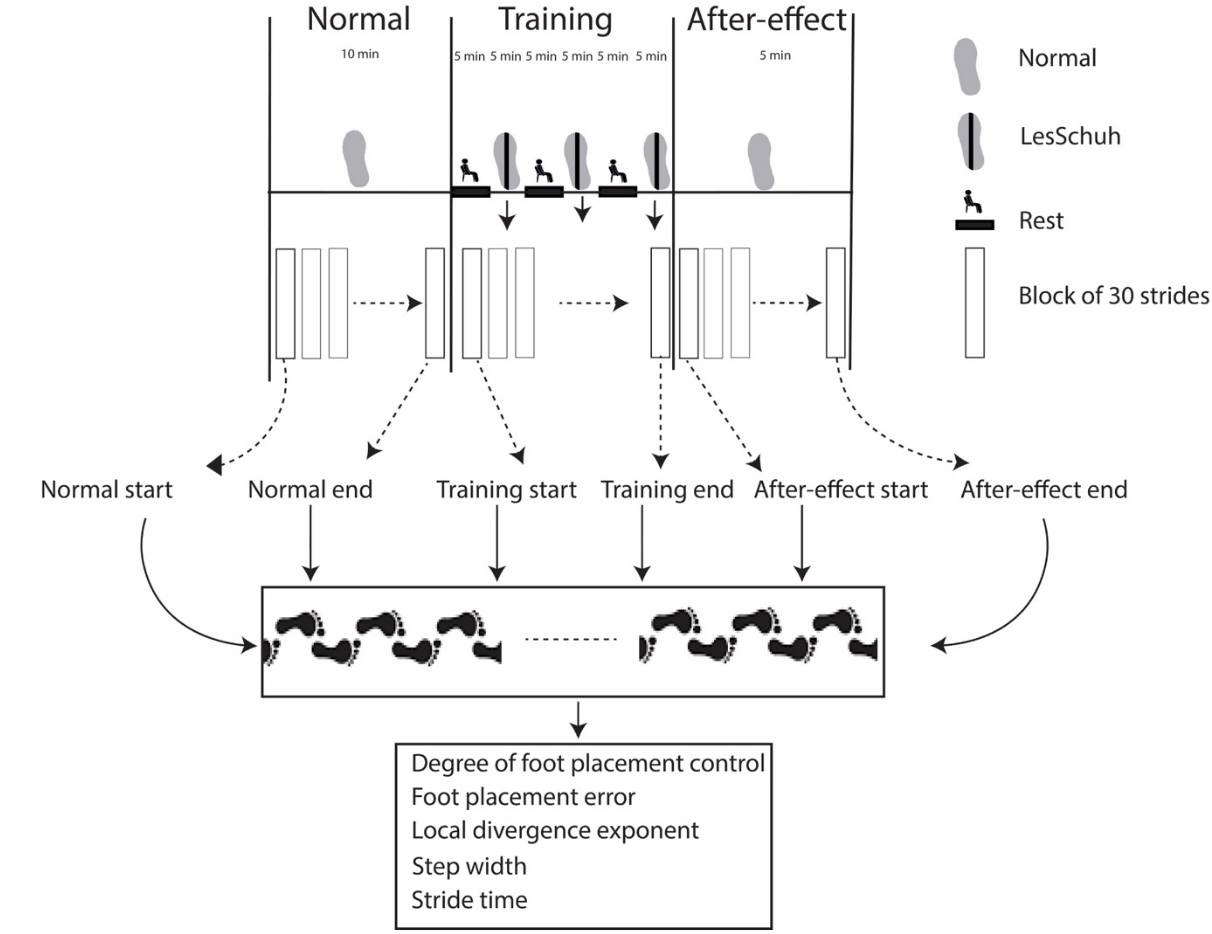
Paired Samples T-Test

Measure 1		Measure 2	t	df	p	Cohen's d
w1_s1_baseline	-	retention_normal	1.821	9	0.102	0.576

Note. Student's t-test.

S3 Within session analyses

In S3, we assess the outcome measures at similar data points as in Hoogstad, van Leeuwen (21), (i.e. based on blocks of 30 strides). In this way, we aim to give more insight in how any improvements over time manifested themselves. First, we looked for immediate effects of LesSchuh (comparing normal walking end to training start). Second, we evaluated changes throughout the training (comparing training start to training end). Third, we considered after-effects (comparing normal walking end to after-effect start). Lastly, we assessed whether any after-effect washed out over time (comparing after-effect start to after-effect end).



S3 Fig 1. Flow of data processing.

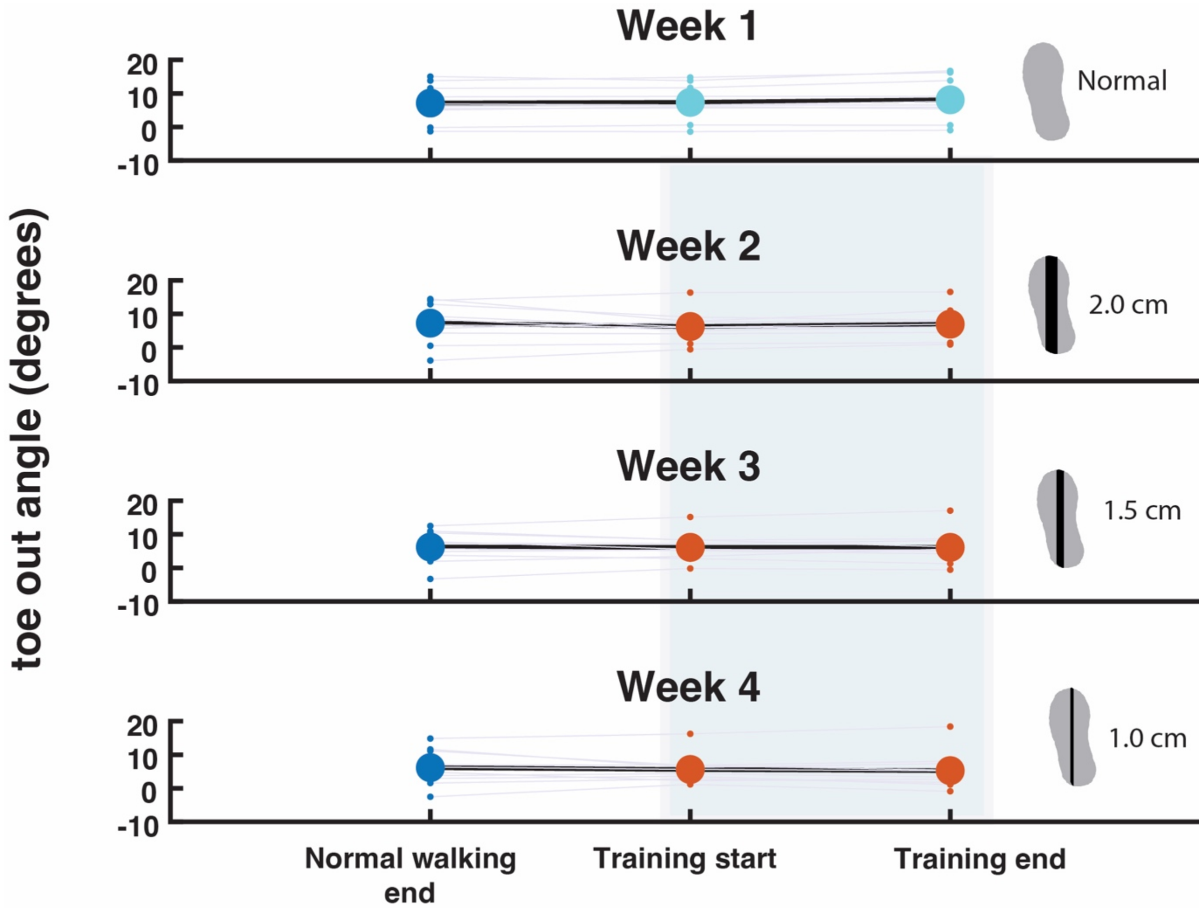
Immediate effect of walking with ankle moment constraints

For evaluating the immediate effect of walking with constrained ankle moments, we performed a repeated-measures ANOVA with the factors Condition ("normal walking end" vs "training start"), Week ("1","2","3","4") and Session ("1", "2"). If the factor Condition, or its interactions, were significant, the repeated-measures ANOVA was followed up by Bonferroni corrected post-hoc t-tests to compare normal walking end to training start.

Compliance with instructions

We computed mean toeing-out angles, to evaluate whether participants complied with the instruction to keep their feet pointing straight ahead, avoiding a toeing-out strategy (25).

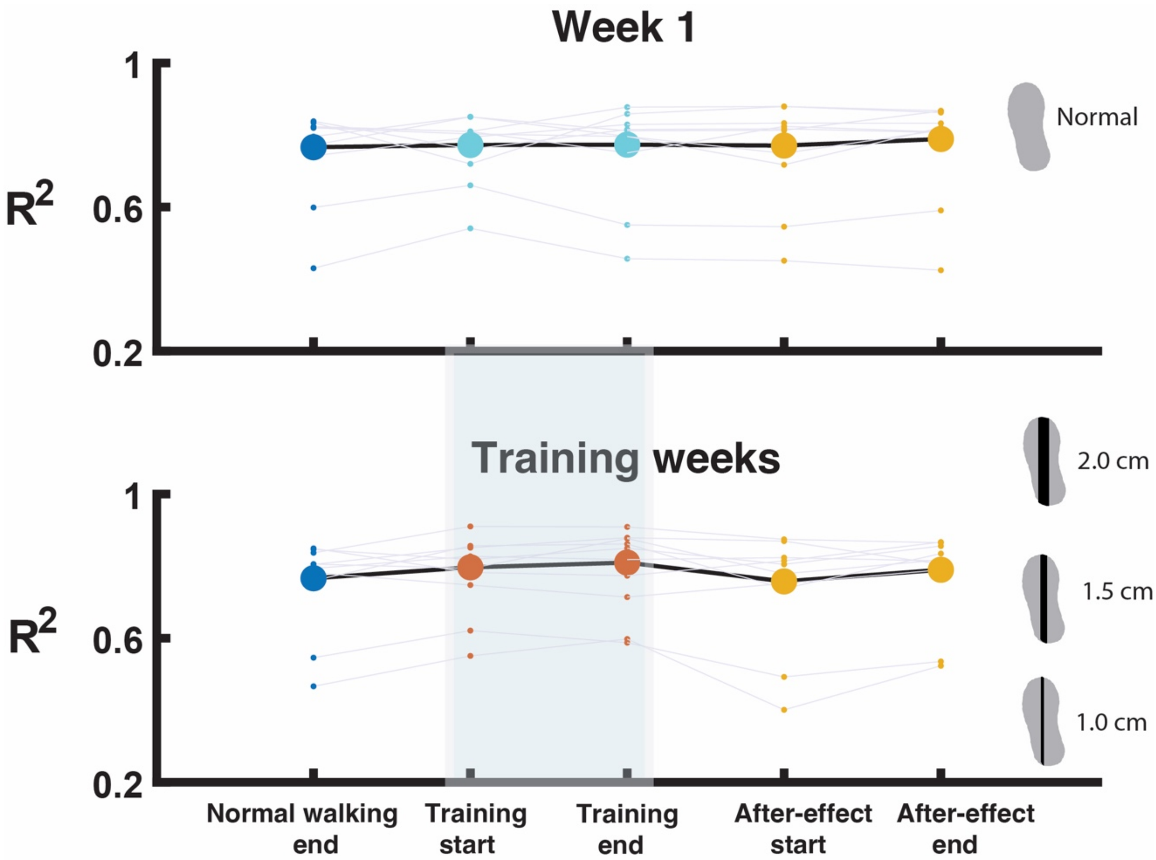
Participants were instructed to point their feet straight ahead while walking with LesSchuh. Yet, when testing for immediate effects on toe-out angles, we found a significant Condition*Session interaction. We averaged across week and performed two Bonferonni corrected t-tests to explore this interaction effect. No significant differences were found, indicating that on average the participants complied with our instructions during the first part of the training.



S3 Fig 2. Toe-out angles. *The angles are averaged across sessions 1 and 2. Positive angles represent more toeing out, whereas negative angles represent more toeing in. Participants did not significantly alter their toe-out angle when walking with LesSchuh (Shaded blue area with red dots) as compared to when walking with normal shoes (blue dots).*

Degree of foot placement control

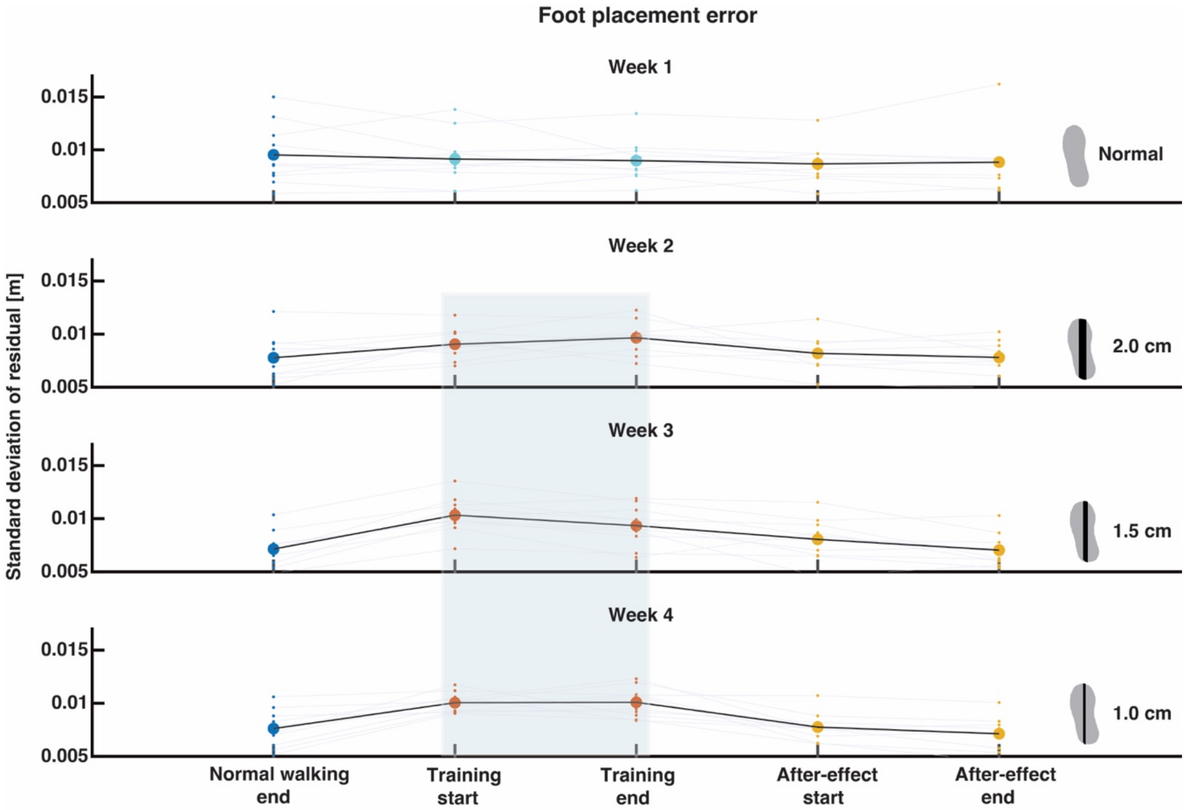
For the relative explained variance (R^2), we found no significant effects for Condition, Week or Session, nor for their interactions (*$p>0.05$*).



S3 Fig 3. Foot placement control quantified as the relative explained variance of the foot placement model (Model 1). The R^2s were averaged across sessions 1 and 2. In the lower panel the R^2s were also averaged across all training weeks (weeks 2,3 and 4). The shaded blue area with red dots represents the data when participants walked with LesSchuh.

Magnitude of foot placement error

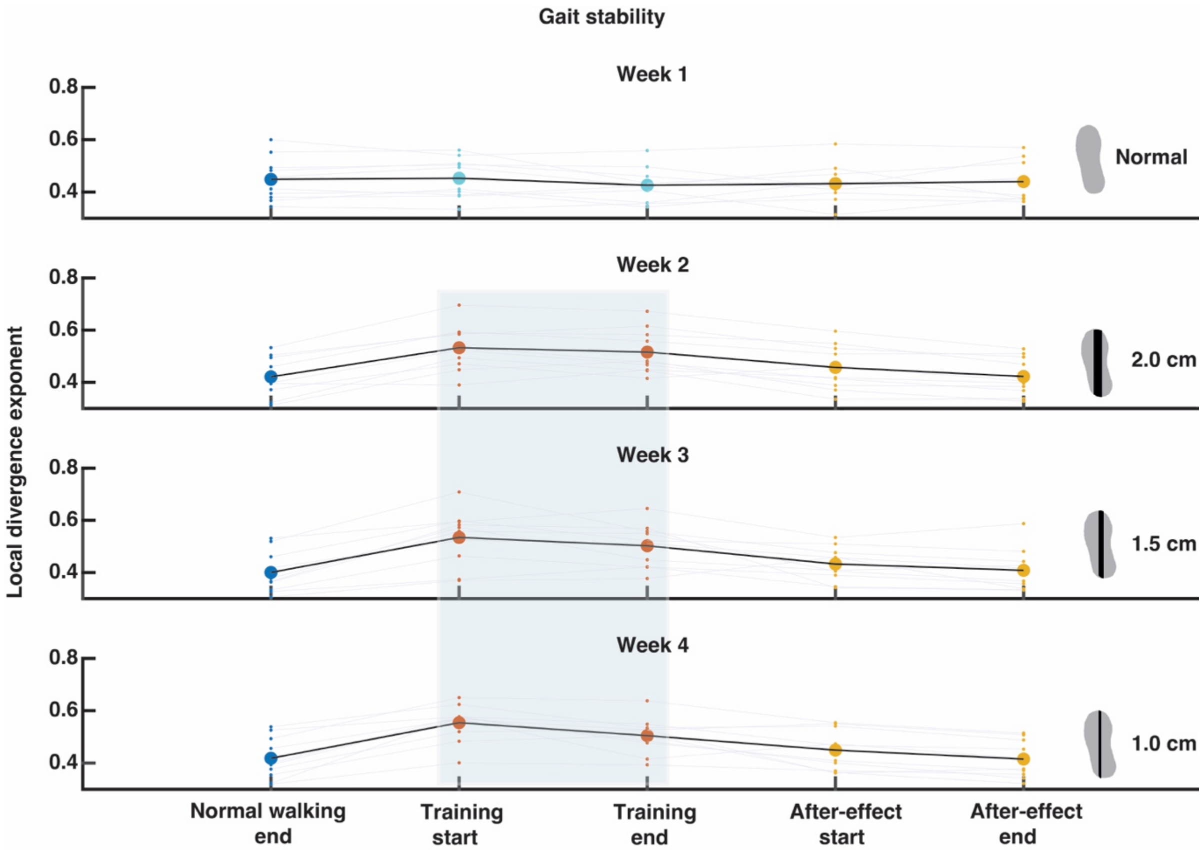
For the magnitude of foot placement error (i.e. the residual of Model 1), we found a significant effect of Condition and of the interaction Condition*Week (*$p<0.05$*). So, we averaged across sessions, and performed four Bonferroni corrected post-hoc t-tests to investigate the effects. In the control week (week 1) and while walking with a two-centimeter ridge (week 2) foot placement error did not significantly change between normal walking end and training start. However, when walking with 1.5- and 1-centimeter ridges (weeks 3 and 4) the foot placement error significantly increased when walking with constrained ankle moments (*$p<0.0125$*).



S3 Fig 4. Foot placement error quantified as standard deviation of the foot placement model (Model 1). The foot placements errors were averaged across sessions 1 and 2. The shaded blue area with red dots represents the data when participants walked with LesSchuh.

Gait stability

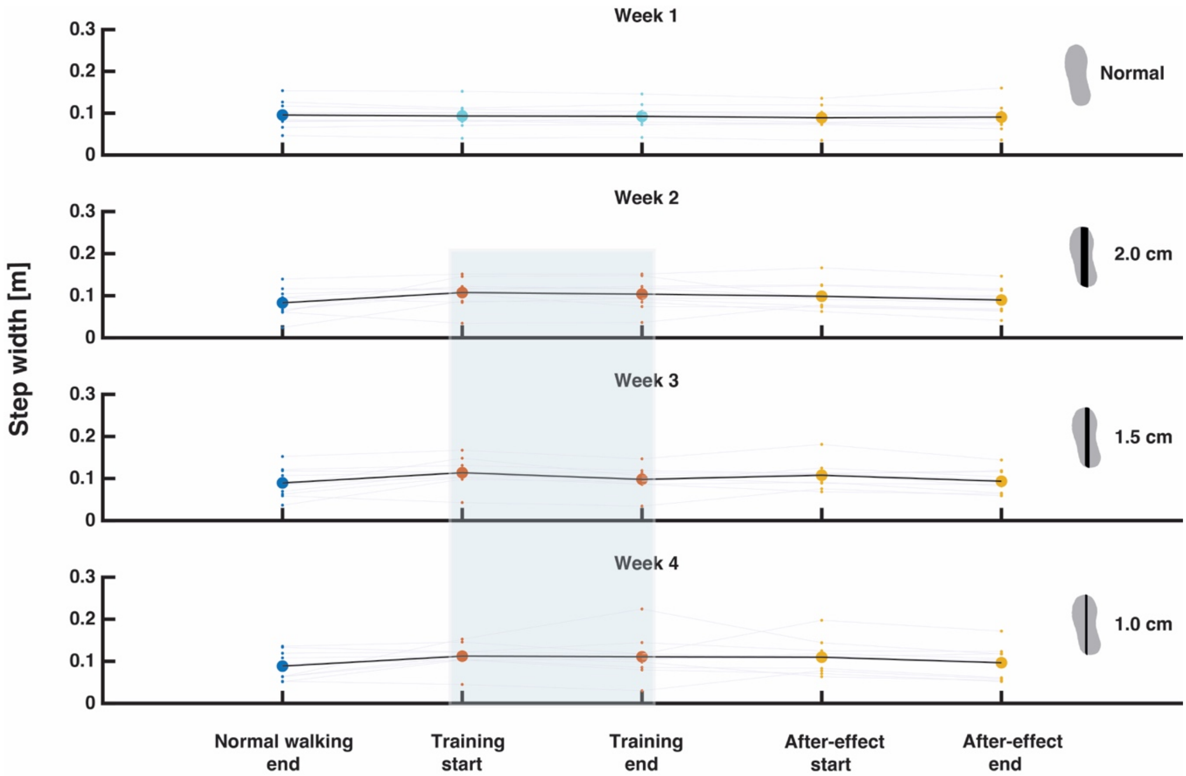
For the local divergence exponent, we found a significant effect of Condition, Session and the interaction Condition*Week (*p<0.05)*. Since any immediate effect of LesSchuh concerns the factor Condition, but not Session, we further investigated the Condition*Week interaction by averaging across sessions and computing four Bonferroni corrected post-hoc t-tests. As expected, when comparing the end of the normal walking condition to the start of the training condition, the local divergence exponents significantly increased (*p<0.0125)* during the training weeks (weeks 2-4), as opposed to in the control week (week 1) (*p>0.0125)*. This indicated that stability immediately decreased when walking with constrained ankle moments.



S3 Fig 5. Short term local divergence exponent. The lower the divergence, the more stable the gait pattern. The local divergence exponents were averaged across sessions 1 and 2. The shaded blue area with red dots represents the data when participants walked with LesSchuh.

Step width

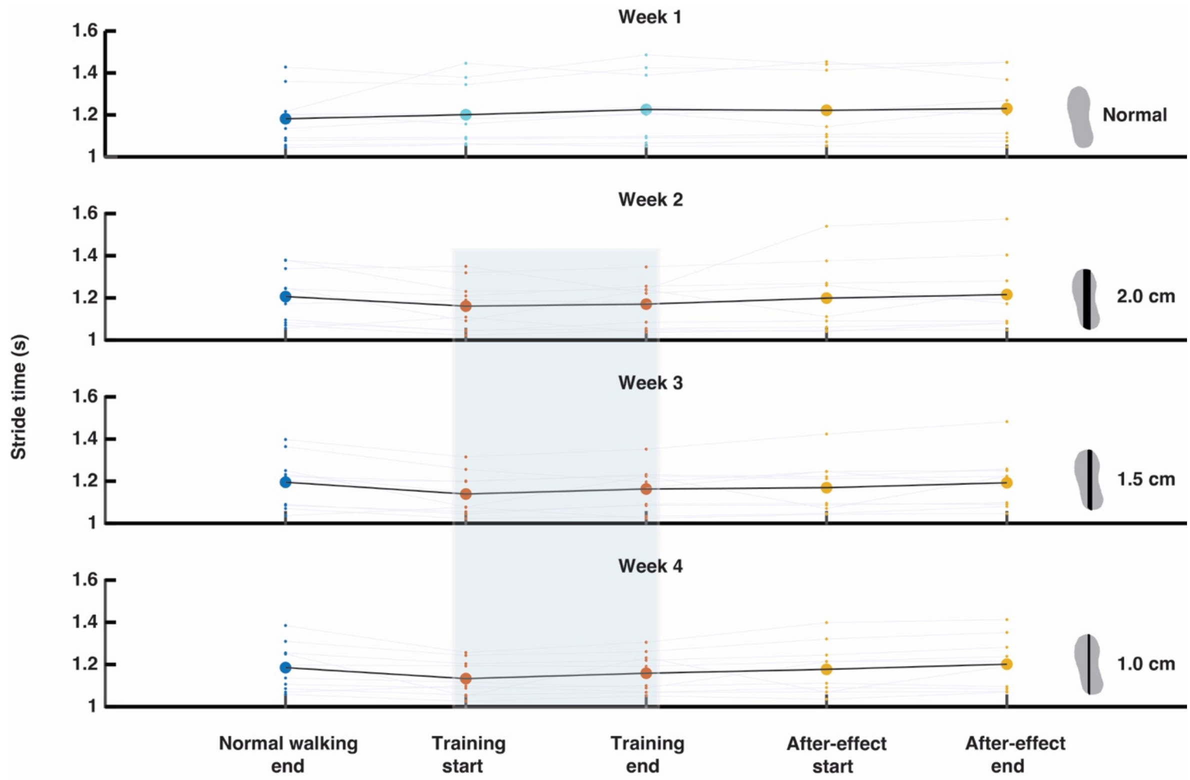
For step width Condition, Session and the interaction Condition*Week were significant (*p<0.05*). Since any immediate effect of LesSchuh concerns the effect of Condition, but not the effect of Session, we further investigated the Condition*Week interaction by averaging across sessions and computing four Bonferroni corrected post-hoc t-tests. Although in S3 Fig 6, when comparing training start to normal walking end, step width seemed to increase in the training weeks (weeks 2-4), as opposed to a decrease in the control week (week 1). These changes in step width were not significant (*p>0.0125)*.



S3 Fig 6. Step width. Step width in meters averaged across sessions 1 and 2. The shaded blue area with red dots represents the data when participants walked with LesSchuh.

Stride time

For stride time we found a significant interaction effect of Condition*Week. So, we averaged across sessions and performed four Bonferroni corrected post-hoc t-tests. Although from S3 Fig 7 it can be observed that, when comparing training start to normal walking end, the control week (week 1) stride time slightly increased, whilst in the training weeks (weeks 2-4) it decreased, these changes in stride time were not significant (*p>0.0125)*.



S3 Fig 7. Stride time. Stride time in seconds averaged across sessions 1 and 2. The shaded blue area with red dots represents the data when participants walked with LesSchuh.

Changes throughout the training

To assess the changes in foot placement control throughout the training, we performed a repeated-measures ANOVA with the factors Condition ("training start" vs "training end"), Week ("1","2","3","4") and Session ("1", "2"). If the factor Condition, or its interactions, were significant, the repeated-measures ANOVA was followed up by Bonferroni corrected post-hoc t-tests to test training end against training start.

Compliance with instructions

Throughout the training there was no significant effect of Week, Condition, Session, nor of their interactions on toe-out angle (S3 Fig 2). As there was no effect of Condition, participants did not change their compliance with the instructions throughout the training condition.

Degree of foot placement control

When comparing the end to the start of the training conditions across weeks and sessions, we found a significant interaction of Week*Session (*$p<0.05$*). Since there was no significant effect of Condition nor its interactions, it seems the degree of foot placement control did not improve within each single training condition (S3 Fig 3).

Magnitude of foot placement error

For foot placement error we did not find a significant effect from start to end of a training condition either, nor were there significant effects of Session nor Week (S3 Fig 4).

Gait stability

We found a significant effect of Condition and Week for the local divergence exponents ($p<0.05$). The effect of Condition indicates that throughout the training the local divergence exponent decreased (S3 Fig 5), indicating participants became more stable over time within each training session, not only when walking with LesSchuh, but also in the control week.

Step width

We did not find any significant effects on step width throughout the training condition, nor of Week or Session (S3 Fig 6).

Stride time

We only found a significant effect of Week on stride time. Without a significant effect of Condition, it seems stride time did not change within a single training condition (S3 Fig 7).

After-effects

To test whether there were any after-effects upon returning to walk on normal shoes, we performed a repeated-measures ANOVA with the factors Condition (“normal walking end” vs “after-effect start”), Week (“1”,”2”,”3”,”4”) and Session (“1”,”2”). If the factor Condition, or its interactions, were significant, the repeated-measures ANOVA was followed up by Bonferroni post-hoc t-tests to test between the start of the after-effect condition and normal walking end.

Degree of foot placement control

For the degree of foot placement control, we found a significant interaction effect of Condition*Week*Session. As such, we performed eight Bonferroni corrected post-hoc t-tests, testing for the effect of condition for each week and session. For none of the sessions there was a significant change in foot placement control. Thus, we did not find an after-effect in foot placement control (S3 Fig 3).

Magnitude of foot placement error

When looking at the foot placement error, we found a significant effect of Week, Session and the interaction of Week*Session, but not of Condition. So, we did not find an after-effect in foot placement error (S3 Fig 4).

Gait stability

For stability we found a significant interaction effect between Condition* Week. We averaged across sessions and performed four Bonferoni corrected t-tests. Only in week two we found a significant aftereffect compared to the normal walking condition (p<0.125), yet this effect was in the opposite as expected, since stability decreased (S3 Fig 5).

Step width

For step width, we found significant effects of Condition and the interaction Condition*Week. Therefore, we performed four Bonferroni corrected t-tests. Only for the first training week (week 2), step width significantly increased in the aftereffect condition as compared to the end of the normal walking condition (S3 Fig 6).

Stride time

For stride time, we found no significant effect of Condition, and hence, no after-effects (S3 Fig 7).

Since we did not find an after-effect for foot placement control, and no consistent after-effect for the other outcome measures, we did not proceed to test for washing-out of any after-effect.

S4 Questionnaires

As S4 we attach the translated (from Dutch to English) questionnaire participants took in the final training session.

1) Do you experience any positive consequences from the training? If yes, what kind of consequences?	
S1	Yes. I am more aware of my walking pattern. You pay attention to your steps. I corrected my old stepping habits and now point my feet more straight ahead. I am happy with it.
S2	Yes, my feeling says my stability improved. My muscles are also stronger.
S3	Not in daily life.
S4	Yes I am more aware of my own steps.
S5	Yes, I think so. I know that stability is not my strongest point. I always brush my teeth on one leg. I know it is not my strongest point, I am aware of it and I found it helpful.
S6	Not that I am aware of.
S7	No
S8	How do I stand on my feet?
S9	Yes, more focused on and more knowledge on how to place the foot. Improvement in stability. Improvement foot placement control as well as initiating the step to be placed forward. Knowing in advance where you want to place your foot. Not displacing it in the air. As much as possible initiating foot placement from the control of the lower back. No longer afraid, [Related to spinal cord injury], to place my foot in the wrong place. Important: - activating foot muscles in such a way that balance is optimal – how to place your foot
S10	Not noticeable. (unfortunately)
2) Do you experience any negative consequences from the training? If yes, what kind of consequences?	
S1	No. It was all very nice for me. I didn't feel pain. It did cost some healthy exertion.
S2	Muscle tension on top of the foot, leg, hip [not able to translate : 's.i.g.'] Disappears after a while.
S3	But also no negative consequences.
S4	None.
S5	Sometimes it takes a bit of effort, you need to stay focused on how you walk. When walking with [the LesSchuh] you sweat a bit more, probably because of the need to focus.
S6	No.
S7	No.
S8	None.
S9	The day after I feel the nervous system has to recover (for example in relation to jogging).
S10	No (fortunately)
3) Did you participate in a balance training program before?	
S1	Not in the past year. I did participate in other experiments
S2	5 x week yoga which also covers balance

S3	No.
S4	No.
S5	No.
S6	I practiced some ballet dance steps for myself.
S7	No.
S8	No.
S9	Not in a class, but I am using 15 different balance exercises (but these are mainly for foot muscles) [The LesSchuh training] reaches out more to above.
S10	No.
4) Did you or are you doing balance training at home?	
S1	No.
S2	5 x week yoga which also covers balance
S3	Not specifically balance training but a lot of resistance training with weights (like standing on toes with 70 kg, which obviously requires balance)
S4	No.
S5	Brushing teeth on one leg (each morning and evening) Also in athletics practice they incorporate balance training.
S6	See above.
S7	Yes, in the gym.
S8	No actually.
S9	- [see previous question]
S10	Yes.
5) How much time do you spend weekly on sports/physical activity? Can you describe what kind of activities?	
S1	Every day. Cycling, walking, I don't drive my car often. I want to start swimming again. I can go 45 km on an electrical bike without getting tired.
S2	Yoga, walking, walking the dog, cycling, making puzzles, 2 hours a day.
S3	3x per week 2 hours strength training. Besides that cycling , skating , playing tennis and every morning 30 minutes a workout.
S4	3-4 times a week.
S5	Running and walking. 5-6 hours a week. (He is a marathon runner)
S6	I learned some exercises in heart rehabilitation.
S7	3.5 hours running, 2 hours gym.
S8	3 times 1 hour gym and cycling ± 100 km/week
S9	Intense sports each day 1.5 hour. (jogging, resistance training)) Walking 1.5 hours a day. On average 40 min. cycling per day, gently on a city bike. Not short.
S10	14 hours Two times per week resistance training. An hour walking/e-bike/gardening.
6) Did you fall or slip in the past year? If yes, how often? And how serious were the consequences?	
S1	No.
S2	No.
S3	No.
S4	No.
S5	I fell max one time, but I cannot remember it.
S6	2x when getting of my bike, the saddle is (really) too high 1 x standing on a bench along the canal, which fell through the ice.

S7	No
S8	Two times, one time while walking, one time with the bike. Consequence was a sore feeling and a bruise.
S9	I didn't fall last year. Before that light hamstring injury during sprinting. Mid June (last year) I fell on my knee, until April knee-cap not the same. I can keep doing sports (both times I tripped across a tree trunk).
S10	No.
7) Do you have any other comments related to this study?	
S1	-
S2	Challenge. Extraordinary fun and helpful guidance. Helpful. Experiencing your own body even better.
S3	Easier to walk with 1 cm than with 1.5 cm ridge. 2 cm is almost the same as normal walking. After that I felt it a little.
S4	Side-effect is that the walking makes me think more clearly. Furthermore, it was a great pleasure to participate sweet researchers! Good luck with your research and in life!
S5	No, positive, fun, safety well taken care of, friendly, kind.
S6	No.
S7	No, but the last time on normal shoes felt really good.
S8	Professional and enjoyable guidance!
S9	I would like a strength/weakness analysis and advice on what to pay attention to. I know it, but I am open to it. I feel lucky that I am still trainable.
S10	Nice researchers ☺.