

# Effect of Haptic Biofeedback on Paretic-Limb Propulsion in Individuals with Chronic Stroke: A Randomized Controlled Trial

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## ABSTRACT

Reduced propulsion generated by the paretic limb is a major biomechanical determinant of slow and inefficient walking after stroke. Real-time biofeedback can increase paretic propulsion, but most paradigms rely on visual or auditory displays. Haptic (vibrotactile) biofeedback is unobtrusive, wearable and does not compete with visual attention, yet its training effects on propulsion remain insufficiently studied. To determine the effect of a four-week gait training programme with real-time haptic biofeedback on paretic-limb propulsion, trailing limb angle (TLA) and walking function in individuals with chronic stroke. In this assessor-blinded randomized controlled trial, 32 community-dwelling adults with chronic hemiparesis were allocated to treadmill gait training with vibrotactile biofeedback targeting peak paretic anterior ground reaction force (HBF, n = 16) or identical training without biofeedback (CON, n = 16). Both groups trained three times per week for four weeks. Peak paretic anterior ground reaction force (AGRF), paretic propulsion (Pp), paretic TLA, ankle plantarflexor moment, self-selected gait speed and six-minute walk test (6MWT) distance were assessed at baseline, post-training and four-week follow-up. Thirty participants completed the study. Compared with CON, the HBF group showed significantly greater post-training increases in peak paretic AGRF (mean difference 2.5 %BW; 95% CI 1.4 to 3.6;  $p < 0.001$ ), Pp (5.2%;  $p < 0.001$ ), paretic TLA (2.8°;  $p < 0.001$ ), gait speed (0.08 m/s;  $p = 0.001$ ) and 6MWT distance (29 m;  $p = 0.001$ ). Gains were largely retained at follow-up, and non-paretic propulsion did not change. Real-time haptic biofeedback added to gait training produces limb-specific, clinically meaningful and retained improvements in paretic-limb propulsion and walking function in chronic stroke, supporting its use as a practical, wearable rehabilitation adjunct.

**Keywords:** Stroke; Hemiparesis; Haptic biofeedback; Vibrotactile feedback; Paretic propulsion; Anterior ground reaction force; Trailing limb angle; Gait rehabilitation

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## 1. INTRODUCTION

### 1.1 Walking Impairment after Stroke

Stroke is a leading cause of long-term disability worldwide, and its global burden has continued to rise with population ageing [1]. Restoring walking is one of the most frequently stated goals of stroke survivors, and gait training is a core recommendation of rehabilitation guidelines [2]. Nevertheless, many individuals remain limited to slow household or restricted community ambulation long after discharge, and gait speed is a strong determinant of community participation [3].

### 1.2 Paretic Propulsion as a Rehabilitation Target

Forward progression during walking depends on the propulsive impulse generated in late stance, to which the ankle plantarflexors make the largest contribution [4]. After stroke, the paretic limb generates a smaller share of the total anterior ground reaction force (AGRF), and this deficit, quantified as paretic propulsion (Pp), is strongly associated with hemiparetic severity and walking speed [5]. Changes in paretic peak propulsive force contribute meaningfully to changes in walking

speed [6], and paretic propulsion together with trailing limb angle (TLA) are key determinants of long-distance walking function [7].

Biomechanically, propulsion depends on two modifiable factors: the ankle plantarflexor moment and the TLA, which orients the limb so that the ground reaction force is directed anteriorly [8]. TLA is closely related to propulsive force and has been proposed as a clinically accessible surrogate [9]. Importantly, individuals post-stroke possess a paretic propulsion reserve that can be recruited when task demands are increased [10], and interventions that increase propulsion do so through combinations of TLA and ankle moment changes [11]. Training that specifically targets paretic propulsion can improve walking function [12], making propulsion an attractive and mechanistically grounded target for rehabilitation.

### 1.3 Real-Time Biofeedback for Gait Training

Biofeedback provides augmented information about a physiological or biomechanical variable that is otherwise difficult to perceive. A systematic review found that biofeedback improves

performance of lower-limb activities after stroke more than usual therapy [13]. Motor learning literature shows that visual, auditory and haptic channels each have distinct advantages, and that feedback frequency and fading influence retention [14], [15]. Real-time AGRF biofeedback delivered on a treadmill has been shown to increase paretic propulsion and improve gait biomechanics in people post-stroke [16]. Subsequent work compared audio, visual and audiovisual formats [17] and demonstrated that both propulsive-force and limb-angle biofeedback induce immediate improvements in paretic AGRF and TLA [18], [19].

### 1.4 Haptic Biofeedback

Most gait biofeedback systems depend on a screen, which requires visual attention, restricts natural head posture and is poorly suited to overground or community walking. Haptic wearables, which deliver information through vibration or kinaesthetic cues to the skin, can act as sensory replacement, sensory augmentation or trainers, and are lightweight, silent and private [20]. In individuals with hemiparetic stroke, integrated kinaesthetic and tactile cues improved gait symmetry during overground walking [21]. Advances in wearable sensors further increase the feasibility of translating feedback-based training from laboratory to clinic and home [22]. However, controlled trials examining whether repeated training with haptic biofeedback specifically targeting paretic propulsion produces lasting improvements are lacking.

### 1.5 Objectives and Hypotheses

The primary objective of this study was to determine the effect of four weeks of gait training with real-time haptic biofeedback on peak paretic AGRF in individuals with chronic stroke. Secondary objectives were to examine effects on paretic propulsion, TLA, plantarflexor moment, gait speed and walking endurance, and to evaluate retention four weeks after training.

- *Null hypothesis ( $H_0$ ):* gait training with haptic biofeedback produces no significantly different change in paretic-limb propulsion compared with the same training without biofeedback.
- *Alternative hypothesis ( $H_1$ ):* gait training with haptic biofeedback produces significantly greater improvement in paretic-limb propulsion than training without biofeedback, without compensatory change in the non-paretic limb.

## 2. MATERIALS AND METHODS

### 2.1 Study Design and Ethics

A two-arm, parallel-group, assessor-blinded randomized controlled trial was conducted in the gait laboratory of [institution] between [month, year] and [month, year]. The protocol was

approved by the Institutional Ethics Committee (reference no. [xxxx]) and registered with [registry, number]. All participants provided written informed consent in accordance with the Declaration of Helsinki. Participant flow is presented in Fig. 1.

### 2.2 Sample Size

Sample size was estimated using G\*Power 3.1 [23] for the between-group difference in change of peak paretic AGRF. Based on effect sizes reported for propulsion biofeedback [16], [17], a conservative effect size of  $d = 1.10$ ,  $\alpha = 0.05$  (two-tailed) and power of 80% required 14 participants per group. Allowing for 10–15% attrition, 16 participants were recruited per group (total  $n = 32$ ).

### 2.3 Participants

Participants were recruited from outpatient stroke services. Inclusion criteria were: (i) age 40–75 years; (ii) single unilateral ischaemic or haemorrhagic stroke at least six months earlier; (iii) ability to walk at least 10 m overground without physical assistance, with or without an assistive device, and to walk on a treadmill for six minutes with handrail support; (iv) measurable paretic propulsion deficit ( $Pp < 45\%$ ); and (v) intact protective sensation to vibration on the lateral thigh. Exclusion criteria were: other neurological or major orthopaedic conditions affecting gait, uncontrolled cardiovascular disease, cognitive impairment preventing understanding of instructions (Mini-Mental State Examination  $< 24$ ), severe spasticity (Modified Ashworth Scale  $\geq 3$  at the ankle), and participation in another gait training programme during the study.

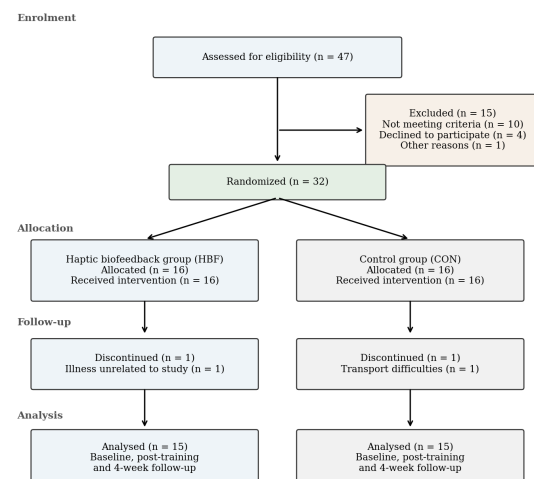


Fig. 1. CONSORT flow diagram of participant enrolment, allocation, follow-up and analysis.

### 2.4 Randomization and Blinding

Following baseline assessment, participants were randomized in a 1:1 ratio using a computer-generated block sequence (block size of four), stratified by baseline self-selected gait speed ( $< 0.8$  or  $\geq 0.8$  m/s). Allocation was concealed in sealed

opaque envelopes opened by the treating therapist. Outcome assessors and the data analyst were blinded to group allocation. Participants were informed that two forms of treadmill training were being compared but were not told the study hypothesis.

## 2.5 Haptic Biofeedback System

Gait training was performed on a dual-belt instrumented treadmill that recorded three-dimensional ground reaction forces from each belt at 1000 Hz. Force signals were low-pass filtered in real time (fourth-order Butterworth, 20 Hz), and paretic stance was identified using a vertical force threshold of 20 N. A custom program calculated peak AGRF during late stance of each paretic step and compared it with an individualized target. When the target was reached, a coin-type eccentric-rotating-mass vibrotactile tactor secured over the lateral aspect of the paretic thigh delivered a brief vibration immediately, providing positive knowledge-of-performance feedback (Fig. 2). Feedback parameters are summarised in Table 1.

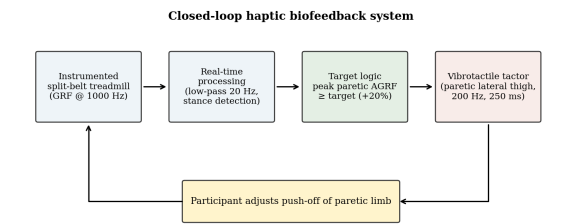


Fig. 2. Schematic of the closed-loop haptic biofeedback system used for paretic propulsion training.

TABLE 1. Haptic biofeedback parameters

| Parameter                 | Specification                                                                                                  |
|---------------------------|----------------------------------------------------------------------------------------------------------------|
| Target variable           | Peak paretic anterior ground reaction force during late stance                                                 |
| Target magnitude          | 20% above baseline peak paretic AGRF; progressed by 5% when success rate exceeded 70% in two consecutive bouts |
| Feedback type             | Positive (success-based) vibrotactile cue delivered on the stride the target was met                           |
| Tactor location           | Lateral mid-thigh of the paretic limb                                                                          |
| Vibration characteristics | ≈200 Hz, 250 ms duration, amplitude above individual detection threshold                                       |
| Latency                   | < 100 ms from peak detection to vibration onset                                                                |
| Feedback schedule         | Faded: 100%, 67% and 33% of eligible strides in bouts 1, 2 and 3                                               |
| Verbal cue                | “Push the ground backwards with your affected leg to feel the buzz”                                            |

## 2.6 Intervention Protocol

Both groups completed 12 sessions (three per week for four weeks). Each session included a five-minute warm-up, three six-minute walking bouts at 100–110% of self-selected treadmill speed separated by two-minute seated rests, and a cool-down (Fig. 3). Participants wore a safety harness without body-weight support and used a light handrail touch. Heart rate and rating of perceived exertion were monitored to maintain moderate intensity (Borg 11–13).

The HBF group received haptic biofeedback as described above. The CON group wore an inactive tactor and performed identical walking bouts at the same speed and duration, receiving only the generic instruction to “walk as normally as possible”. No other physiotherapy targeting walking was permitted during the study.

Training session structure (both groups, 3 sessions/week × 4 weeks)



HBF: faded haptic feedback (100% → 67% → 33% of strides across bouts) | CON: identical walking without feedback

Fig. 3. Structure of each training session and biofeedback fading schedule.

## 2.7 Outcome Measures

Assessments were conducted at baseline, within three days after the final session (post-training) and four weeks after training (follow-up), without biofeedback. Participants walked on the instrumented treadmill at their baseline self-selected speed for 60 seconds while three-dimensional kinematics were captured with an eight-camera motion capture system (100 Hz) using a lower-limb marker set. Outcomes were averaged over at least 20 consecutive strides.

- *Peak paretic AGRF (primary outcome)*: maximum anterior force during paretic late stance, normalized to body weight (%BW).
- *Paretic propulsion (Pp)*: paretic propulsive impulse divided by the sum of paretic and non-paretic propulsive impulses, expressed as a percentage; 50% indicates symmetry [5].
- *Paretic TLA*: peak angle in the sagittal plane between the vertical and the line joining the greater trochanter and fifth metatarsal head during late stance [7], [9].
- *Peak paretic plantarflexor moment*: derived by inverse dynamics and normalized to body mass (Nm/kg).
- *Walking function*: overground self-selected gait speed over the 10-metre walk test and distance on the six-minute walk test (6MWT), both with established reliability in hemiparesis [24].

Minimal detectable change values for treadmill gait variables in stroke [25] were used to interpret

individual responses. Non-paretic peak AGRF was analysed as a control variable for compensatory strategies.

## 2.8 Statistical Analysis

Analyses were performed in IBM SPSS Statistics version 27 on a per-protocol basis. Normality was confirmed with the Shapiro–Wilk test. Baseline characteristics were compared with independent *t*-tests or chi-square tests. A  $2 \times 3$  (group  $\times$  time) mixed-model ANOVA was performed for each outcome, followed by comparison of change scores (post-training minus baseline and follow-up minus baseline) between groups using independent *t*-tests. Mean differences with 95% confidence intervals (CI) and Cohen's *d* are reported. Pearson correlation examined the association between change in paretic AGRF and change in gait speed in the HBF group. Significance was set at  $p < 0.05$ .

## 3. RESULTS

### 3.1 Participants

Of 47 individuals screened, 32 were randomized and 30 (15 per group) completed all assessments (Fig. 1). Mean attendance was 11.6 of 12 sessions in HBF and 11.4 in CON. No serious adverse events occurred; two participants reported transient calf fatigue. All HBF participants reported that the vibration was clearly perceptible and easy to interpret. Baseline characteristics were similar between groups (Table 2).

**TABLE 2. Baseline characteristics of participants**

| Variable                                              | HBF (n = 15)    | CON (n = 15)    | p-value |
|-------------------------------------------------------|-----------------|-----------------|---------|
| Age (years), mean $\pm$ SD                            | 58.7 $\pm$ 8.4  | 60.1 $\pm$ 7.9  | 0.641   |
| Gender (male / female)                                | 10 / 5          | 9 / 6           | 0.705   |
| Time since stroke (months), mean $\pm$ SD             | 26.4 $\pm$ 14.2 | 29.1 $\pm$ 15.8 | 0.627   |
| Stroke type (ischaemic / haemorrhagic)                | 11 / 4          | 12 / 3          | 0.666   |
| Paretic side (left / right)                           | 8 / 7           | 7 / 8           | 0.715   |
| Lower-extremity Fugl-Meyer score (/34), mean $\pm$ SD | 22.3 $\pm$ 4.1  | 21.8 $\pm$ 4.5  | 0.753   |
| Berg Balance Scale (/56), mean $\pm$ SD               | 46.2 $\pm$ 5.3  | 45.6 $\pm$ 5.9  | 0.772   |
| Use of ankle-foot orthosis (yes / no)                 | 4 / 11          | 5 / 10          | 0.690   |

### 3.2 Effect on Paretic-Limb Kinetics and Kinematics

Mixed-model ANOVA revealed significant group  $\times$  time interactions for peak paretic AGRF, Pp,

paretic TLA and plantarflexor moment (all  $p < 0.01$ ). In the HBF group, peak paretic AGRF increased from  $8.2 \pm 3.1$  %BW at baseline to  $11.6 \pm 3.4$  %BW post-training (41.5% increase), compared with a change from  $8.4 \pm 3.0$  to  $9.3 \pm 3.2$  %BW in CON (Fig. 4). The between-group difference in change was 2.5 %BW (95% CI 1.4 to 3.6;  $p < 0.001$ ;  $d = 1.77$ ). Paretic propulsion improved by 6.7 percentage points in HBF versus 1.5 in CON, and paretic TLA increased by  $3.8^\circ$  versus  $1.0^\circ$  (Table 3). Importantly, non-paretic peak AGRF did not change in either group ( $p = 1.000$ ), indicating that improvements were specific to the paretic limb.

**TABLE 3. Paretic-limb biomechanical outcomes across time points (mean  $\pm$  SD)**

| Outcome                      | Group | Baseline        | Post-training   | Follow-up       |
|------------------------------|-------|-----------------|-----------------|-----------------|
| Peak paretic AGRF (%BW)      | HBF   | 8.2 $\pm$ 3.1   | 11.6 $\pm$ 3.4  | 10.9 $\pm$ 3.3  |
|                              | CON   | 8.4 $\pm$ 3.0   | 9.3 $\pm$ 3.2   | 8.9 $\pm$ 3.1   |
| Paretic propulsion, Pp (%)   | HBF   | 35.4 $\pm$ 7.8  | 42.1 $\pm$ 7.2  | 41.0 $\pm$ 7.5  |
|                              | CON   | 36.1 $\pm$ 8.0  | 37.6 $\pm$ 7.9  | 37.0 $\pm$ 8.1  |
| Paretic TLA ( $^\circ$ )     | HBF   | 12.6 $\pm$ 3.9  | 16.4 $\pm$ 3.6  | 15.8 $\pm$ 3.8  |
|                              | CON   | 12.9 $\pm$ 4.1  | 13.9 $\pm$ 4.0  | 13.5 $\pm$ 4.2  |
| Plantarflexor moment (Nm/kg) | HBF   | 0.72 $\pm$ 0.21 | 0.86 $\pm$ 0.22 | 0.84 $\pm$ 0.22 |
|                              | CON   | 0.74 $\pm$ 0.20 | 0.77 $\pm$ 0.21 | 0.76 $\pm$ 0.21 |
| Non-paretic peak AGRF (%BW)  | HBF   | 15.1 $\pm$ 3.6  | 15.4 $\pm$ 3.5  | 15.3 $\pm$ 3.6  |
|                              | CON   | 15.3 $\pm$ 3.4  | 15.6 $\pm$ 3.5  | 15.4 $\pm$ 3.4  |

AGRF, anterior ground reaction force; %BW, percentage of body weight; TLA, trailing limb angle; HBF, haptic biofeedback; CON, control.

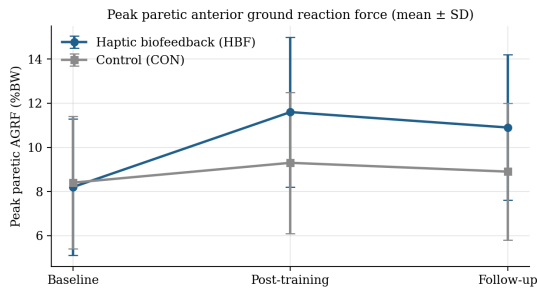


Fig. 4. Peak paretic AGRF at baseline, post-training and follow-up in both groups (mean  $\pm$  SD).

### 3.3 Effect on Walking Function

Self-selected gait speed increased by  $0.14 \pm 0.07$  m/s in HBF and  $0.06 \pm 0.05$  m/s in CON (difference 0.08 m/s; 95% CI 0.03 to 0.13;  $p = 0.001$ ). The HBF group's mean gain exceeded the commonly cited threshold of 0.10 m/s for a meaningful change, whereas the CON group's did not. 6MWT distance improved by  $47 \pm 24$  m in HBF versus  $18 \pm 19$  m in CON ( $p = 0.001$ ) (Table 4, Fig. 5).

TABLE 4. Walking function outcomes across time points (mean  $\pm$  SD)

| Outcome                        | Group | Baseline        | Post-training   | Follow-up       |
|--------------------------------|-------|-----------------|-----------------|-----------------|
| Self-selected gait speed (m/s) | HBF   | 0.62 $\pm$ 0.18 | 0.76 $\pm$ 0.19 | 0.74 $\pm$ 0.19 |
|                                | CON   | 0.60 $\pm$ 0.17 | 0.66 $\pm$ 0.18 | 0.64 $\pm$ 0.18 |
| Six-minute walk test (m)       | HBF   | 245 $\pm$ 62    | 292 $\pm$ 64    | 285 $\pm$ 65    |
|                                | CON   | 240 $\pm$ 60    | 258 $\pm$ 61    | 252 $\pm$ 62    |

Change from baseline to post-training (mean  $\pm$  SD; \*  $p < 0.05$ )

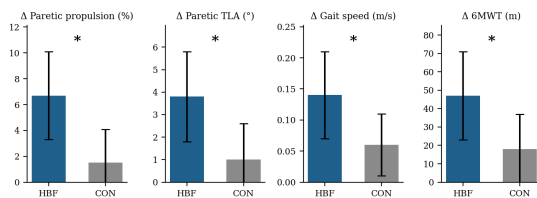


Fig. 5. Change from baseline to post-training in paretic propulsion, TLA, gait speed and 6MWT distance.

### 3.4 Between-Group Differences and Retention

Table 5 presents between-group differences in change scores at post-training and follow-up. All paretic-limb and walking outcomes favoured HBF at both time points with large effect sizes ( $d > 1.2$ ). At follow-up, the HBF group retained approximately 80% of the post-training gain in paretic AGRF and 86% of the gain in gait speed.

TABLE 5. Between-group differences in change scores (HBF – CON)

| Outcome                      | Post-training MD (95% CI) | p      | d    | Follow-up MD (95% CI) | p      | d    |
|------------------------------|---------------------------|--------|------|-----------------------|--------|------|
| Peak paretic AGRF (%BW)      | 2.5 (1.4 to 3.6)          | <0.001 | 1.77 | 2.2 (1.1 to 3.3)      | <0.001 | 1.45 |
| Paretic propulsion (%)       | 5.2 (2.9 to 7.5)          | <0.001 | 1.72 | 4.7 (2.4 to 7.0)      | <0.001 | 1.50 |
| Paretic TLA (°)              | 2.8 (1.4 to 4.2)          | <0.001 | 1.55 | 2.6 (1.2 to 4.0)      | <0.001 | 1.36 |
| Plantarflexor moment (Nm/kg) | 0.11 (0.06 to 0.16)       | <0.001 | 1.56 | 0.10 (0.05 to 0.15)   | <0.001 | 1.41 |
| Gait speed (m/s)             | 0.08 (0.03 to 0.13)       | 0.001  | 1.32 | 0.08 (0.03 to 0.13)   | 0.001  | 1.32 |
| 6MWT (m)                     | 29 (13 to 45)             | 0.001  | 1.34 | 28 (11 to 45)         | 0.002  | 1.24 |
| Non-paretic AGRF (%BW)       | 0.0 (-0.8 to 0.8)         | 1.00   | 0.00 | 0.1 (-0.8 to 1.0)     | 0.81   | 0.09 |

MD, mean difference in change from baseline; CI, confidence interval; d, Cohen's effect size. Independent t-test,  $df = 28$ .

### 3.5 Association between Propulsion and Gait Speed

In the HBF group, the change in peak paretic AGRF was strongly and positively correlated with the change in self-selected gait speed ( $r = 0.73$ ,  $p = 0.002$ ), indicating that participants who increased propulsion most also gained the most walking speed (Fig. 6). Using the minimal detectable change for paretic AGRF [25], 11 of 15 HBF participants (73%) were classified as responders compared with 3 of 15 CON participants (20%).

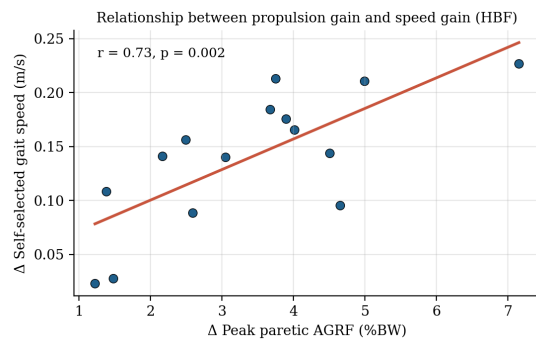


Fig. 6. Correlation between change in peak paretic AGRF and change in gait speed in the HBF group.

## 4. DISCUSSION

### 4.1 Principal Findings

This randomized controlled trial demonstrated that adding real-time haptic biofeedback to treadmill gait training produced substantially greater improvements in paretic-limb propulsion than identical training without feedback. The gains extended to TLA, plantarflexor moment, gait speed and walking endurance, were largely retained four weeks after training, and occurred without changes in non-paretic propulsion. The null hypothesis was therefore rejected.

### 4.2 Comparison with Previous Studies

The immediate increases in paretic AGRF reported with visual and audiovisual biofeedback [16]–[19] are consistent with the present findings, and this study extends that evidence in two ways. First, the effect was achieved with a purely vibrotactile cue, confirming that propulsion information need not be delivered through a screen. Second, repeated training produced retained change rather than only within-session modulation. Awad *et al.* previously showed that training specifically targeting paretic propulsion improves walking function [12]; the gait speed gains here are comparable in magnitude while requiring no additional equipment beyond a tactor and force-sensing treadmill. The limb-specific response agrees with earlier reports that unilateral propulsion feedback increases paretic output without compensatory non-paretic changes [16], [19].

### 4.3 Possible Mechanisms

Two complementary mechanisms may explain the findings. Biomechanically, both TLA and plantarflexor moment increased, suggesting that participants used a combination of improved limb orientation and greater ankle output to raise propulsion [8], [11]. The larger relative change in TLA supports the view that limb posture is a readily modifiable contributor [9]. Individuals post-stroke are known to possess an under-used propulsive reserve [10], and haptic cues may have provided the task-specific stimulus required to access it repeatedly.

From a motor learning perspective, the success-based haptic cue offered immediate knowledge of performance while allowing an external, goal-

directed focus, conditions associated with better learning [15]. The fading schedule reduced dependence on feedback, which is thought to promote retention [14]. Haptic stimulation is also processed with low latency and does not load visual attention, which may allow participants to maintain natural head posture and gait during training [20].

### 4.4 Clinical Implications

The strong correlation between changes in propulsion and gait speed supports propulsion as a mechanistically meaningful rehabilitation target [6], [7]. Because vibrotactile tactors are inexpensive and wearable, haptic propulsion feedback could be combined with inertial sensors that estimate TLA or propulsion [26] to extend training to overground and home settings [21], [22]. Clinicians may consider this approach particularly for ambulatory patients with residual plantarflexor function, who were most likely to respond; recognition of responder characteristics is important given the variability in locomotor training outcomes after stroke [27].

### 4.5 Limitations

Several limitations should be noted. The sample size was modest and drawn from a single centre, and participants were relatively high-functioning community ambulators, limiting generalisability to more impaired individuals. Training occurred on an instrumented treadmill, so transfer to overground walking was assessed only through clinical walking tests. The treating therapist was not blinded, and the follow-up period was short. Finally, the study did not directly compare haptic with visual or auditory feedback, so conclusions about the superiority of the haptic modality cannot be drawn.

### 4.6 Future Directions

Future trials should examine wearable, sensor-based haptic propulsion feedback during overground and community walking, compare feedback modalities and dosages, include longer follow-up and participation outcomes, and identify predictors of response to guide individualized prescription.

## 5. CONCLUSION

Real-time haptic biofeedback targeting peak paretic anterior ground reaction force, delivered during a four-week gait training programme, significantly improved paretic-limb propulsion, trailing limb angle, plantarflexor moment, gait speed and walking endurance in individuals with chronic stroke compared with training alone. The improvements were limb-specific and largely retained at four weeks. Haptic biofeedback is a practical, wearable and effective adjunct for targeting propulsion deficits in post-stroke gait rehabilitation.

## 6. DECLARATIONS

*Ethical approval:* Institutional Ethics Committee of [institution], reference no. [xxxx]. *Trial registration:* [registry and number]. *Conflict of*

*interest:* The authors declare no conflict of interest.  
*Funding:* [funding details or “None”].  
*Acknowledgement:* The authors thank all participants and laboratory staff for their contribution.

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