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CASE REPORT



## Mirror therapy and treadmill training for a patient with chronic stroke: A case report

Patrick Broderick MSc<sup>a</sup>, Frances Horgan PhD<sup>b</sup>, Catherine Blake PhD<sup>c</sup>, Paula Hickey MB<sup>d</sup>, Joanne O'Reilly BSc, PT<sup>e</sup>, Monika Ehrensberger BA<sup>a</sup>, Daniel Simpson BSc<sup>a</sup>, David Roberts BA<sup>f</sup>, and Kenneth Monaghan PhD, PT<sup>g</sup>

<sup>a</sup>Department of Science, Institute of Technology Sligo, Sligo, Ireland; <sup>b</sup>Department of Physiotherapy, Royal College of Surgeons in Ireland, Dublin, Ireland; <sup>c</sup>Department of Health Science, University College Dublin, Dublin, Ireland; <sup>d</sup>Department of Geriatrics, Sligo University Hospital, Sligo, Ireland; <sup>e</sup>Department of Physiotherapy, Sligo University Hospital, Sligo, Ireland; <sup>f</sup>Department of Design, Institute of Technology Sligo, Sligo, Ireland; <sup>g</sup>Department of Health Science, Institute of Technology Sligo, Sligo, Ireland

### ABSTRACT

**Introduction:** A large proportion of patients with chronic stroke have permanent lower limb functional disability leading to reduced levels of independent mobility. Individually, both mirror therapy and treadmill training have been shown to improve aspects of lower limb functioning in patients with stroke. This case report examined whether a new combination of both interventions would lead to improvements in lower limb functional disability for a patient with chronic stroke.

**Case Description:** The participant was a 50-year-old female who had a left middle cerebral artery infarction (47 months' post stroke). Due to hemiparesis, she had lower limb motor impairment and gait deficits. **Intervention:** The participant engaged in a combination of mirror therapy and treadmill training for 30 minutes per day, 3 days per week, for 4 weeks. **Outcomes:** Modified Ashworth Scale, Fugl-Meyer Assessment-Lower Extremity and the 10 m Walk Test demonstrated clinically meaningful change. The 6 Minute Walk Test did not demonstrate meaningful change.

**Discussion:** The positive outcomes from this new combination therapy for this participant are encouraging given the relatively small dose of training and indicate the potential benefit of mirror therapy as an adjunct to treadmill training for enhancing lower limb muscle tone, motor function and walking velocity in patients with chronic stroke.

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Stroke; mirror therapy;  
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## Introduction

There are an estimated 15 million patients who have a stroke worldwide each year, resulting in stroke being the leading cause of high level disability in people living in the community and in their own homes (Murray et al., 2012; World Health Organization, 2008). Typical factors that are found to influence functional disability after stroke include three interrelated motor impairments consisting of paresis, which occurs as a result of a lesion induced disruption of voluntary motor command execution, followed by immobilization and disuse of the affected limb and finally spasticity (Thibaut et al., 2013).

Motor impairment has been reported to develop in about 80% of patients with stroke and almost two-thirds experience lower extremity functional limitations, including functional disability and gait impairments (Pollock et al., 2014). Approximately, 30% of patients with chronic stroke have permanent difficulties in independent walking at 6 months and this increases fall risk and energy expenditure during gait and ultimately leads to a more

sedentary lifestyle in these patients (Langhorne, Coupar, and Pollock, 2009). Stroke rehabilitation aims to return the highest functional independence possible in patients, and increase quality of life, however conventional treatment methods are insufficient to enable lower extremity functional recovery (Pollock et al., 2014). Spasticity occurs in approximately 25–30% of patients, usually emerging within the first few days or weeks and in the lower limbs it has been found to primarily affect the ankle (66%) (Mayer and Esquenazi, 2003; Wissel et al., 2010). This contributes to common gait impairments, including reductions in walking velocity and endurance (Schmid et al., 2007).

The most common and basic intervention for motor impairment and spasticity following stroke is physical therapy yet the evidence supporting its effectiveness in relation to spasticity reduction is lacking (Gracies, 2005a). Stretching does not promote significant improvement in spasticity and there is also little scientific evidence to support the method of casting (Katalinic, Harvey, and Herbert, 2011; Lannin, Novak, and Cusick, 2007). Additionally, a small number of studies have demonstrated that the Bobath technique

is conducive for spasticity reduction following stroke but its effectiveness appears to be limited (Ansari and Naghdi, 2007; Dias et al., 2007). To date, weight bearing treadmill training has been employed mainly to benefit the rehabilitation of gait characteristics, such as walking velocity and endurance (Mehrzholz, Pohl, and Elsner, 2014). There is a dearth of evidence concerning the application of this repetitive and goal orientated (e.g. to improve walking) lower limb rehabilitation technique to motor impairment and only one previous study has found it to reduce spasticity in affected hamstrings following a pilot three month 'task-orientated' treadmill training intervention (Smith, Silver, Goldberg, and Macko, 1999). This was the first study to establish the 'modification of spastic reflexes' in the chronic phase of stroke as a consequence of ambulatory exercise alone. More importantly, this study indicated that the deconditioning of chronic stroke patients as a result of stroke can be reversed if modified by regular treadmill training. However, this study only assessed spasticity affecting the hamstrings.

Mirror therapy is a novel intervention that utilizes new visual information via mirror visual feedback (MVF) to stimulate the mirror neuron system and reduce motor impairment in the upper and lower limbs following a stroke (Thieme et al., 2012). Imaging studies have shown mirror therapy to facilitate neuroplasticity by stabilizing cortical activity within the primary motor cortex (M1), which is an area key to the development of paresis and spasticity and consequently, restore motor command execution and function (Bartur et al., 2015; Lappchen et al., 2012). Previous non-weight bearing lower limb mirror therapy studies have found improvements in motor functioning but only one non-weight bearing upper limb study has found any effectiveness in relation to spasticity reduction (Beom et al., 2016; Sutbeyaz, Yavuzer, Sezer, and Koseoglu, 2007). This recent study by Beom et al. (2016) utilized a robotic mirror therapy system to facilitate movement of the paretic limb during conventional mirror therapy leading to enhanced proprioceptive input to the sensory cortex, which is key to the occurrence of neuroplasticity and functional recovery of hemiplegic limbs. No lower limb study has yet examined mirror therapy with a functional weight bearing exercise.

This case report explored the feasibility and effectiveness of a new combination therapy of mirror therapy and treadmill training for the purpose of improving lower limb muscle tone, voluntary motor function, walking velocity and endurance for a person with chronic stroke. The authors hypothesized that this combination therapy would lead to clinically

meaningful improvements as indicated by the minimal detectable change (MDC) and the minimal clinically important difference (MCID) for each outcome measure. The MDC indicates a clinically significant amount of change required to exceed measurement variability, whereas the MCID indicates clinically meaningful change for the patient (Tilson et al., 2010).

## Case description

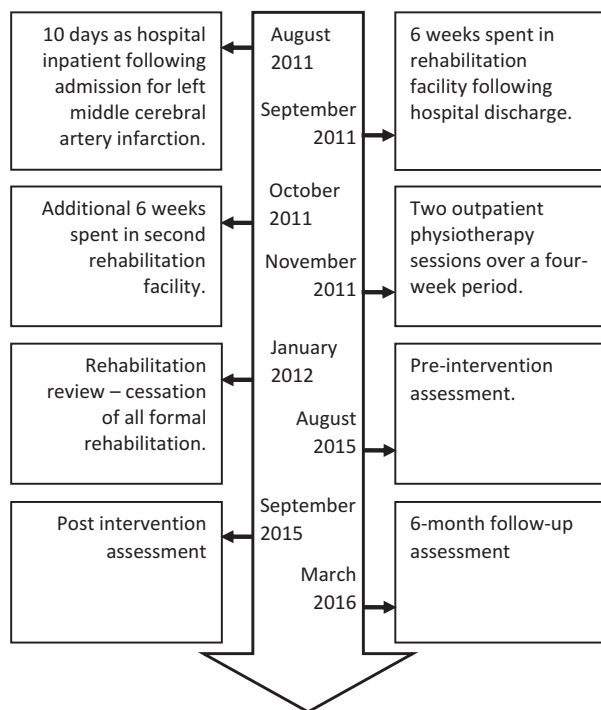
### Participant history

This case report examines an ambulatory 50-year-old female participant with a first episode of left ischemic stroke, 3 years and 11 months prior to the beginning of the trial, with resultant spastic hemiparesis in her dominant (right) lower limb. The participant reported being in overall good health since the stroke and was free from any major post-stroke complications. Her medical history reported that she had been taking medication for hypertension prior to her stroke. The participant's pharmaceutical regimen consisted of Co-Vantan 160 mg once per day.

The participant lived independently in the community and was ambulatory, however there was residual motor and gait impairment due to her stroke. The participant independently engaged in activities of daily living and instrumental activities of daily living. She did not employ a walking aid and no falls were reported in the preceding year. Following her stroke, the participant was thrombolysed upon hospital admission in August 2011 and spent 10 days as a hospital inpatient with initial deficits of hemiplegia, increased muscle tone, dysarthria and dysphasia. The participant received a total of 12 weeks' rehabilitation following hospital discharge and an additional two physiotherapy sessions upon returning home. The participant's timeline from hospital admission to formal rehabilitation cessation is presented in Figure 1. By taking part in mirror therapy and treadmill training the participant hoped to improve the functioning of her paretic limb. She gave informed consent to participate in training based on procedures approved by the Research Ethics Committee at Sligo University Hospital and which complied with the Declaration of Helsinki.

### Examination

The participant's anthropometric measurements were height 149.86 cm and weight 142 lbs (64.4 kg). The participant had no discernible differential diagnosis and was ambulatory with no apparent limitations in relation to treadmill walking. Valid and reliable outcome



**Figure 1.** Participant recovery timeline.

measures were chosen to reflect the potential of the combined intervention and in order to address the participant's goal of improved lower limb functioning. Outcome measures were administered 1 day before (baseline), 1 day after (post-training) and 6 months after the 4-week mirror therapy and treadmill training intervention (6 month follow-up).

The first of two primary outcome measures chosen was the Modified Ashworth Scale (MAS), which was used to evaluate lower limb muscle tone (Bohannon and Smith, 1987). The MAS is a 6-point (0, 1, 1+, 2, 3 and 4) rating scale with 0 representing 'no increase in muscle tone' and 4 representing 'affected part(s) rigid in flexion or extension'. The MAS has demonstrated adequate intrarater reliability in the assessment of lower limb muscle tone in patients with chronic stroke, with a Kendall tau-b ranging from 0.44 to 0.66 (Blackburn, Van Vliet, and Mockett, 2002) and excellent convergent validity with the Fugl-Meyer Assessment ( $r = -0.94$ ) (Katz, Rovai, Brait, and Rymer, 1992). The MAS has a proposed MDC of a 1-point decrease but to the authors knowledge no MCID has been established (Albright et al., 1993; Shaw et al., 2010). The second primary outcome measure chosen was the motor function subscale of the Fugl-Meyer Assessment-Lower Extremity (FMA-LE), which was used to evaluate lower limb motor function (Fugl-Meyer, Jääskö, Leyman, and Olsson,

1975). This measure has a score range of 0 (severe impairment) to 34 (normal functioning), with items scored on 3-point ordinal scale with ratings from 0 (cannot perform) to 2 (performs fully). The FMA-LE has demonstrated excellent intrarater Pearson correlation coefficients for the motor subscale (0.96) (Duncan, Propst, and Nelson, 1983) and excellent content validity (Crow and Harmeling-Van Der Wel, 2008). The FMA-LE has a proposed MDC of a 4-point increase (Hiengkaew, Jitaree, and Chaiyawat, 2012) and a proposed MCID of a 6-point increase (Pandian, Arya, and Kumar, 2016) for patients with chronic stroke.

Secondary outcome measures were the 10 Meter Walk Test (10MWT) (Rossier and Wade, 2001), which was used to evaluate comfortable walking speed and the 6 Minute Walk Test (6MWT) (Butland et al., 1982), which was used to evaluate walking endurance. The 10MWT was carried out using white tape markers placed at the 0-, 2-, 8-, and 10-m points along a designated walkway. The patient was instructed to walk at her comfortable walking speed and she was timed over the central 6 m, with the first and last 2 m not timed to allow for acceleration and deceleration (Lam, Lau, Chan, and Sykes, 2010). Velocity was calculated from three successive trials. The 10MWT has demonstrated excellent intrarater reliability in patients with stroke (Intraclass Correlation Coefficient (ICC) = 0.87–0.88) (Collen, Wade, and Bradshaw, 1990) and excellent convergent validity with the 6MWT (ICC = 0.89) (Flansbjerg et al., 2005). The 10MWT has a proposed MDC ranging 0.05 m/s to 0.08 m/s and a proposed MCID of 0.16 m/s for comfortable walking velocity for patients with chronic stroke (Tilson et al., 2010). The 6MWT followed American Thoracic Society (2002) guidelines and utilized a 30 m walkway measured every 3 m (American Thoracic Society, 2002). The 6MWT has demonstrated adequate intrarater reliability in patients with stroke (ICC = 0.74) (Kosak and Smith, 2005) and excellent concurrent validity with the 10MWT for comfortable walking speed ( $r = -0.89$ ) (Flansbjerg et al., 2005). The 6MWT has a proposed MDC ranging from 34.37 m (Eng, Dawson, and Chu, 2004) to 36.6 m (Flansbjerg et al., 2005) and a proposed MCID of 34.4 m (Tang, Eng, and Rand, 2012) for patients with chronic stroke. All outcome assessments were carried out by a chartered physiotherapist with 25 years' clinical experience specializing in stroke rehabilitation and who was blinded to the intervention. All mirror therapy and treadmill training sessions were carried out by a separate therapist with over 10 years' experience in stroke rehabilitation.



## Evaluation and diagnosis

Upon pre-intervention evaluation, the participant was observed presenting with postural and gait deficits that included increased forward-head posture, decreased step length on the non-affected limb and asymmetrical stride length. The asymmetrical walking pattern became more prominent during walking assessment. The participant described the following lower limb issues as affecting her; ‘a lack of fluidity in the movement of her affected limb accompanied by stiffness throughout and reduced ankle mobility’.

All joints assessed in the affected limb exhibited increased muscle tone, with highest muscle tone in the ankle. This resulted in limiting non-paretic limb swing during gait. Assessment outcomes are presented in Table 1. Increased ankle muscle tone will reduce gastrocnemius muscle control in the paretic limb and reduce the forward momentum for the swing phase of the non-paretic limb (Hesse and Werner, 2003). Voluntary motor function demonstrated a moderate level of impairment indicating the presence of paresis and lower limb disability (Park and Choi, 2014). Both comfortable walking speed and walking endurance scores were substantially below that of healthy, aged matched females and this translated into impaired functional mobility for the participant (Bohannon, 1997; Bohannon and Williams, 2011; Casanova et al., 2011). These outcomes combined with the participant’s subjective reports of lower limb motor impairment represented functional disability for the participant.

## Prognosis

Optimal duration of treatment with mirror therapy following stroke remains a grey area (Thieme et al., 2012). Previous non-weight bearing mirror therapy studies have provided treatment for: two weeks (Beom et al., 2016; Mohan et al., 2013); four weeks (Ji and Kim, 2015; Kim, Ji, and Cha, 2016; Salem and Huang, 2015; Sütbeyaz, Yavuzer, Sezer, and Koseoglu, 2007); and six weeks (Ji, Cha, Kim, and Lee, 2014) with 15 minute (Ji and Kim, 2015) to 30 minute

**Table 1.** Clinical outcome measure scores.

Outcome measures <sup>a</sup>	Score at:		
	Baseline	Post-training	6 month follow-up
FMA-LE (motor function)	26	32	34
MAS	10	8	2
10MWT (m/s)	0.93	1.07	1.17
6MWT (m)	353.5	387	375.65

Note: <sup>a</sup>FMA-LE = Fugl-Meyer Assessment-Lower extremity; MAS = Modified Ashworth Scale; 10MWT = 10 Meter Walk Test; 6MWT = 6 Minute Walk Test. m/s = metres per second; m = metres.

sessions (Ji, Cha, Kim, and Lee, 2014; Kim, Ji, and Cha, 2016; Salem and Huang, 2015; Sütbeyaz, Yavuzer, Sezer, and Koseoglu, 2007). Recent Cochrane Reviews addressing both treadmill training (Mehrholtz, Pohl, and Elsner, 2014) and rehabilitation approaches (Pollock et al., 2014) after stroke have demonstrated that interventions applied for 30–60 minutes per day, 3–5 times per week and for 4–6 weeks are optimal for motor and gait recovery.

As our participant was of moderate impairment following stroke, the design for the number of treatment sessions for this case report was formed to reflect the lower end of this spectrum. This case report included mirror therapy and treadmill training for 3 days per week, 30 minutes per day for 4 weeks.

## Intervention

The participant verbally guided the speed of the treadmill at the beginning of each of the 12 therapy sessions, which was adjusted by the therapist. A COSMED h/p/cosmos T170 treadmill was used for the intervention. The participant was encouraged to walk at her comfortable walking velocity when on the treadmill. Treadmill velocity in session one was guided by baseline data from the 10MWT, which provided an average comfortable walking velocity in meters per second. For safety and because no weight bearing harness was employed during the intervention, the participant was advised to use the treadmill handrails for support when required. There was a stationary handrail in front of the participant where individual hands or both hands could be



**Figure 2.** Hand rail locations on treadmill.

placed and individual stationary handrails for single hand placement on the left and right sides (Figure 2). The participant was also provided with contact-guard assistance throughout each mirror and treadmill session. The participant was asked to wear dark sports leggings so that the non-paretic leg could be fully viewed by rolling the fabric above the knee joint and the paretic limb was kept completely covered by the sports leggings to assist in appropriate MVF of the non-paretic limb.

The participant walked on the treadmill while viewing a reflection of her non-paretic limb in a custom built acrylic mirror apparatus (Figure 3), positioned in the mid-sagittal plane between the legs that provided a full view of non-paretic leg movement, both in rear and forward positions. The angle of the mirror was then adjusted according to participant preference to gain a full view of the non-affected limb. Treadmill velocity was increased or decreased according to clinician judgment and participant tolerance. Each session was divided into two 15-minute sessions with a 5-minute rest period between them. Additionally, according to the Borg RPE Scale comfortable exertion occurs at 13/14 and the participant was asked to let it be known if she experienced feelings of 'very hard' while walking



Figure 3. Mirror therapy apparatus for treadmill.

(Borg and Kaijser, 2006). At this point the participant was encouraged to slow down or take a break.

No adverse effects were observed with the exception that the participant reported that she felt as though she had gained an 'additional' or 'third limb' when she closed her eyes following the cessation of the first mirror and treadmill session. This sensory irregularity lasted for a number of hours on the day of the treatment and then dissipated with no reoccurrence. This was not an uncomfortable feeling and the patient reported this as an 'unusual experience'. The patient also reported an increased sensation and light paraesthesia in the calf and heel regions during the initial sessions which lasted throughout the episode of care. These areas of the leg were described as being previously numb with little sensation. The participant did not report any obvious distraction of observing the non-paretic limb and in fact was surprised how quickly she 'forgot' that there was a mirror in place.

## Outcomes

The intervention including the follow-up assessment was carried out from August 2015 to March 2016 at the Institute of Technology Sligo, Ireland. All 12 sessions were completed without issue. Baseline outcome assessments confirmed the presence of symptoms commonly associated with post-stroke recovery that were as follows: MAS = 10; FMA-LE = 26; 10MWT = 0.93 m/s; 6MWT = 353.5 m. Post-training assessment scores were as follows: MAS = 8; FMA-LE = 32; 10MWT = 1.07 m/s; 6MWT = 387 m. Six-month follow-up assessment scores were as follows: MAS = 2; FMA-LE = 34; 10MWT = 1.17 m/s; 6MWT = 375.65 m. Assessment outcomes are presented in Table 1 and a breakdown of individual MAS scores is presented in Table 2.

Over the 4-week intervention, patient-selected treadmill velocity increased by 52% from 0.58 KPH to 0.88 KPH and walking distance increased by approximately 50% from 290 m in session one to 436 m in session 12. Participant's self-reports after the second therapy session stated improved stability and maintenance of pare-

Table 2. Modified ashworth scale: individual muscle scores.

Muscle <sup>a</sup>	Score at:		
	Baseline	Post-training	6 month follow-up
Hip flexor	1	1	0
Hip extension	1	1	0
Hip adduction	1	1	0
Hip abduction	1	1	0
Knee flexor	1	1	1
Knee extension	1	1	0
Ankle plantarflexion	1+	1	0
Ankle dorsiflexion	1+	1	1

Note: <sup>a</sup>Muscles assessed using the Modified Ashworth Scale (MAS).

tic limb positioning and after the sixth therapy session stated that the participant had ran a short distance for the first time since her stroke. These improvements were also cited at follow-up assessment. Additionally, our participant reported an increased motivation to walk following the 4-week trial and reported that her perceived increased ability to 'walk further and faster' further boosted this motivation.

## Discussion

The authors of this case report hypothesized that mirror therapy combined with treadmill training would lead to clinically meaningful improvements in lower limb muscle tone, lower limb motor function as measured by the FMA-LE and gait characteristics in a patient with chronic stroke. While outcome measurements did not demonstrate meaningful change in all aspects clinically, the results from this new combination therapy lead to some interesting findings. Muscle tone improved in a clinically significant manner in seven out of eight lower limb muscles assessed with greatest improvement in the ankle. There were clinically meaningful improvements in motor function as measured with the FMA-LE and comfortable walking speed. A trend towards improved walking endurance was also demonstrated. These results do not provide conclusive evidence for the effectiveness of this intervention in all individuals with stroke; however, for post-stroke motor impairment, this case report demonstrated the feasibility of this combination therapy as an effective lower limb rehabilitation technique.

The first ability of the central motor system is to synchronize and increase motor unit recruitment upon voluntary command to execute movement and the second is the ability to relax the muscle when it is not engaged in voluntary movement. A partial loss of both these abilities often coexists after injury to the central motor pathways following stroke (Gracies, 2005b). Disruption of the central execution of motor command within the M1 causes immediate unilateral paresis accompanied by gradual lesion- and activity-dependent adaptive changes within the higher centers, which are further promoted by immobilization and disuse. Spasticity develops as a repercussion of these successive changes (Thibaut et al., 2013).

Although the mechanisms underlying spasticity are not well understood, its onset could be explained by an anarchic neuronal reorganization following a lesion to the M1 (Sheean, 2002; Thibaut et al., 2013). The result of this neuronal reorganization may be increased activity in the muscles and exaggerated reflex responses to peripheral stimulation (Thibaut

et al., 2013). Mirror therapy has been shown to reverse the cortical reorganization, which can occur following a stroke (Michielsen et al., 2011). The improvements in both lower limb muscle tone and motor functioning as measured by the FMA-LE demonstrated in this case report could be explained by mirror therapy mechanism data from functional imaging studies, which have shown mirror therapy to illicit cortical changes within the ipsilateral and contralateral M1's, reducing asymmetric activation between hemispheres by facilitating a shift toward the affected M1 (Läppchen et al., 2012; Nojima et al., 2012). Adaptation mechanisms, such as increased recruitment of the unaffected M1 and subsequent loss of interhemispheric inhibition is associated with motor impairment after stroke by reducing selectivity of motor unit activation (Calautti et al., 2007; Carey et al., 2006; Murase, Duque, Mazzocchio, and Cohen, 2004; Ward, Brown, Thompson, and Frackowiak, 2003), whereas normal dispersal of interhemispheric activation is commonly found in better recovered patients (Ward, Brown, Thompson, and Frackowiak, 2003).

A potential additional contribution to the reduction of motor impairment seen in the present case report is that this is the first lower limb mirror therapy study to employ a goal orientated weight bearing exercise. This type of movement has been shown to be important for the recruitment of mirror neurons during movement observation, which are proposed as forming the neural basis for mirror therapies positive impact on motor recovery and are primarily found within the M1 brain region (Bartur et al., 2015; Carvalho et al., 2013). Goal-directed movement is based on the integration of sensory information into a motor format and it has been shown that mirror neurons do not mirror specific motoric actions but instead the goal of the action (Hickok, 2014). In order to receive appropriate MVF during treadmill walking, an additional cognitive goal for the participant is to place the non-affected limb in a correct position in front of the mirror and to replicate this accurate limb placement repeatedly with each step. The primary act of walking on a treadmill is also a goal orientated task. Previous lower limb studies have all employed isolated joint movements that are not goal directed and this may have reduced their effectiveness in relation to mirror neuron recruitment and consequently, the reduction of motor impairment (Kim, Ji, and Cha, 2016; Salem and Huang, 2015). Observation of the mirror illusion of a corrected walking pattern during treadmill walking may alter activation of the mirror neuron system to adapt the motor commands being sent from the ipsilesional M1. Ultimately, this



may explain the observed improvement in motor recovery and consequent reduction in muscle tone.

Traditional rehabilitation methods, such as treadmill training with body weight support have had limited success in reducing step length asymmetry as it is maintained not only by control of foot placement (spatial strategy) but also by the relative timing between foot strikes (temporal strategy) (Hornby et al., 2008; Malone and Bastian, 2010). During mirror therapy in the current case report, the affected limb of the patient is not visible due to mirror design and so the patient views the reflection of their non-paretic limb engaged in a movement pattern with symmetrical and reduced stride length. It is possible that the benefit of mirror therapy combined with treadmill training is to allow the participant to regain symmetry of both steps by reducing the length of the paretic step. This may occur as a result of observation of the shortened stride length of the non-paretic limb in the mirror rather than encouraging, for example, a non-paretic limb to take a longer step as seen in split-belt treadmill training (Reisman, McLean, and Bastian, 2010). To achieve appropriate MVF the participant must also position the same step repeatedly in the mirror during each 30-minute session receiving visual confirmation of foot placement with each step. Visual feedback of foot strike location has been shown to reduce asymmetry and this feedback is repeatedly provided by the mirror during treadmill walking in our study (Malone and Bastian, 2010). Asymmetrical gait arises due to the recognition that patients with hemiparesis have a stopping moment to prepare for the next step (step-through gait) and this can be aided by the provision of appropriate peripheral sensory feedback in a repetitive manner, consistent speed of walking and rhythmical step-through gait (Combs, Dugan, Ozimek, and Curtis, 2013). The initial visual decrease in step length could provide a stimulus driving patients to recalibrate their motor commands in a feed-forward approach to reduce asymmetry and repeated exposure to movement adaptation can result in permanent reductions in step length asymmetry (Reisman, McLean, and Bastian, 2010; Reisman et al., 2013).

A recent Cochrane review by Mehrholz, Pohl, and Elsnar (2014) has shown treadmill training to specifically benefit the gait characteristics of walking velocity and walking endurance in ambulatory patients with stroke. It has also been shown to improve motor function but in a limited amount of studies with a focus on body weight support (Mao et al., 2015; Nilsson et al., 2001; Visintin, Barbeau, Korner-Bitensky, and Mayo, 1998). To the authors knowledge only one other

treadmill training study has demonstrated a significant improvement in lower limb muscle tone, following a 12-week intervention consisting of 36 walking sessions (Smith, Silver, Goldberg, and Macko, 1999). Our finding of improved muscle tone in 7 out of 8 hip, knee and ankle muscles is a new finding, as the previous study by Smith, Silver, Goldberg, and Macko (1999) was limited to the assessment of hamstring (knee flexor) spasticity. Another important aspect is that the intervention employed in the present case report had a dosage of 12 therapy sessions over a 4-week period, which is significantly less than that applied by Smith, Silver, Goldberg, and Macko (1999). The observed reduction in muscle tone in this case when treadmill training with a mirror suggests its potential future use for both motor impairment and gait variable improvements.

Importantly, our finding of a clinically meaningful decrease in muscle tone has not been demonstrated in previous lower limb mirror therapy research (Salem and Huang, 2015; Sütbeyaz, Yavuzer, Sezer, and Koseoglu, 2007). Only one recent upper limb study by Beom et al. (2016) has found an effect of reduced spasticity, where conventional mirror therapy was combined with a simple robotic system to mobilize the affected upper limb during 10 sessions of mirror therapy over a two-week period. A key similarity between this study and the present case report is the forced mobilization of the affected limb during mirror therapy, leading to an increase in proprioceptive input to the primary sensory motor area which has the potential to enhance neuroplastic facilitation (Beom et al., 2016). The increased input from weight bearing bilateral movement combined with the visual stimulation of the improved symmetrical movement may be important for the reduction of muscle tone of the lower limbs and needs to be explored further. An additional point of interest is that the treatment dosage of 10 individual sessions is similar to this case report which carried out 12 sessions, it is possible that the increased mobilization of the affected limb may play a role in effective mirror therapy of limited frequency.

We examined the muscle tone of three lower limb joints (hip/knee/ankle). Previous studies limited their range of assessment to ankle dorsiflexion and ankle plantarflexion (Salem and Huang, 2015; Sütbeyaz, Yavuzer, Sezer, and Koseoglu, 2007). When our MAS results are examined in more detail, ankle plantarflexion muscle tone decreased by 1-point at post training and decreased a further 1-point at follow-up. Ankle dorsiflexion muscle tone decreased by 1-point at post-training and this decrease remained stable at follow-up. Interestingly, although no changes were observed in the remaining muscles at post-training assessment (4 weeks), follow-up



assessment (24 weeks) demonstrated a 1-point reduction in muscle tone for hip flexion, hip extension, hip adduction, hip abduction and knee extension. Thus, 7 out of 8 muscles assessed demonstrated a clinically significant improvement in muscle tone. Although no MCID has been established for the MAS, it is proposed that an MCID should reflect a larger improvement than that of an MDC (Tilson et al., 2010). Taking this into consideration, coupled with the fact that the participant made self-reports of improved lower limb control and functioning, the authors suggest that the 2-point decrease in ankle plantarflexion muscle tone could potentially reflect a MCID in muscle tone change for the participant.

Abnormal sensitivity to muscle stretch follows the emergence of paresis, which is caused by an initial disruption to motor command execution in the M1 (Thibaut et al., 2013). As described previously, MVF has been shown to stabilize activity within ipsilesional and contralesional M1 following stroke, and treadmill training significantly increases mobilization and active use of the paretic limb potentially reducing the consequences of muscle contracture and increasing proprioceptive input (Michielsen et al., 2011; Skalsky and McDonald, 2012). It is possible that the combination of both mirror therapy and treadmill training serve to reduce these concomitant factors which facilitate the emergence and maintenance of spasticity, resulting in its reduction. Concerning the observation of a reduction of muscle tone in an additional five lower limb muscles at follow-up assessment, we propose that as the emergence of increased muscle tone is a relatively gradual process, which is succeeded by the immediate onset of paresis, the reduction in muscle tone as a result of possible stabilization of M1 activation could also be a gradual process facilitated by more rapid improvements in voluntary motor command. Thus, our 4-week post-training assessment that took place immediately after intervention cessation, may have been too soon to pick up on the full extent of muscle tone reduction. This is supported by the fact that the only other treadmill training study to observe a reduction in lower limb spasticity was 3 months long with 36 individual sessions and this may have provided sufficient time for spasticity reduction to become evident (Smith, Silver, Goldberg, and Macko, 1999). The only other lower limb mirror therapy study to have a follow-up assessment was by Sütbeyaz, Yavuzer, Sezer, and Koseoglu (2007) at 6 months', but the intervention employed in this study was not task orientated and so potentially less able to recruit the mirror neuron system to stabilize motor command execution and reduce spasticity.

Voluntary motor function at pre-intervention assessment was 8 points below normal functioning as measured by the FMA-LE, pointing to a moderate level of motor impairment for our participant (Park and Choi, 2014). Motor functioning increased by 6 points at post training and an additional increase of 2 points at follow up assessment. This improvement by our participant means that her lower limb motor functioning improved from a moderate to a normal level of functioning as a result of the 4-week intervention. Results exceeded the 4 point MDC for lower limb motor recovery in patients with chronic stroke at both assessment time points (Hiengkaew, Jitaree, and Chaiyawat, 2012). Additionally, the post-training FMA-LE score equalled the proposed MCID for this measure and exceeded it at follow-up assessment signaling meaningful change for the participant. This finding supports previous non-weight bearing lower extremity mirror therapy research but importantly this is the first reported case to employ a weight bearing functional exercise and this participant's outcome demonstrates the potential of this combination intervention for future mirror therapy rehabilitation and research (Salem and Huang, 2015; Sütbeyaz, Yavuzer, Sezer, and Koseoglu, 2007; Wada et al., 2011). Again, it is interesting to note that significant improvements in motor functioning occurred in the current intervention despite the treatment dosage being substantially lower than previous studies.

Self-selected walking velocity increased by 0.14 m/s at post-training and an additional increase 0.10 m/s at follow-up assessment, demonstrating a 0.24 m/s total improvement. Consequently, both post-training and follow-up assessment scores exceeded the proposed MDC for this measure and the follow-up score exceeded the proposed MCID for this measure signaling real and meaningful change for the participant. It is suggested that due to the mirror, and its effect in improving muscle tone and motor functioning, that the participant may be walking with an improved symmetrical gait. A more symmetrical gait has been shown to correlate with increased walking velocity and improved ankle muscle tone and this fits with our theory of how mirror therapy combined with treadmill training may improve symmetry of gait (Lin, Yang, Cheng, and Wang, 2006; Savin, Morton, and Jill, 2014). Previous non-weight bearing mirror therapy studies have demonstrated significant improvements in walking velocity but a key problem with the interpretation of these results is that it is not clear whether these studies assessed self-selected or fast velocity and all were performed in a static semi-seated position (Ji, Cha, Kim, and Lee, 2014; Ji and Kim, 2015; Salem and Huang, 2015).

Walking endurance increased 33.5 m at post-training assessment and reduced to 22.2 m above baseline at follow-up assessment. Although the post-training increase in walking endurance falls marginally below the proposed MDC and MCID thresholds for individuals following stroke, the initial increase in endurance and approximate maintenance at follow-up assessment is promising. To the authors knowledge this is the first lower limb mirror therapy report to show improved walking endurance and the result shows that despite the addition of mirror therapy to treadmill training, potential gains from the established intervention are not affected.

There are some limitations to this case report. Confirmation of the efficacy of this new combination therapy is impossible based on a single case and thus, studies with larger samples and implementation of more stringent design, such as a randomized controlled trial are needed. Potential increased ability of our participant to activate muscles in the affected limb as result of motor execution restoration when walking during daily activities could have led to increased activity levels during the 6-month interval. However, no assessment of this was carried out. No assessment of gait asymmetry took place and future studies should investigate the effects of mirror therapy and treadmill training on this area. The fact that the number of therapy sessions was limited to 12 could have influenced the effectiveness of the treatment and it is recommended that future studies in this area explore varying treatment dosage. As outcome assessments were limited to one assessment at each of the three time points (i.e. baseline, post-intervention and follow-up), it is possible that additional assessments could increase accuracy of patient scoring.

This case report is the first of its kind to design a custom mirror apparatus that can be used on a treadmill and combine the established rehabilitation intervention of treadmill training with mirror therapy. Results from our study demonstrate that for a patient with chronic stroke, this new approach has the potential to affect meaningful change in muscle tone, motor function and self-selected walking velocity. It has also demonstrated improvements in walking endurance. The proposed combined intervention is feasible for therapists to provide a protocol for patients involving mirror therapy that maintains weight bearing during goal orientated treadmill walking. A randomized controlled trial is currently underway to establish whether similar improvements can be observed in a larger group of individuals following stroke.

## Declaration of interest

The authors declare no conflicts of interest.

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