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Authors: Michiel Punt[1,2], Sjoerd M. Bruijn[2,3], Ingrid G. van de Port[4], Ilona J.M. de Rooij[4], Harriet Wittink[1], and Jaap H. van Dieën[2]

Affiliations: [1] Research Group Lifestyle and Health, Utrecht University of Applied Sciences, Utrecht, The Netherlands. [2]Department of Human Movement Sciences, Vrije Universiteit Amsterdam, Amsterdam Movement Sciences, Amsterdam, the Netherlands. [3]Department of Orthopedics, first affiliated Hospital of Fujian Medical University, Fuzhou, Fujian, P.R. China. [4]Revant Rehabilitation Center Breda, Breda, the Netherlands.

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Does a perturbation based gait intervention enhance gait stability in fall prone stroke survivors? A pilot study.

Michiel Punt MSc [1,2], Sjoerd M. Bruijn PhD [2,3], Ingrid G. van de Port PhD [4], Ilona J.M. de Rooij MSc [4], Harriet Wittink PhD [1], Jaap H. van Dieën PhD [2]

[1] Research group Lifestyle and Health, Utrecht University of Applied Sciences, Utrecht, The Netherlands
[2] Department of Human Movement Sciences, Vrije Universiteit Amsterdam, Amsterdam Movement Sciences, Amsterdam, the Netherlands
[3] Department of Orthopedics, first affiliated Hospital of Fujian Medical University, Fuzhou, Fujian, P.R. China
[4] Revant Rehabilitation Center Breda, Breda, The Netherlands

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Corresponding author:
Michiel Punt, PhD
Research group Lifestyle and Health, Utrecht University of Applied Sciences
Bolognalaan 101
3584 JW Utrecht
The Netherlands
Michiel.punt@hu.nl; +31 6 21 57 40 59

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Abstract

A recent review indicated that perturbation based training (PBT) interventions are effective in reducing falls in older adults and patients with Parkinson's disease. It is unknown whether this type of intervention is effective in stroke survivors. We determined whether PBT can enhance gait stability in stroke survivors. Ten chronic stroke survivors who experienced falls in the past six months participated in the PBT. Participants performed 10 training sessions over a six-week period. The gait training protocol was progressive and each training contained, unexpected gait perturbations and expected gait perturbations. Evaluation of gait stability was performed by determining steady-state gait characteristics and daily-life gait characteristics. We previously developed fall prediction models for both gait assessment methods. We evaluated whether predicted fall risk was reduced after PBT according to both models. Steady-state gait characteristics significantly improved and consequently predicted fall risk was reduced after the PBT. Daily-life gait characteristics, however, did not change and thus predicted fall risk based on daily-life gait remained unchanged after the PBT. A PBT resulted in more stable gait on a treadmill and thus lower predicted fall risk. However, the more stable gait on the treadmill did not transfer to a more stable gait in daily life.

Keywords: gait; stroke; stability; falls; perturbations

Word Count: 3601 (introduction through discussion)

Introduction

Falls are common in community dwelling stroke survivors [1] and post-stroke patients are more often frequent fallers than older adults [2]. In addition, hip fractures resulting from a fall more often lead to immobility in stroke survivors [3]. Other consequences of falls are loss of independence and social isolation [3]. These consequences underline the importance of developing effective fall prevention programs for stroke survivors.

While a recently updated review indicated that effective fall prevention programs exist for older adults [4], a review on fall prevention in stroke survivors found no effective programs [5]. Fall prevention programs generally aim to improve physical activity and thereby physical functioning [5]. By participating in fall prevention programs fall prone stroke survivors may be able to improve their physical activity level to some extent. However, this improvement in physical activity might increase fall risk, due to an increase in exposure. This may explain the ineffectiveness of fall prevention programs for stroke survivors[5]. Before the exposure is increased by stimulating daily walking activities, training may be necessary to improve gait stability in fall prone stroke survivors. Here we define stable gait as gait that does not result into falls despite of perturbations[6].

In comparison to conventional treadmill training of gait stability, perturbation based training (PBT) may offer a more ecologically valid training approach. Meaning that the exercises practiced during a PBT are more representative to daily-life situations than conventional training programs as in convention programs it is difficult to practice unexpected gait perturbations while guaranteeing safety. PBT has shown promising evidence in reduction of the numbers of falls in older adults and people with Parkinson's disease [7]. At present, it is unknown whether this type of intervention is effective for decreasing falls in stroke survivors.

Most falls occur during walking[1,8] and we recently found that gait characteristics derived from daily life gait and from a laboratory gait assessment are able to predict fall risk in stroke survivors[9] . Therefore, as a first step in the development of an effective fall prevention program, we studied whether PBT enhances gait stability in ambulatory chronic stroke survivors who are prone to falls.

We assessed the effect of a perturbation based gait training on three outcomes. We assessed whether steady-state and daily-life gait characteristics improved, whether predicted fall risk decreased and whether participants were able to progressively increase training workload.

Methods

Participants

Participants were recruited from the rehabilitation centre Revant, Breda, The Netherlands, through day care centers and by contacting participants that already participated in our previous studies [10]. Stroke survivors were included if they were at least 12 months post stroke, had a Functional Ambulation Category score of 3 or higher [11], reported at least one fall in the six months prior to inclusion in the study, were free of other disorders which could have affected gait such as Parkinson's disease and were able to walk on the treadmill without handrail support. Participants were not included in the study if they followed already a rehabilitation program on the same perturbation system due to potential learn effects which might affect the results.

Intervention

The intervention was executed on the Gait Real-time Analysis Interactive Lab (GRAIL, Motekforce Link bv, Amsterdam, The Netherlands). For technical details about the GRAIL and perturbation characteristics see our previous studies [10]. The design of the intervention is in line with the framework for motor learning developed by Guadagnoli and Lee[12]. The participants received ten perturbation based gait training sessions in a six-week period, which appears to be sufficient to evaluate changes in gait [13]. Prior to each training session, four reflective markers were placed on the pelvis, and one marker one each lateral malleolus. The markers were used to collect gait kinematics. In addition, participants wore a safety harness that prevented falls but did not restrict motion, nor provided body weight support. Each training session lasted at least 30 minutes and could last up to 1 hour, depending on the physical condition of the participant. A custom-designed virtual reality application allowed us to adjust each training session to the abilities of the participant. Each training session started with a warming up trial without gait perturbations, followed by multiple trials with unexpected gait perturbations and multiple trials with expected gait perturbations. The number of perturbations were equally divided between paretic and non-paretic limb. The length of each trial i.e. the number of minutes of continues walking without break and the number of trials performed during a single training session depended on the physical condition of the participant.

Unexpected gait perturbations

Unexpected, gait perturbations included simulated trips and slips (induced by belt deceleration or acceleration) as well as medio-lateral (ML) belt translations. The intensity of the perturbations was set at one of five different levels. For the trips and slips each level roughly corresponded to a belt deceleration / acceleration of 0.1m/s per level during 20% of the gait cycle, for the medio-lateral belt translations each level increase corresponded with roughly a 1 cm increase of displacement [10]. The interval between perturbations ranged from 4 to 2 strides, thus 4 strides was allowed participants to fully recover from the perturbation before experiencing another one, while this may was not the case when only 2 strides were given to recover from a perturbation. The moment in the gait cycle were the perturbation was triggered was at one of three moments in the gait cycle: foot contact, mid stance or foot off. Gait events were detected using the method from Roerdink et al (2008) [14].The perturbations were applied to both the paretic and non-paretic limb.

Expected gait perturbations

Expected gait perturbations were created by virtual obstacles. The obstacles were projected on the entire width of the treadmill by default indicating that both limbs have to cross the obstacle. However, the obstacles could be targeted to one of the limbs by projecting the virtual obstacle on only one side of the treadmill indicating that only the limb on the side were the obstacle is projected needs to cross the obstacle. The crossing width of the obstacles ranged from 7 cm up to 49 cm in steps of 7 cm. The interval between presentation of obstacles ranged from 4 to 2 strides and traveled with the same speed as the treadmill speed, so similar to what can be expected in daily life.

Progression of training load

The settings within each training session for both unexpected and expected gait perturbations, were varied as much as possible such that participants were exposed to a variety of different gait perturbations within a range of plus / minus one perturbation level from the average. Comfortable gait speed was determined during the first two minutes of each training session per participant. During those first one or two minutes gait speed was gradually incremented with direct communication with the participant. During the sessions the default gait speed was the comfortable gait speed. From this comfortable gait speed, gait speed was frequently increased and decreased by the researcher, in order to practice gait and gait perturbations at all kind of gait speeds.

The settings were adjusted between training sessions, such that training load was progressively increased. After each training session the patient's rate of perceived exertion[15] was determined and based on the judgment of the researcher and the performance of the participant in previous training sessions, gait speed, walking time, frequency and intensity of the perturbations were in- or decreased for the upcoming training session. Finally, after several training sessions, participants received an additional task, a visual Stroop task together with the gait perturbations. This Stroop task functioned as a cognitive dual task, which made the training session more challenging and was aimed at establishing a more automated response after gait was perturbed. For a visual demonstration of the intervention see the electronic supplement.

Primary outcomes gait stability

Before and after the training period, gait stability was assessed by determining steady-state gait characteristics and daily life gait characteristics. For a detailed explanation how the gait characteristics are determined in both, steady state and daily life see respectively [9] and [16].

Steady-state gait characteristics

We assessed steady-state gait characteristics in a standardized laboratory setting. As gait characteristics are affected by gait speed, the assessment of steady-state gait characteristics was performed twice. First gait characteristics were determined at preferred gait speed. Second steady-state gait characteristics were determined at the same gait speed between pre- and post-assessments regardless of any changes in preferred gait speed within the participant between assessments, to eliminate effects of gait speed on gait variability [17,18] which together with gait speed is one of the most important predictors for fall risk [19].

Data analysis for determining steady-state gait characteristics was consistent with our previous study [9]. Briefly, participants walked on the GRAIL treadmill. Data was collected for 60 consecutive strides using Vicon Nexus and transferred to Matlab 2013B (The MathWorks Inc., Natick, MA). The gait events foot contact (FC) and foot off (FO) were determined using the Center of Pressure (CoP) [14]. Gait characteristics like; spatio-temporal, variability and local divergence exponent were determined using 60 consecutive strides [9].

Daily life gait characteristics

Daily-life gait characteristics were assessed using accelerometry. For daily-life gait stability assessment, we applied the same data collection and analysis method as in our previous experiment [9,16]. Briefly, participants wore a tri-axial accelerometer (McRoberts, The Hague, The Netherlands) at the lower back during seven consecutive days. Gait episodes were detected by a previously validated algorithm [20]. Quantity and frequency of gait activity were expressed as number of walking minutes per day and number of walking bouts per day. Next, qualitative gait characteristics that have been shown to predict fall risk in older adults [21] and stroke survivors [16] were estimated. For a detailed explanation on how daily life characteristics were estimated see Rispens et al [22].

Predicting fall risk

Fall risk was predicted based on steady-state gait characteristics and based on daily-life gait characteristics using our previous established fall prediction models [9]. The on steady-state gait characteristics based model exists out of ten included gait characteristics namely; step length of paretic and non-paretic limb, gait speed, index of harmonicity in medio-lateral and anterior-posterior direction, variability of stride time and step length of paretic limb, local divergence exponent in the medio-lateral direction, which reflects sensitivity to small changes in initial conditions (which may in turn be regarded as the reactions to small perturbations) and finally the forward margins of stability of both limb. However, prior to entering the data into the prediction model, we adjusted the steady-state fall risk prediction model to a new model without Margin of Stability (MoS) measures because in our present study we were not able to determine MoS due to the limited marker set up. We re-evaluated the performance of this model, which appeared to be exactly the same as in our previous study [9]. Thus we were able to use a marker set up of six markers and determine the relevant gait characteristics for the fall prediction model. Finally, we followed the exact same data collection procedure as in the study of the development of the fall prediction model. For instance, the same equipment was used and the same number of strides were included in the determination of gait characteristics. For steady-state gait characteristics only the trial at preferred gait speed was evaluated by the steady-state fall risk prediction model, because the model requires gait speed as input. For our daily-life fall prediction model, no modifications were made.

Secondary outcomes training workload

Training load per session was assessed by (1) determining the number of walking minutes per training session over the three walking conditions (steady-state, unexpected and expected). (2) The number of minutes walked combined with a visual Stroop task. (3) The average gait speed per training session, (4) the intensity of unexpected, expected gait perturbations and the (5) frequency of gait perturbations.

Statistics

Non-parametric Wilcoxon signed rank tests were used to assess differences between steady-state and daily-life gait characteristics before and after the PBT. In addition, if significant differences were found, we calculated the effect size per gait characteristic, by dividing the Z value derived from the Wilcoxon signed rank test divided by the square root of N. Wherein N is the summed number of participants in the pre- and post-assessments. Effect sizes of 0.1 correspond with a small effect, 0.3 with a medium effect and 0.5 with a large effect[23].

Changes in input parameters of the fall risk prediction models, which were principal component scores [9] as well as in the predicted fall risk, the output of the model, were examined using Wilcoxon signed rank tests. The evaluation was performed for both the steady-state fall prediction model and the daily-life fall prediction model.

Finally, non-parametric Friedman tests were used to determine differences in the secondary outcome measures, training workload among the training sessions.

Results

All included participants were at least 12 months post stroke, and reported at least one fall in the previous six months. At the time of the intervention, participants were not enrolled in any other study and or exercise program which could have caused interference with this study. Seven out of ten participants completed all training sessions. Three participants missed one training session. All ten participants performed the steady-state gait assessments before and after the intervention. Due to a technical failure of the accelerometer, one participant (number 8) was not included in the results of daily-life gait characteristics.

Primary outcomes

Steady-state gait characteristics

In regard to preferred gait speed gait characteristics several differences between pre and post assessment were found. Gait speed and step length for both the paretic and non-paretic limb increased significantly with respectively large to medium effect sizes after the PBT. Stride time variability, step time variability for both limbs and swing time variability for the paretic limb significantly decreased after PBT, with large to medium effect sizes (table 2). No significant effects of PBT were found for local dynamic stability.

The fixed preferred gait speed results showed no differences in gait characteristics between pre and post assessment. Results for the steady-state gait characteristics measured at the fixed preferred gait speed are reported in table 3. Note that any differences at pre assessment between table 2 and 3 stem from the fact that these are derived from different measurements, and are thus basically test-retest differences.

Daily-life gait characteristics

The quantity of walking, expressed as number of walking minutes per day, showed an increasing trend after PBT, but this did not reach statistical significance. The number of walking bouts did increase significantly (table 4). Of the gait quality characteristics, stride time increased and the smoothness of walking (index of harmonicity in the VT direction) decreased after PBT (table 4).

Predicted fall risk

Nine out of ten participants significantly improved their steady-state gait after the PBT as reflected in the input principal component score of the fall prediction model (p=.005) and in the predicted probability of falling (p=.027) (figure 1 upper panel). For daily-life gait, no changes after the PBT were observed in model input scores (p=.30) nor in predicted probability of falling (p=.35)(figure 1 lower panel).

Training load

The first training session started with an average gait speed of 0.42m/s and between participant SD of 0.06m/s, the perturbation intensity at the first training session was 2 and between participant SD of 0.3 and the perturbation frequency was 4 strides at the first session with a between participant SD of 0.1. Subsequently, figure 2 illustrates the relative progression of training load along the training sessions. As some participants missed a training session and a Friedman test excludes these participants from the analysis, we removed the three incomplete training sessions from our statistical analysis. For the remaining seven training sessions, all participants were able to increase (1) training time (p<.01), (2) combining gait perturbations with a Stroop task (p<.01), (3) increase gait speed(p<.01), (4) perturbation intensity(p<.01) and (5) perturbation frequency(p<.01) over the course of the PBT sessions.

Discussion

The main purpose of the present investigation was to explore whether a perturbation based intervention can enhance gait stability in fall prone ambulatory chronic stroke survivors. We found that several steady-state gait characteristics associated with fall risk in stroke survivors [9] were significantly improved after PBT. Additionally, our prediction model based on steady-state gait indicated a lower predicted fall risk. This is in line with a recent fall intervention study in Parkinson's disease, which showed improved spatio-temporal gait parameters after a single perturbation training compared to a control group with regular gait training [24]. However, daily-life gait characteristics indicated no improvement of gait quality after the PBT. Consequently, the daily-life fall risk prediction model indicated a similar fall risk after the PBT as before the intervention. Thus it seems that PBT enhances gait stability in a standardized laboratory setting, yet this does not translate to a daily-life setting.

There are several issues that need to be addressed to place the present results into perspective. We did not apply a statistical correction for multiple comparisons, because this was a pilot study examining whether gait stability improves after PBT. Thus our results require further validation in a larger pre-registered trial. We determined gait characteristics at preferred gait speed. During the post-intervention assessment, preferred gait speed was higher, which may be related to the increase in gait speed during training over the intervention period (figure 2). The improvements in gait quality could (in part) be caused by the increased gait speed. For example, it is known that gait variability, which is an important variable in our fall prediction model [9], decreases with increasing gait speed [17]. The fact that gait characteristics did not change when participants were tested at a fixed speed, while gait characteristics did change when tested at preferred speed, which was higher during the post assessment, raises the question to what extent changes in gait characteristics were fully caused by differences in gait speed. To gain a better understanding we determined the correlation coefficients between change in speed and changes in gait characteristics between pre and post assessment, for all significantly changed gait characteristics. Correlations ranged from -0.15 towards 0.15, except for step length of the non-paretic limb which was correlated 0.67. Moreover, previous literature has shown that local divergence exponents in medio-lateral direction increase with gait speed over a specific range (0.4 to 0.6 m/s) of speeds [25]. Interestingly, our participants gained gait speed over this range on average, while their local divergence exponent in medio-lateral direction values decreased although not significantly so. All in all, this suggests that improvements in gait quality were not mediated by changes in speed alone.

In this study, we aimed to expose participants to many repetitions of as many different kinds of perturbations as possible, thereby improving the ecological validity of the training, because in daily life one may be exposed to a wide range of perturbation types. Pai & Bhatt (2007) indicated that, at least in older adults, feed forward control improves when experiencing gait perturbations in training sessions, thereby creating more adequate responses [26]. This finding is supported by our study, as we found that participants were able to handle more, and larger perturbations during their training sessions and even were able to combine these with a visual Stroop task. However, we did not actually measured if participants were able to give the perturbations less attention due to the combined dual task. Neither do we know if the found improvements are a result of the perturbations, gained gait speed over the course of the training sessions or maybe both.

Actual improvement of gait was shown in the steady-state gait characteristics. These characteristics quantify how people walk in steady-state conditions without external perturbations. We did not evaluate whether the quality of the perturbation responses was improved, because in contrast to steady-state gait characteristics [9], measures derived from gait perturbations were found not to be associated with fall risk in stroke survivors [10,27]. However, the lack of transfer of the improved steady-state gait characteristics to daily-life conditions does not necessarily imply that PBT is not useful in fall prone stroke survivors. It may be that this type of intervention improves participants' ability to deal with perturbations such as the ones that the PBT focused on and as such have a positive impact on fall incidence. Especially because previously several studies already found promising results that stroke survivors are able to improve their ability to handle expected perturbations [28,29]. Finally, in regard to potential improvements, the equipment allows for continuous monitoring of changes in gait characteristics. This is an important advantage for future studies but as well for current implemented rehabilitation programs.

When interpreting the daily-life gait characteristics results, it should be kept in mind that despite their value in assessing fall risk [16,21,22], daily-life assessments are prone to many confounding effects. After the PBT intervention, participants walked more often (significantly more bouts), and walked more minutes per day (although not significantly so). It may be that such behavioral changes coincide with more frequent walking in complex environments and conditions that would lead to less smooth, more variable and less stable walking and hence negatively affect gait characteristics. This might explain the lack of improvement of daily-life gait characteristics. A final limitation of the study was the number of outcome measures that were compared.

In conclusion, a perturbation based gait intervention improved steady-state gait characteristics at preferred gait speed and reduced the predicted fall risk in fall prone chronic stroke survivors. These improvements did not transfer to gait in daily life and thus neither reduced fall risk predictions from daily-life gait data. The progression that could be realized during the training indicates that participants improved their ability to deal with expected and unexpected gait perturbations. The positive effects in steady-state gait and potential effects on perturbations responses warrant further study to determine the effect of a perturbation based gait training on fall incidence in stroke survivors.

Conflict of interest

Michiel Punt was supported by a grant from the Netherlands organization for Scientific Research (NWO #023-003-141). Sjoerd M. Bruijn was supported by a grant from the Netherlands Organization for Scientific Research (NWO #451-12-041).

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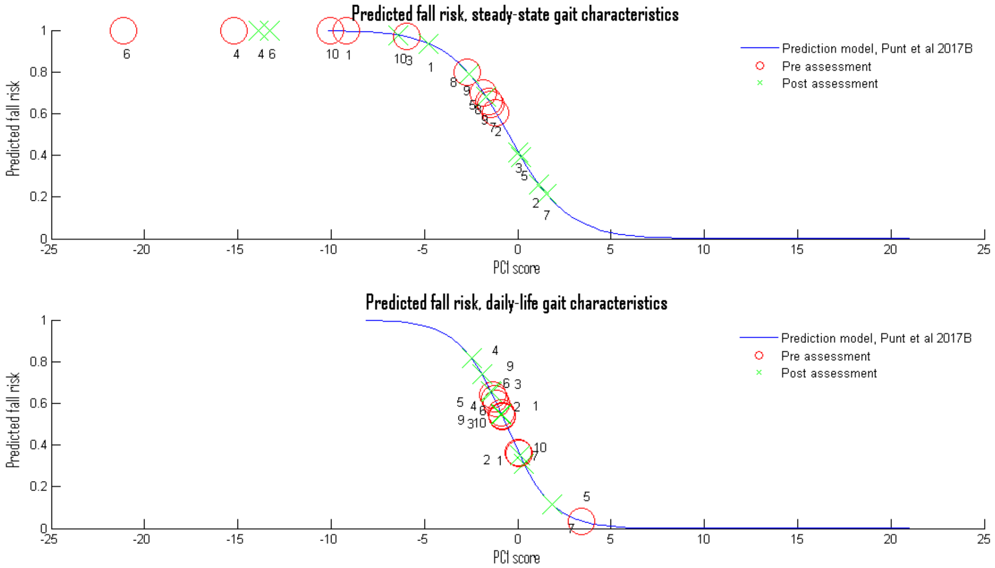

Figure 1: Predicting fall risk.

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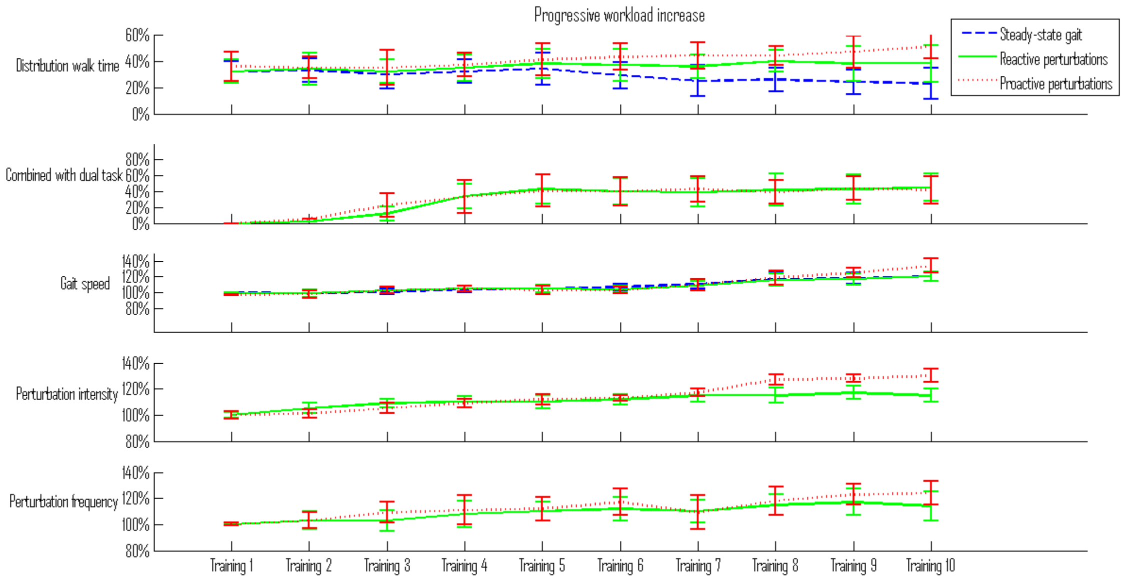

Figure 2: Workload for each training session.

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Table 1: Demographics.

Participant	male/female	Age (year)	Length (cm)	Weight (kg)	BMI	Paretic side	Time since stroke (year)	FAC score	Co-morbidities
1	Male	65	190	90	23.6	Left	4	3	
2	Female	49	182	83	25.1	Right	3	4	
3	Female	64	170	113	39.1	Left	10	3	
4	Male	63	172	78	26.4	Right	2	3	
5	Female	58	163	65	24.4	Right	2	5	
6	Male	70	172	76	25.6	Right	4	3	scoliosis
7	Male	50	190	89	24.6	Left	20	5	Broken hip due to fall
8	Male	61	171	85	29.1	Right	4	4	
9	Male	67	168	85	29.5	Left	1.2	5	
10	Male	68	185	105	30.8	left	1.5	3	epileptic

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Table 2: Laboratory based steady-state qualitative gait characteristics. Prior (T0) and after (T1) the perturbation based gait intervention. Gait speed was preferred gait speed.

	T0	T1				
Gait characteristics	Mean ± SD	Mean ± SD	differ	Z-score	P-value	ES
Spatio temporal gait characteristics						
Gait speed (m/s)	**0.46 ± 0.2**	**0.62 ± 0.2**	0.16	**-2.81**	**<.01**	**0.63**
Step length PL (mm)	**318 ± 73**	**388 ± 101**	70	**-2.19**	**.03**	**0.49**
Step length NPL (mm)	**210 ± 109**	**270 ± 122**	60	**-2.70**	**<.01**	**0.60**
Step time PL (sec)	0.75 ± 172	0.71 ± 152	-0.04	-1.78	.07	
Step time NPL (sec)	0.59 ± 120	0.56 ± 101	-0.03	-1.78	.07	
Swing time PL (sec)	0.51 ± 149	0.47 ± 125	-0.04	-1.27	.20	
Swing time NPL (sec)	0.32 ± 83	0.30 ± 64	-0.02	-1.37	.17	
Stride time (sec)	1.35 ± 0.21	1.27 ± 0.15	-0.08	-1.88	.06	
Step width (mm)	343 ± 30	343 ± 54	0	-0.35	.72	
Symmetry gait characteristics						
Step length SI	0.25 ± 0.23	0.22 ± 0.24	-0.03	-0.06	.95	
Step time SI	0.11 ± 0.14	0.11 ± 0.15	0	-0.41	.67	
Swing time SI	0.21 ± 0.22	0.20 ± 0.21	-0.01	-1.12	.26	
Variability gait characteristics (SD)						
Stride time (sec)	**0.10 ± 0.06**	**0.07 ± 0.05**	-0.03	**-2.59**	**<.01**	**0.58**
Step length PL (mm)	53 ± 23	51 ± 24	-2	-0.15	.87	
Step length NPL (mm)	48 ± 17	52 ± 30	4	-0.56	.57	
Step time PL (sec)	**0.08 ± 0.05**	**0.06 ± 0.04**	-0.02	**-2.59**	**<.01**	**0.58**
Step time NPL (sec)	**0.07 ± 0.04**	**0.05 ± 0.03**	-0.02	**-1.88**	**.05**	**0.42**
Swing time PL (sec)	**0.08 ± 0.04**	**0.06 ± 0.04**	-0.02	**-1.98**	**.04**	**0.44**
Swing time NPL (sec)	0.06 ± 0.04	0.05 ± 0.02	-0.01	-1.37	.16	
Step-width (mm)	22 ± 5.7	22 ± 4.8	0	-0.76	.44	
Smoothness gait characteristics						
Index Harmonicity VT	0.44 ± 0.21	0.46 ± 0.22	0.02	-1.17	.24	
Index Harmonicity ML	0.96 ± 0.02	0.95 ± 0.04	-0.01	-0.15	.87	
Index Harmonicity AP	0.59 ± 0.22	0.62 ± 0.23	0.03	-0.15	.87	
Stability gait characteristics						
LDE VT	1.47 ± 0.13	1.52 ± 0.20	0.05	-1.07	.29	
LDE ML	1.82 ± 0.37	1.79 ± 0.43	-0.03	-1.07	.29	
LDE AP	1.83 ± 0.32	1.82 ± 0.47	-0.01	-0.15	.87	

PL is the paretic limb, NPL the non-paretic limb. SI is symmetry index, LDE is the local divergence exponent.

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Table 3: Laboratory based steady-state qualitative gait characteristics. Prior (T0) and after (T1) the perturbation based gait intervention. Gait speed was preferred gait speed at pre assessment.

	T0	T1				
Gait characteristics	Mean ± SD	Mean ± SD	differ	Z-score	P-value	Effect Size
Spatio temporal gait characteristics						
Gait speed (m/s)	0.46 ± 0.2	0.46 ± 0.2	-	-	-	-
Step length PL (mm)	300 ± 70	334 ± 85	34	-1.27	.20	
Step length NPL (mm)	200 ± 94	198 ± 86	-2	-0.35	.72	
Step time PL (sec)	0.77 ± 163	0.78 ± 161	0.01	-1.07	.28	
Step time NPL (sec)	0.62 ± 114	0.62 ± 123	0	-0.25	.79	
Swing time PL (sec)	0.51 ± 138	0.51 ± 144	0	-0.35	.72	
Swing time NPL (sec)	0.33 ± 86	0.30 ± 65	-0.03	-1.48	.13	
Stride time (sec)	1.39 ± 180	1.40 ± 186	0.01	-0.25	.79	
Step width (mm)	342 ± 28	350 ± 46	8	-1.17	.24	
Symmetry gait characteristics						
Step length SI	0.23 ± 0.2	0.28 ± 0.2	0.05	-1.1	.28	
Step time SI	0.11 ± 0.1	0.11 ± 0.1	0	-0.76	.44	
Swing time SI	0.20 ± 0.2	0.24 ± 0.2	0.04	-1.27	.20	
Variability gait characteristics (SD)						
Stride time (sec)	0.1 ± 0.06	0.09 ± 0.05	-0.01	-0.86	.38	
Step length PL (mm)	54 ± 23	51 ± 17	-3	-0.05	.96	
Step length NPL (mm)	49 ± 17	52 ± 18	3	-0.45	.64	
Step time PL (sec)	0.08 ± 0.04	0.07 ± 0.04	-0.01	-1.1	.28	
Step time NPL (sec)	0.07 ± 0.03	0.06 ± 0.03	-0.01	-0.66	.51	
Swing time PL (sec)	0.08 ± 0.04	0.07 ± 0.04	-0.01	-0.86	.38	
Swing time NPL (sec)	0.07 ± 0.04	0.06 ± 0.04	-0.01	-1.1	.28	
Step-width (mm)	21 ± 5	21 ± 5	0	-0.15	.87	
Smoothness gait characteristics						
Index Harmonicity VT	0.43 ± 0.22	0.45 ± 0.22	0.02	-1.17	.24	
Index Harmonicity ML	0.95 ± 0.02	0.95 ± 0.04	0	-0.11	.91	
Index Harmonicity AP	0.60 ± 0.22	0.62 ± 0.23	0.02	-0.15	.87	
Stability gait characteristics						
LDE VT	1.45 ± 0.1	1.52 ± 0.2	0.07	-1.27	.20	
LDE ML	1.81 ± 0.3	1.95 ± 0.4	0.14	-1.58	.11	
LDE AP	1.85 ± 0.3	1.88 ± 0.4	0.03	-0.25	.79	

PL is the paretic leg, NPL the non-paretic leg. SI is symmetry index. LDE is the local divergence exponent.

Table 4: Daily life gait characteristics. Prior (T0) and after (T1) the perturbation based gait intervention.

Gait characteristics	T0	T1				
Quantitative measures	Mean ± SD	Mean ± SD	dif	Z-score	P-value	Effect Size
Gait activity (min/day)	17 ± 11	21.9 ± 9.7	4.9	-1.36	.17	
Walking bouts / day	**76.5 ± 38**	**99.6 ± 37.2**	**23**	**-2.19**	**.02**	**0.51**
Monitoring time	5.9 ± 1	5.5 ± 1.6	-0.4	-0.77	.44	
Qualitative measures						
Gait speed (m/s)	0.59 ± 0.14	0.54 ± 0.11	-0.05	-0.77	.44	
Stride time (s)	**1.29 ± 0.45**	**1.47 ± 0.19**	**0.18**	**-2.38**	**.02**	**0.56**
SD VT	1.35 ± 0.51	1.31 ± 0.36	-0.04	-0.06	.95	
SD ML	1.49 ± 0.58	1.49 ± 0.39	0	-0.18	.85	
SD AP	1.23 ± 0.55	1.28 ± 0.40	0.05	-0.89	.37	
HR VT	0.99 ± 0.08	0.99 ± 0.04	0	-0.18	.85	
HR ML	1.25 ± 0.19	1.27 ± 0.17	0.02	-0.06	.95	
HR AP	0.98 ± 0.11	0.91 ± 0.07	-0.07	-1.59	.11	
IH VT	**0.29 ± 0.11**	**0.18 ± 0.09**	**-0.11**	**-2.07**	**.04**	**0.49**
IH ML	0.51 ± 0.21	0.59 ± 0.20	0.08	-1.12	.26	
IH AP	0.34 ± 0.17	0.35 ± 0.15	0.01	-0.88	.37	
Amplitude (psd) VT	0.29 ± 0.06	0.27 ± 0.05	-0.02	-0.53	.59	
Amplitude (psd) ML	0.49 ± 0.26	0.51 ± 0.21	0.02	-0.41	.67	
Amplitude (psd) AP	0.36 ± 0.11	0.39 ± 0.16	0.03	-0.53	.59	
Width (psd) VT	1.16 ± 0.20	1.29 ± 0.23	0.13	-1.24	.21	
Width (psd) ML	1.09 ± 0.48	0.94 ± 0.22	-0.15	-0.05	.95	
Width (psd) AP	1.15 ± 0.39	0.98 ± 0.39	-0.17	-0.89	.37	
LDE/stride VT	1.05 ± 0.55	1.18 ± 0.21	0.13	-1.36	.17	

Gait characteristics	T0	T1				
Quantitative measures	Mean ± SD	Mean ± SD	dif	Z-score	P-value	Effect Size
LDE/stride ML	1.18 ± 0.75	1.06 ± 0.19	0.12	-0.77	.44	
LDE/stride AP	1.14 ± 0.72	1.06 ± 0.24	0.08	-0.77	.44	

SD is standard deviation, HR is harmonic ratio, IH is index harmonicity, Amplitude of the power spectral density(psd), width of the psd, LDE is local divergence exponent.