

CALIFORNIA STATE UNIVERSITY, NORTHRIDGE

Effects of Treadmill Walking With Visual Feedback on Gait Outcomes in People Post Stroke

A thesis submitted in partial fulfillment of the requirements

For the degree of Masters of Science

in Kinesiology

By

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## DEDICATION

This work is dedicated to my family who has supported me and encouraged me to complete this program. To my parents and my brothers who have raised me and impacted my life so much; you have all prepared me for the challenges ahead. I wouldn't be the person I am today if it weren't for Gloria Piceno and Nino Galindo. Adrian and Aaron, thank you so much for the phone calls and the sibling moments we have shared over the last three years. Thank you for minimizing my struggle and giving me that harsh love to keep me going. I have felt the love and support of my whole family throughout these last three years. Thank you to my extended family who didn't always know what I was doing, but always found a way to encourage me.

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## Abstract

Effects of Treadmill Walking With Visual Feedback on Gait Outcomes in People Post Stroke

By

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Master of Science in Kinesiology

Compromised gait is prevalent in people post stroke. Gait training is one of the major components in stroke rehabilitation. Treadmill walking is often used for gait training in people post stroke. Limited studies have examined the effects of a visual feedback system in combination with treadmill-based gait training.

Purpose: The purpose of this study was to investigate the effects of treadmill walking with real-time visual feedback on gait outcomes in people post stroke.

Methods: 6 participants (age 59.3 $\pm$ 12.34 years old) participated in this case study. They were assigned to either visual feedback gait training group or control based on initial walking speed. Both groups performed 30 minutes of treadmill walking, three times a week, for eight weeks. The control group performed the training with no visual feedback (NVF). The experimental treatment group received real-time visual feedback (VF) on a LCD screen which displayed foot placement and prompts. Data collection was performed before and after the eight weeks, as well as four weeks after the completion of intervention. The kinematic and spatiotemporal variables were recorded and analyzed by using a 3D motion analysis system. (VICON Bonita System). Data process and analysis was performed using VICON Polygon software.

Results: Group averages demonstrated an increase in walking speed and cadence in the VF group. The VF group demonstrated an increase of 11.7% in cadence of the AF and NAF limb. Walking speed of the VF group increased by 21.7% from .95m/s to 1.16m/s. NVF group revealed no notable change in spatiotemporal, or kinematic variables. Neither VF nor NVF group demonstrated notable changes in the kinematic values or gait symmetry.

Conclusion: The findings indicate that gait training with visual feedback can be more effective in improving gait spatiotemporal values than conventional treadmill walking.

## **Introduction**

Stroke occurs when blood flow to the brain is interrupted by either a block (Ischemic) or a bleed (Hemorrhagic). This interruption causes brain cells to die and in turn causes detriments in the cognitive as well as motor domain. Gait deviation is common in individuals post stroke. Stroke occurs when a blood vessel to the brain is blocked (ischemic) or broken (hemorrhagic). This causes a lack of oxygen within the brain, as well as damage to the brain. This damage typically causes hemiparesis of the body which affects the body unilaterally. Characteristics of hemiparesis include increased spasticity, reduction in strength and decrease in flexibility on the affected side (Chen et al., 2005). The spasticity increase and flexibility decrease results in a lack of active and passive range of motion; while strength weakness often results in a reduction of force. These factors change the capability of an individual to walk and often result in an asymmetrical gait. Change in gait of people post stroke can be due to "difficulty moving the body over an unstable limb" (von Schroeder et al., 1995). Several studies have investigated methods of visual feedback in an effort to improve gait in various methods and different populations (Almeida et al., 2012; Mirelman et al., 2010; Walker et al., 2000). Experiments with people from healthy populations, people with Parkinson's Disease and people post stroke, as will be discussed later.

Compromised gait is prevalent in people post stroke. Gait training is one of the major components of stroke rehabilitation. Gait is a significant indicator of independent functions and ability to perform activities of daily living. Several studies have approached gait training for people post stroke in different ways (Chen et al., 2005; Olney et al., 1996; Langhammer et al., 2012; Teasell et al., 2003). No other studies have used real time visual

feedback in combination with treadmill training. Visual feedback in this study is defined as the visual representation in the form of a range. This range demonstrates the optimal foot strike location of the participant on the screen attached to the treadmill. Assuming that the motion analysis system (VICON, Oxford, UK 2010) is able to accurately and reliably detect the kinematic variables and the visual feedback presented will be accurate, this study will provide accurate scientific results. Limitations will include the geographical location in which participants will be found as well as the amount of time post stroke. People post stroke often experience the greatest improvement in their first few months after the stroke. To avoid any abnormal gait increases in the participants, the first six months are avoided. Because gait analysis of the participants requires unassisted walking, delimitation includes the ability to walk unassisted.

The purpose of this study is to investigate the effects of treadmill walking with real-time visual feedback on gait outcomes in people post stroke. This study can provide scientific evidence about visual feedback that can change rehabilitation efforts and methods when working with individuals post stroke. This type of training can be long-term and cost-effective alternative that is easily implemented into rehabilitation for people post stroke.

## Literature Review

### Gait in people post stroke

People post stroke often have a very similar gait pattern and the specifics of their deviations have been well documented. Chen et al. (2005) distinguished compensatory patterns as well as swing and stance variations between people post stroke and people of a healthy population. Various gait deviations have been monitored and reported using a standard measurements of the Qualisys Motion Analysis System. Chen (2005) directed 6 subjects post stroke and 6 healthy subjects to walk on a treadmill while recorded by the motion analysis system. Post stroke subjects were instructed to walk at a comfortable pace while the healthy matched control group were instructed to walk at the same pace of their matched post stroke subjects. The results show compensatory actions including hip-hiking, circumduction, decreased toe-off, and excessive trunk motion during the initiate of swing-phase. There was also a greater step width, and step length asymmetry in the people post stroke. In this study, paretic and non-paretic leg comparisons during walking were measured. On average the paretic limb was involved with increased swing time and trunk energy cost when compared to the non-paretic leg. Paretic leg also had a decreased kinetic energy at toe-off and peak knee flexion in swing phase when compared to the non-paretic leg. It is clear with these results that people post stroke have an asymmetrical gait.

Von Schroeder (1995) also performed a study to assess gait parameters of people post stroke with a much larger sample size. 49 ambulatory people post stroke and 24 age-matched controls walked down an 18-meter hallway. Their gait was monitored by a portable stride analyzer of foot pads which were located in each shoe and connected to a belt that the subject wore during the trial. The data was recorded and saved in the belt until

analyzed. Gait velocity, cadence, stride length, double limb support, single leg support, and gait cycle were recorded in this study. The results indicated that hemiplegic subjects experienced a significantly slower gait ( $p < .0001$ ), decreased cadence ( $p = .005$ ), increased stance phase ( $p = .01$ ), increased single limb support ( $p = .04$ ), and increased gait cycle ( $p = .02$ ). Trends of increased double limb support time, and shorter stride length in the non-affected leg were reported.

Olney (1996) conducted a systematic review involving hemiplegic gait characteristics. They analyzed several different articles and found tendencies in kinetic, kinematic, spatiotemporal, biomechanic and electromyographic variables. Only the kinematic and spatiotemporal variables are relevant for this review. Previous research found notable spatiotemporal differences including increased stance phase, longer stance phase on the unaffected side, and an increase in double support compared to an able-bodied individual. Kinematic variations included hip, knee and ankle excursion throughout the gait cycle. Foot strike involves decreased hip flexion with an increase in knee and plantar flexion, compared to able-bodied individuals. Swing phase involves decreased hip and knee flexion, with an increase in plantar flexion. Finally, toe-off consisted of decreased hip flexion, decreased knee flexion and decreased plantar flexion (Olney et al., 1995). This study reiterates the lack of symmetry in people-post stroke while providing more information about alternate variables.

Another article by Hsu (2003) analyzed impairments that influenced gait asymmetry and velocity of people post stroke. Specializing in the mild to moderate stroke is relevant to the future study because subjects will need to walk independently. 26 post stroke subjects participated in this descriptive analysis (Hsu et al., 2003). Variables in this

study included isometric and isokinetic torque measurements, levels of spasticity, gait velocity and spatiotemporal asymmetry. The gait velocity and spatiotemporal asymmetry was measured using the GaitMat II. Significant differences in single leg support phase ( $p < .01$ ) and step length ( $p < .05$ ) indicate asymmetrical gait pattern of an individual post stroke.

While these four articles demonstrate frequent gait deviations in people post stroke, they all have limitations. Chen (2005) found strong deviations similar to Olney (1996), von Schroeder (1995) and Hsu (2003), but the sample size was much smaller. Small sample size is a limitation of Chen's research. Olney (1996) reviewed previous articles and a large spectrum of results including biomechanical, electromyographical, kinematic and kinetic. Hsu (2003) and von Schroeder (1995) both had a much larger sample size of subjects post stroke as well as a larger control group.

### Gait training

Gait is most commonly evaluated using symmetry, speed of an individual's gait and 3-dimensional motion analysis system (Lewek et al., 2012). These tools are used to define the kinetic and kinematic variables of an individual's gait. Increased walking speed is often indicative of a more sophisticated walking pattern in individuals post stroke. Symmetry is an indicator of a refined gait because most stroke-survivors have a very asymmetrical gait. (Lewek et al., 2012). It is possible to quantify the symmetry of an individual's gait and speed by the same standard by using a motion analysis system such as the VICON. By recording a 3-dimensional model, it is possible to observe small changes during data collection. The spatiotemporal and kinematic variables are quantified when utilizing a

three-dimensional analysis program, providing detailed information about the movement. Values established during data collection can be compared between and within trials of each participant.

In an effort to increase the symmetry of gait in people post stroke, many practitioners focus on the paretic side. Treadmill training is a very popular method when working with individuals post stroke. Several studies have used a treadmill with various speeds (Pohl et al., 2002), visual feedback (Kim et al., 2012), and body weight support (Chen et al., 2005). These studies all show that treadmill training can improve gait in either speed, symmetry, or both.

Langhammer and Stanghelle (2009) found that treadmill walking was a more effective tool than over ground walking in regards to the functionality of the participants' gait. Treadmill walking showed improved walking speed and distance when compared to walking outdoors. Functionality was determined using the Motor Assessment scale, 6-Minute Walk Test and a timed 10-meter walk with sensors on their feet. A total of 39 participants were able to complete the randomized control study. Both groups were instructed to walk at a comfortable pace five days a week. Their results indicated an increase in step length of both affected and non-affected side with a high degree of gait symmetry during treadmill walking. Treadmill walking is shown to improve symmetry more than over-ground walking in people post stroke which is why over-ground walking will not be included in this study.

Roerdink (2007) evaluated gait patterns with acoustic feedback while treadmill walking in people post stroke and a control group. The control group included 9 healthy age matches and the other group included 10 subjects post stroke. All subjects were

instructed to walk on a treadmill while a cluster of markers were attached and monitored by a motion analysis system. Subjects also listened to acoustic cues through a headset that was worn throughout treadmill walking. The study found that acoustic feedback had a direct impact on the heel strike and step symmetry of people post stroke. Complete statistical analysis could not be performed in this study because of the small sample size, however paired t tests were utilized to distinguish the difference between the controls and post stroke subjects.

### Visual feedback training

Previous studies have shown that visual feedback is a viable method to train for gait symmetry. Kim et al. (2012) reported that visual feedback has a significant impact on the step length of 12 healthy individuals on a treadmill. This study focused on manipulating visual feedback by falsely elongating the right step length, and observed the action taken by the participant. During the first and last minute, visual feedback provided an accurate depiction of current step length while treadmill walking. After the completion of the first minute, feedback was slowly manipulated in 30-second intervals over an 8.5-minute training session. Manipulation increased between each 30-second interval until the 4<sup>th</sup> minute of training, manipulation then decreased by the same method to avoid detection. Peak manipulation occurred during the first 30 seconds of minute 4. As the visual feedback was manipulated away from actual symmetry, the action taken by subjects created an asymmetrical gait. Perception of a longer right stride length led to an actual reduction of right stride length in an effort to maintain symmetry. This result shows that visual feedback does indeed have an immediate effect on step length. Shortcomings of this article include

the lack of lasting effects, healthy population subjects, and a lack of 3-dimensional gait analysis.

A study by Almeida and Bhatt (2012) have investigated the effect of visual feedback on individuals with Parkinson's Disease (PD). This randomized control study trained 42 subjects 3 times a week, for 6 weeks either treadmill or over ground walking. Subjects were separated into two groups, a treadmill walking group and an overground walking group. Transverse lines were present in both environments to test the effect of optic flow. Treadmill training included transverse lines taped to the floor where the participants could view. They found that individuals with PD were able to increase their stride length in both groups. The results indicated that optic flow is not required to establish short term or long lasting benefits in people with PD.

Both Kim (2012) and Almeida (2012) utilized manipulated visual feedback with healthy subjects as well as the individuals with Parkinson's Disabilities, respectively. Lack of visual feedback intervention with people post stroke indicates the need for further study.

### Conclusion

Gait training is clearly a large part of rehabilitation for people-post stroke and extensive studies have taken place using various methods (Chen et al., 2005; Hsu et al., 2003; Langhammer et al., 2009; Lewek et al., 2012; Manning et al., 2003; Pohl et al., 2002; Roerdink et al., 2007; Teasell et al., 2003 and Walker et al., 2000). This research indicated that gait asymmetry is an issue among people post stroke and that visual feedback could be a viable alternative for rehabilitation (Chen et al., 2005; Hsu et al., 2003; Lewek et al., 2012; Kim et al., 2012). Although there are numerous studies that have investigated the

effects of gait training, visual feedback and treadmill walking, there is no study that combines these three elements with people post stroke. In addition, some of the studies analyze gait of their subjects lacking three-dimensional analysis. The effect of treadmill walking is significant enough to encourage treadmill training (Langhammer et al., 2012). Visual feedback integration in exercise protocol was impactful with different populations and results encourage future implementation in more studies (Kim et al., 2012; Mirelman et al., 2010; Almeida et al., 2012).

In theory, these studies lay ground work to attempt a study with visual feedback and treadmill walking in people post stroke. It is hypothesized that people post stroke will improve gait symmetry and overall outcomes after an 8-week intervention. The purpose of my study is to investigate the effects of visual feedback on gait outcomes in people post stroke.

## **Methods**

### Participants

Six individuals diagnosed with Stroke were recruited for this study. They were recruited from support groups and through word of mouth. Prior to participation, all individuals obtained medical clearance and signed an informed consent form. Participant inclusion criteria included: diagnosis of stroke; occurrence of stroke more than six months prior; age over 18; and ability to follow instruction in English. Participant exclusion criteria included: fall risk; visual impairment; concurrent participation in another research study; and/or additional musculoskeletal or neurological condition that could inhibit gait training.

### Research Setting and Design

This study was performed at the Center of Achievement located at California State University, Northridge. Both the intervention and data collection equipment were housed in this facility. Research design was a quasi-experimental intervention. Participants were placed into the Visual Feedback (VF) Group, or the Non-Visual (NVF) Group based on walking speed. This separation allowed for both groups to begin with a similar walking speed.

### Research Variables and Instrumentation

The independent variable was visual feedback while the dependent variables included spatiotemporal (cadence and stride length) and kinematic (excursion of the hip, knee and ankle joints) components. These variables were monitored and recorded using the

VICON Bonita System (VICON, Oxford, UK, 2010). Treadmill (Biodex Gait Trainer II Treadmill) was used for the 8-week intervention.

### Intervention Protocol

Both groups walked on the Biodex treadmill for 30 minutes a day, 3 days a week, for 8 weeks. The VF group viewed a screen provided on the treadmill. This screen provided a visual representation of actual step length and optimal future step length dependent upon the participants' height, age, and previous steps. The NVF group did not view this screen and walked on the treadmill for the same amount of time. Each session the participants were encouraged to improve their walking speed when comfortable. The participants were allowed to increase or decrease speed as needed to complete the entire 30-minute session.

### Data Collection Procedures

The initial data collection began with an explanation of the data collection process. At this point in time the participant completed paperwork and turned in a completed medical release form. After all paperwork was completed, the data collection took place. For all three data collections, participant was instructed to wear appropriate clothing so that the researcher could properly take anthropometric measurements and attach markers. 15 In this study 15 markers were used with the Plug-In-Gait model. Once these markers were attached, the participant walked through a 10-meter pathway while monitored by the VICON cameras. There were 3 trials at a comfortable speed and 3 trials at a fast speed. Rest and water were provided for the participant, as needed. After the completion of the initial data collection, the participant walked on the treadmill for 5 minutes to become

familiar with the machine. After the completion of the post and follow up data collection, the participant was free to leave.

### Data Analysis

Data collected using the VICON system was processed using Polygon software, and was then extracted into Microsoft Excel for further analysis. Changes in overall values and symmetry were calculated at all three data collection points; pre, post, and follow up. Data was recorded and compared within and between groups. Between groups was analyzed using averages and percentage change. Spatiotemporal values included walking speed, cadence, and stride length. Kinematic values included the excursion of hip, knee, and ankle joints. Both spatiotemporal and kinematic values were used to calculate gait symmetry. Symmetry at each of the joints was calculated by dividing the excursion value of the Affected (AF) side by the Non-Affected (NAF) side, with the goal being “1”. A value greater than one is indicative of a higher value of the affected limb, and a value less than one is indicative of a higher value of the non-affected limb.

## Results

### Participant #1

#### *Spatiotemporal Values*

Participant #1 was a 58-year-old female 11 months post stroke and she was assigned to the NVF group. Walking speed showed no change from pre to post measure (Figure 1.1). Stride length of the affected and non-affected leg both did not change throughout the treatment, or follow up (Figure 1.1). Cadence did not change after the 8-week treadmill training and increased from post to follow up (Figure 1.1). Follow up did increase from 88.9 steps per minute (s/m) to 106 s/m.

#### *Kinematic Values*

Changes were seen in the non-affected (NAF) hip, affected (AF) knee, and NAF ankle. There were no changes in AF hip, NAF knee and AF ankle excursion. The NAF hip increased from 22.85 to 29.65 degrees from post to follow up measure. AF knee showed an increase from 14.53 to 19.69 degrees from post to follow up. NAF ankle decreased from 27.9 to 20.37 degrees after the 8-week intervention and an increase to 38.9 degrees at the final measure.

#### *Gait Symmetry*

Symmetry among cadence and stride length displayed little to no change throughout all three measures (Figure 1.3). Hip and knee symmetry did not change (Figure 1.3). Ankle symmetry increased slightly from an initial .50 to .67 after the 8-week intervention. At follow up, ankle symmetry decreased to .31 (Figure 1.3).

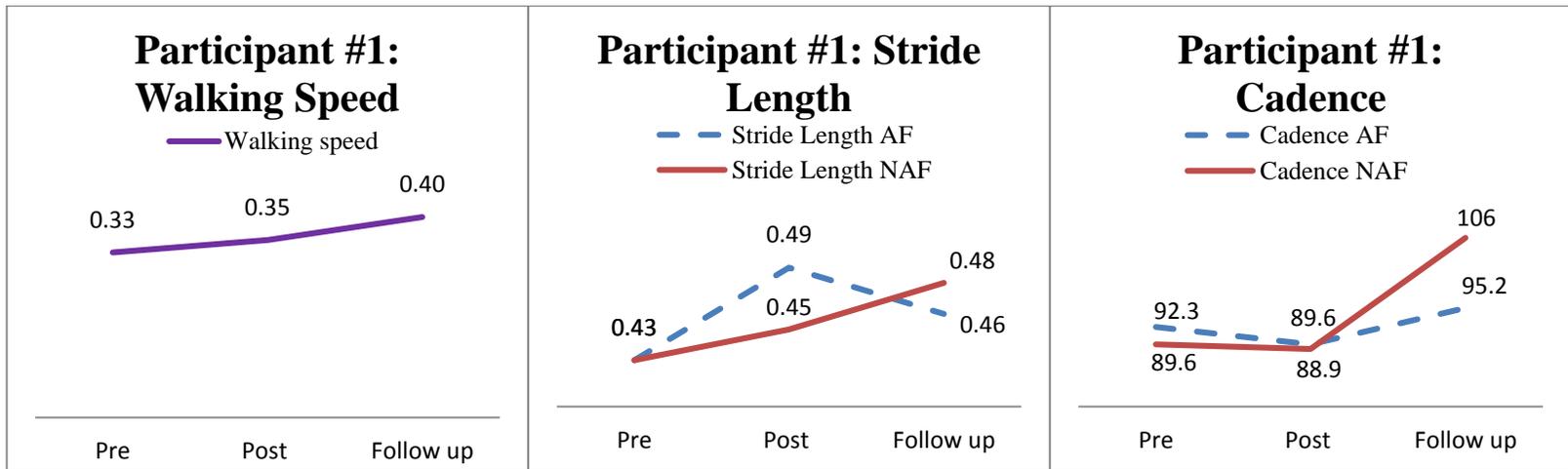


Figure 1. 1- Participant #1 Spatiotemporal values.

Walking speed is in meters per second. Stride length in in meters. Cadence is in steps per minute.

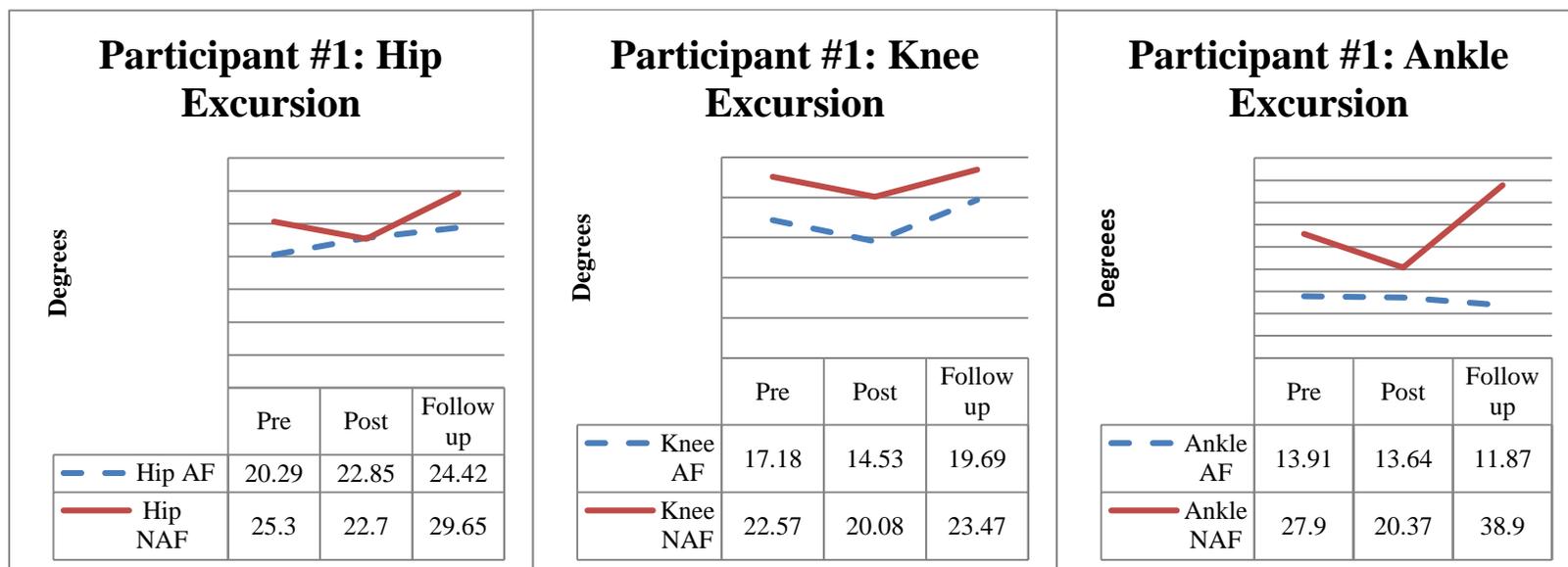


Figure 1. 2- Participant #1 Kinematic values.

All measures are in degrees.

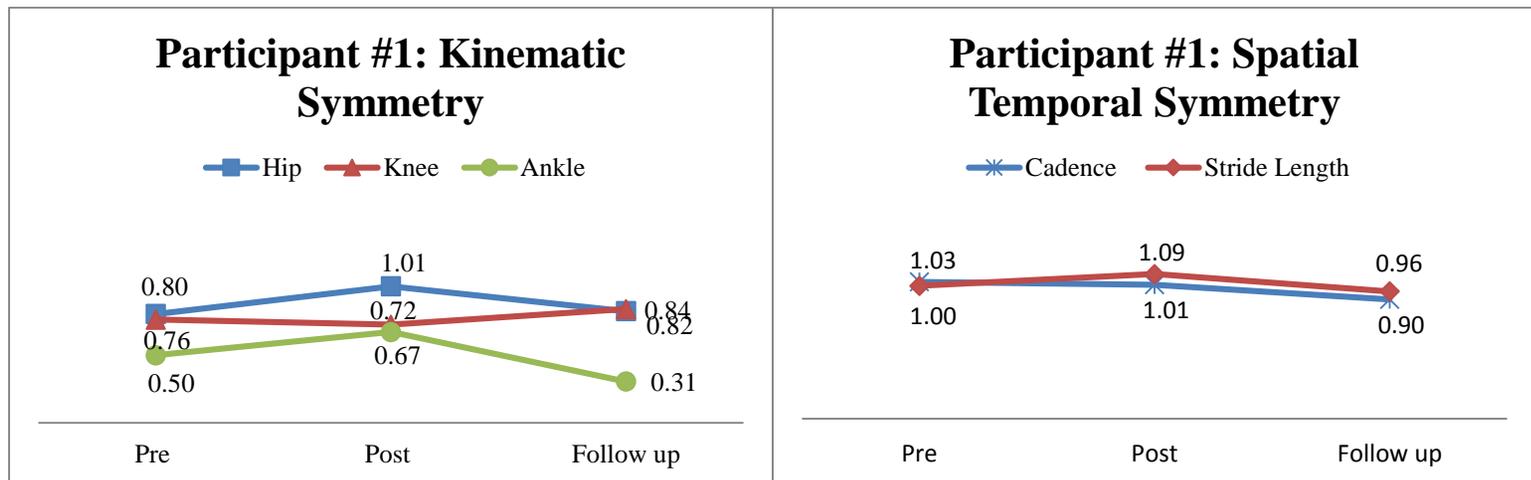


Figure 1. 3- Participant #1: Gait Symmetr

## Participant #2

### *Spatiotemporal Values*

Participant #2 was a 71-year-old male 60 months post stroke and he was assigned to the NVF group. Walking speed changed from an initial 1.02 m/s to 1.07m/s at post and 1.1m/s at follow up (Figure 2.1). Stride length of the AF and NAF leg did not change (Figure 2.1). Cadence showed a 3% decrease in the NAF limb after the 8-week intervention. This change was not sustained at follow up, as the measure returned to the initial measure. (Figure 2.1). AF limb showed no change in cadence.

### *Kinematic Values*

Hip excursion values of the AF limb increased and NAF limb decreased from pre to post data collection (Figure 2.2). Initial excursion of the AF hip was 36.6 degrees, and increased to 60.2 degrees after the 8-week intervention. After the 4-week follow up, this increase was not maintained. AF knee excursion increased from 35.8 degrees to 43.3 degrees at post data collection (Figure 2.2). Change was sustained after the 4-week follow up. NAF knee excursion increased from 35.8 to 51.52 degrees after the 8-week intervention. The effects of the intervention did not persist at follow up as the excursion declined to 42.06 degrees. Kinematic excursion of the NAF ankle displayed improvement from 24.5 to 30.2 degrees (Figure 2.2). All other ankle kinematics did not change.

### *Gait Symmetry*

Stride length demonstrated a small increase (Figure 2.3). Cadence symmetry did not change (Figure 2.3). Kinematic symmetry of the hip changed from .69 at the initial data collection to 1.18 at the post data collection (Figure 2.3). This change was not sustained as the follow up data collection indicated a decline to .64 (Figure 2.3). Knee symmetry declined from 1.06 to .84 from pre to post and follow up was recorded at 1.11(Figure 2.3). Excursion symmetry of the ankle indicated a negligible decline (Figure 2.3).

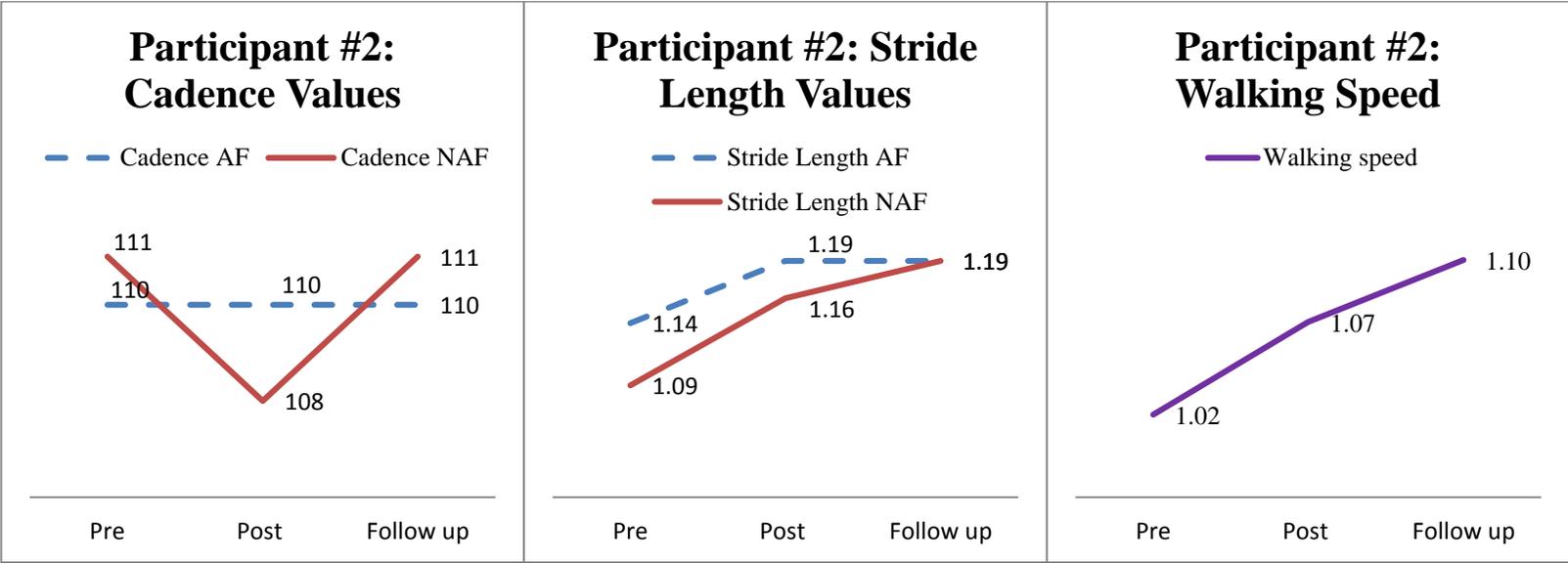


Figure 2. 1-Participant #2: Spatiotemporal values

Walking speed is in meters per second. Stride length in in meters. Cadence is in steps per minute.

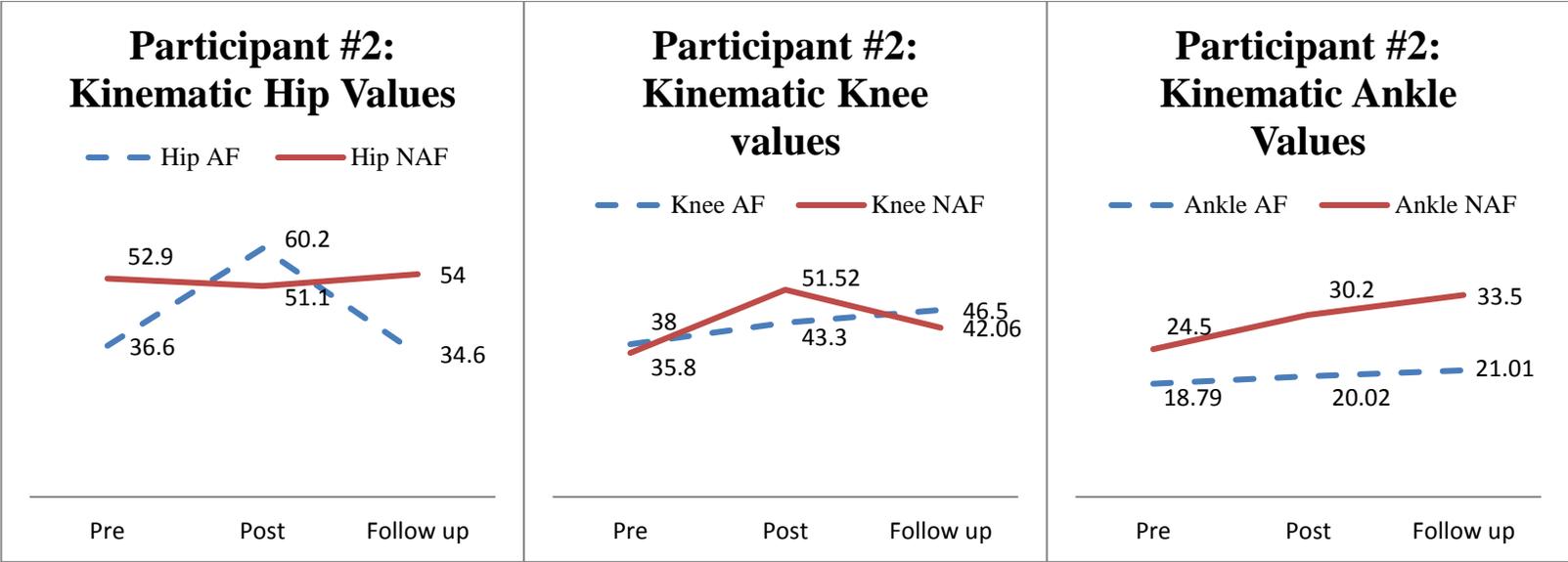


Figure 2. 2- Participant #2: Kinematic values

All measures are in degrees.

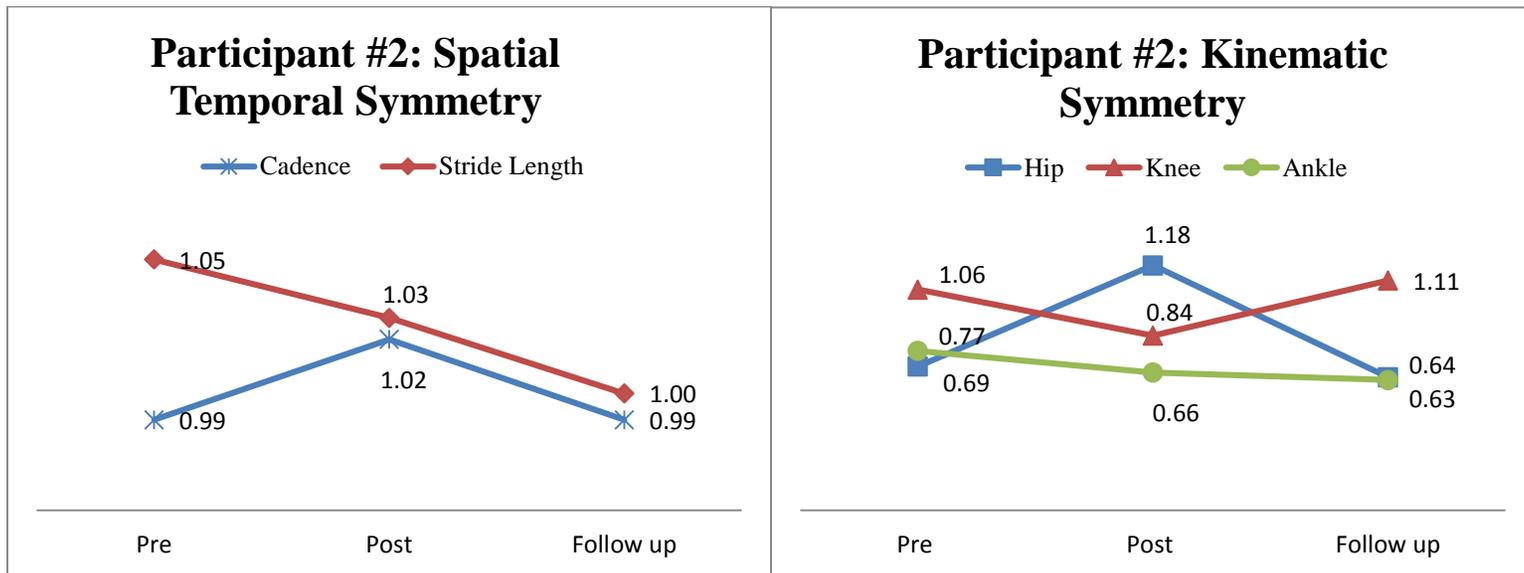


Figure 2. 3-Participant #2: Gait Symmetry

### Participant #3

#### *Spatiotemporal Values*

Participant #3 was a 63-year-old male 11 months post stroke and he was assigned to the VF group. Initial walking speed of .65 m/s increased to .83 m/s after the 8-week intervention (Figure 3.1). Walking speed at the follow-up point increased further to .93 m/s. Cadence increased for both the AF and the NAF limbs from pre to post and post to follow-up measure (Figure 3.1). The AF leg showed an increase from 103 (s/m) to 112s/m at post and another increase to 128 s/m at the follow up. NAF leg displayed a positive trend was an initial cadence of 104 s/m, and an increased to 109 s/m at post data collection. Stride length values increased in both the AF and NAF leg from pre to post, .77m to .92m and .73m to .87m, respectively. Follow-up showed a slight decrease in the AF to .88m while the NAF leg showed no change (Figure 3.1).

#### *Kinematic Values*

Hip excursion values did not change (Figure 3.2). AF knee excursion decreased from 35.07 degrees at pre data collection to 24.04 degrees at post data collection (Figure 3.2). Follow up data of the AF knee increased to 34.67 degrees. NAF Ankle excursion decreased from 29.6 degrees to 19.73 degrees after intervention. Excursion of the NAF ankle slightly increased to 21.06 degrees at follow up data collection (Figure 3.2). AF ankle excursion did not show visible change, but did effect the symmetry of the ankle (Figure 3.2).

### *Gait Symmetry*

Ankle excursion displayed the greatest increase in symmetry from .57 pre to .88 post and maintained at follow up (Figure 3.3). Symmetry of stride length did not change (Figure 3.3). Cadence symmetry changed from .99 pre to 1.03 post and increased at follow up to 1.01. Kinematic excursion symmetry increased for the ankle from pre to post. Symmetry of hip excursion did not change (Figure 3.3). Knee excursion symmetry decreased from .65 pre to .44 post and later increased to .60 at follow up (Figure 3.3).

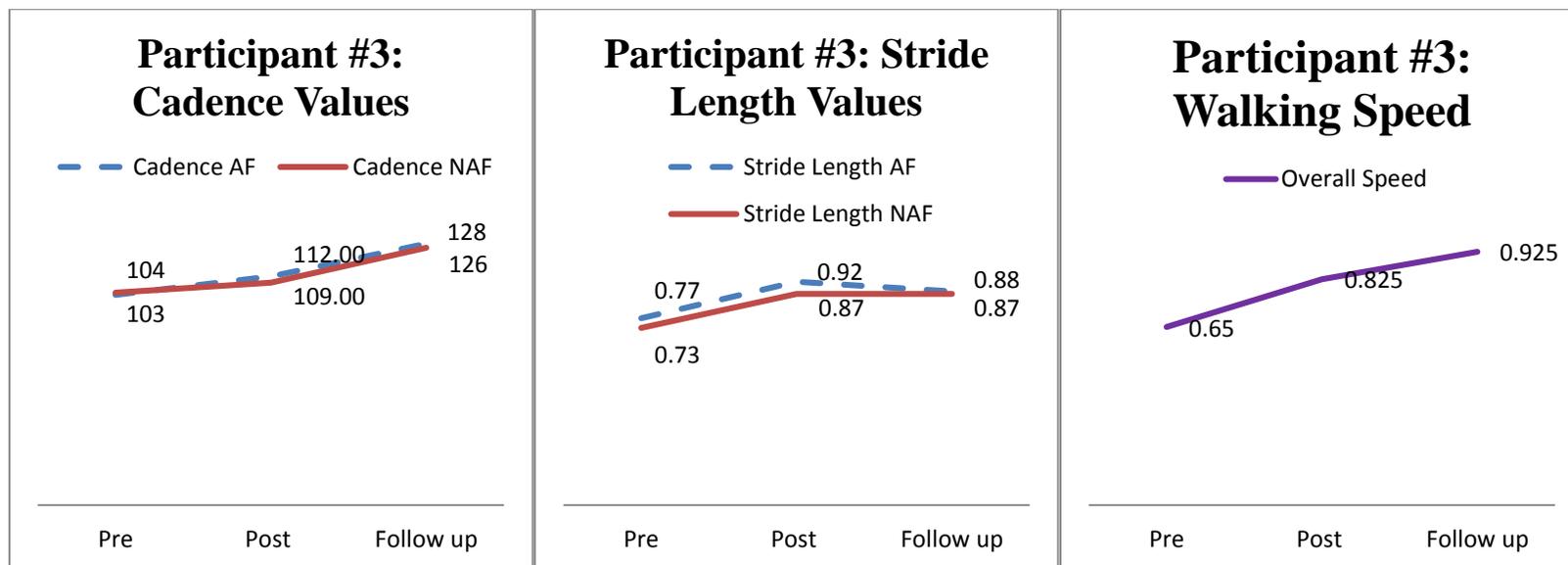


Figure 3. 1 - Participant #3 Spatiotemporal values.

Walking speed is in meters per second. Stride length in in meters. Cadence is in steps per minute.

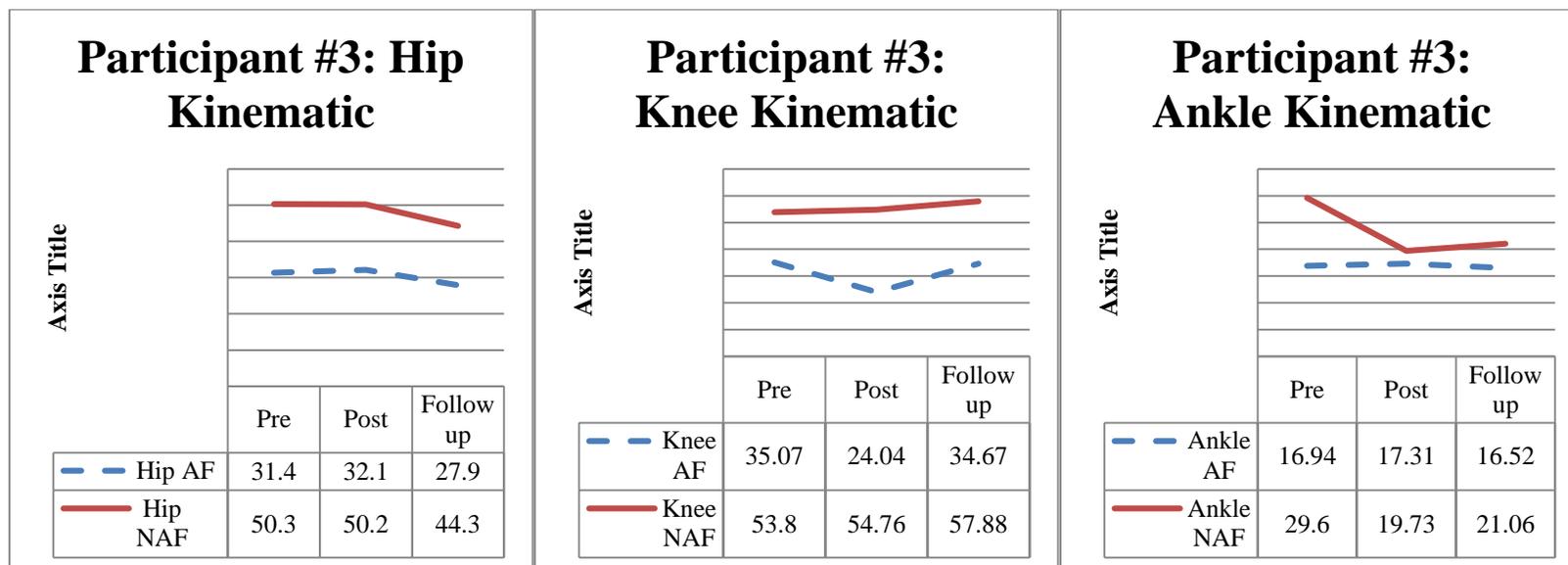


Figure 3. 2-Participant #3 Kinematic values.

All measures are in degrees.

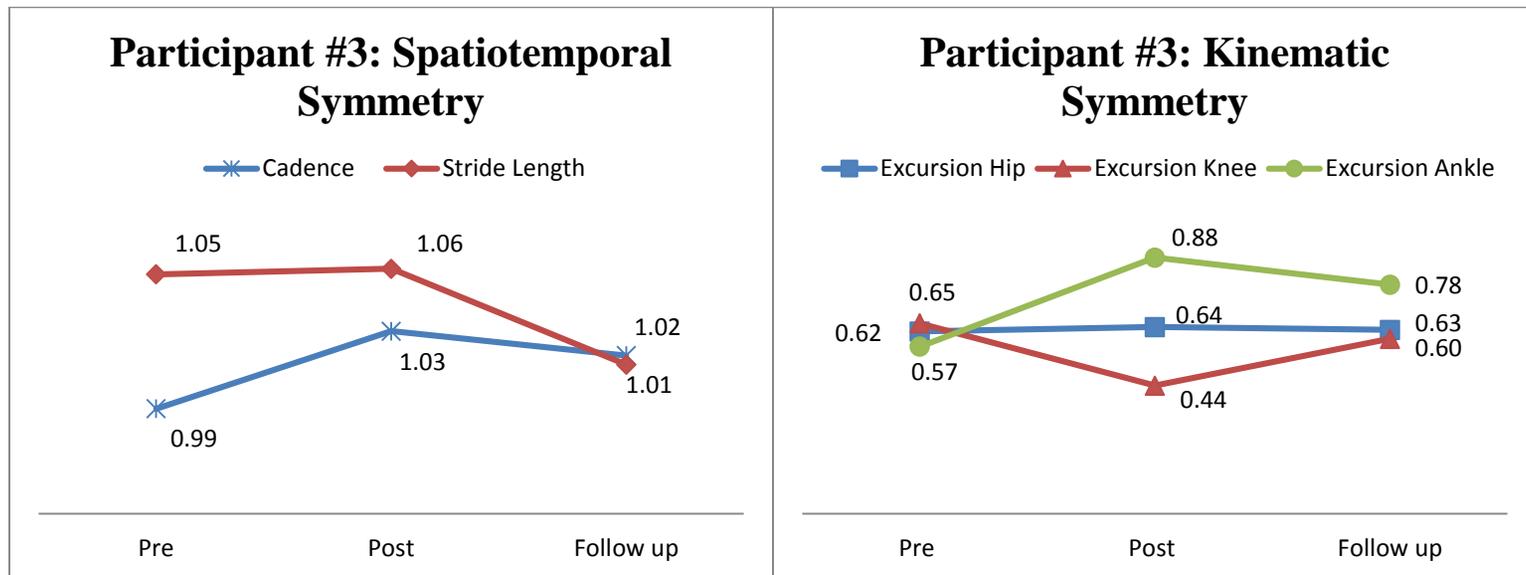


Figure 3. 3- Participant #3: Gait Symmetry

## Participant #4

### *Spatiotemporal Values*

Participant #4 was a 60-year-old female 245 months post stroke and she was assigned to the VF group. Preliminary walking speed increased from 1.0 m/s to 1.18m/s after the 8-week intervention (Figure 4.1). Walking speed at the follow up was not sustained. Cadence and stride length values increased from pre to post and were not maintained at follow up data collection (Figure 4.2). Cadence of the NAF leg was initially recorded at 105 s/m and improved to 122 s/m after the treadmill training. Follow up measure decline in the NAF cadence to 104 s/m.

### *Kinematic Values*

Kinematic excursion values decreased from pre to post in all three AF joints, and the NAF ankle (Figure 4.2). These aforementioned joints also increased the degrees of excursion from post to follow up data collection. Hip and knee values of the NAF limb increased slightly from pre to post, and later declined at the follow up measure. AF hip excursion decreased from 41.9 degrees to 36.51 after the 8-week intervention (Figure 4.2). AF knee excursion increase from an initial measure of 53.5 to 37.6 degrees (Figure 4.2). At follow up, the AF knee declined to 51.2 degrees (Figure 4.2). This change did affect knee symmetry. NAF knee excursion increased from 65.8 to 83.1 degrees, but decreased to 67.72 degrees at follow up (Figure 4.2). A decrease from 11.13 to 8.43 degrees was seen in AF excursion before and after the 8-week intervention (Figure 4.2). Follow up was recorded at 15.01 degrees.

### *Gait Symmetry*

Overall spatiotemporal symmetry decreased from pre to post, but did not maintain for the follow up (Figure 4.3). Kinematic symmetry decreased for all three joints at the completion of the treatment (Figure 4.3). At the 4-week follow up, the symmetry decreased to a value closer to the initial symmetry. Hip excursion symmetry changed from .67 to .58 after the 8-week treatment and was recorded at .74 for the follow up (Figure 4.3). Knee symmetry excursion displayed the greatest change with an pre measure of .81 and a post measure of .45 (Figure 4.3). These changes were not sustained as the follow up measure was .76 (Figure 4.3).

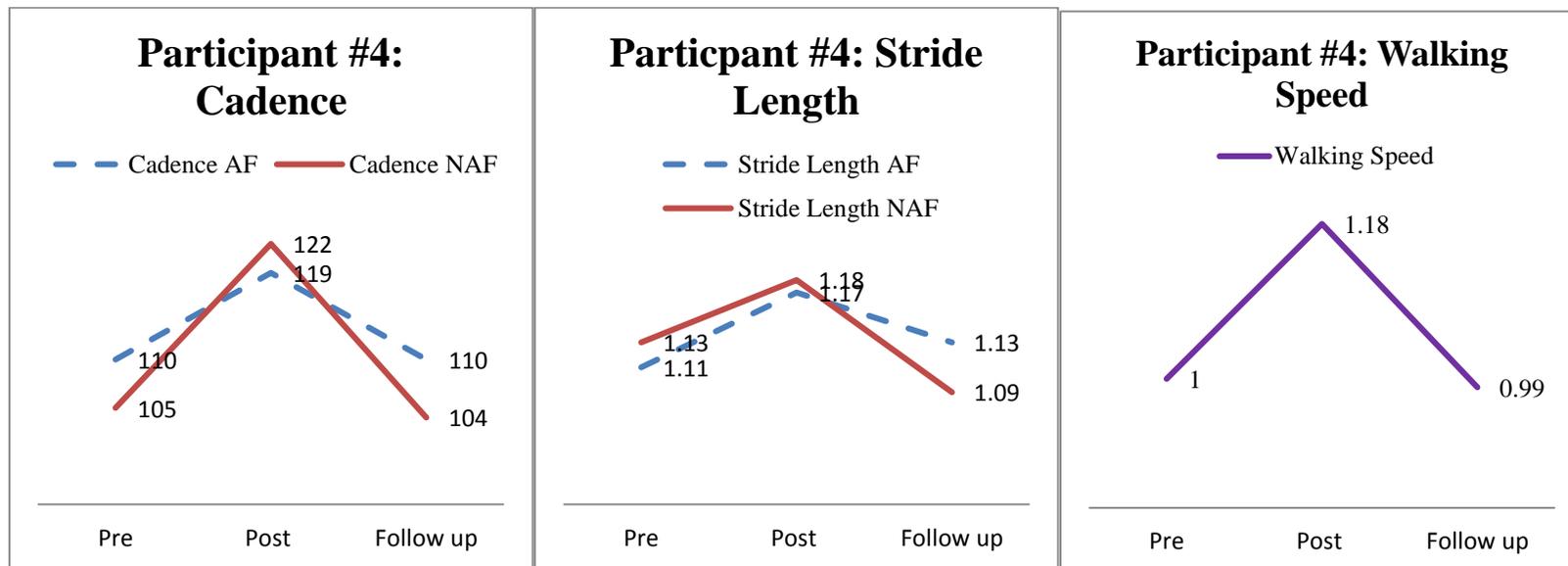


Figure 4. 1-Participant #4 Spatiotemporal variables.

Walking speed is in meters per second. Stride length in in meters. Cadence is in steps per minute.

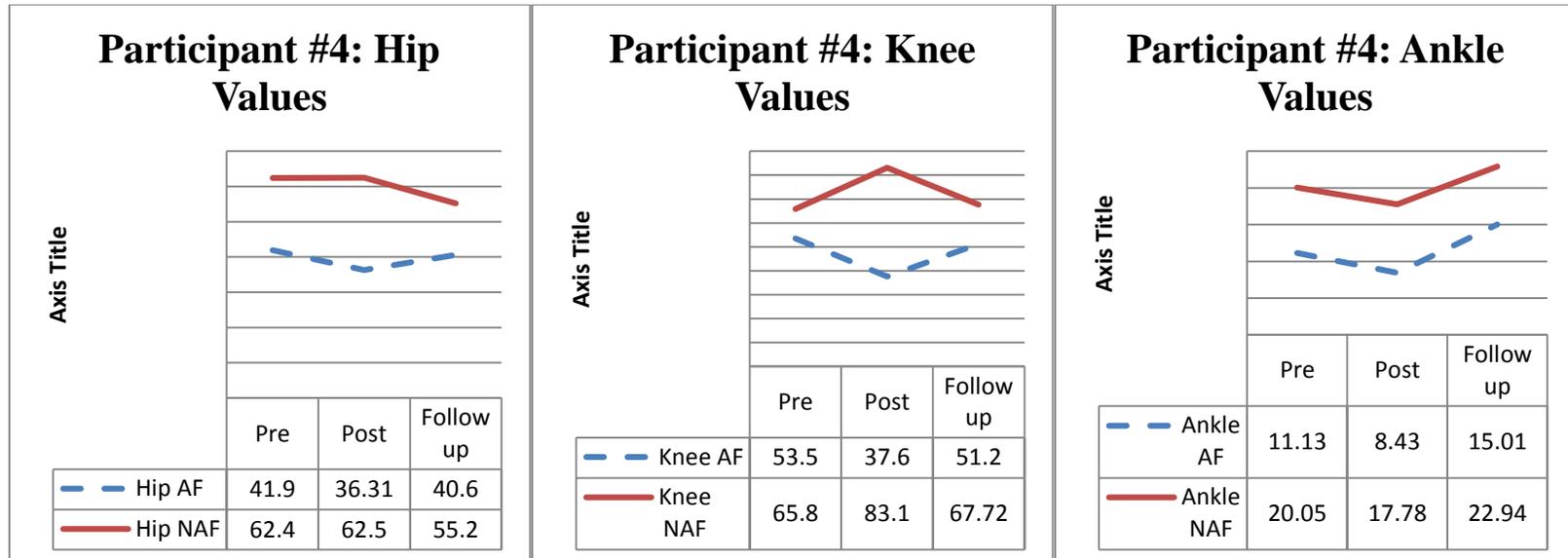


Figure 4. 2- Participant #4: Kinematic values

All measures are in degrees.

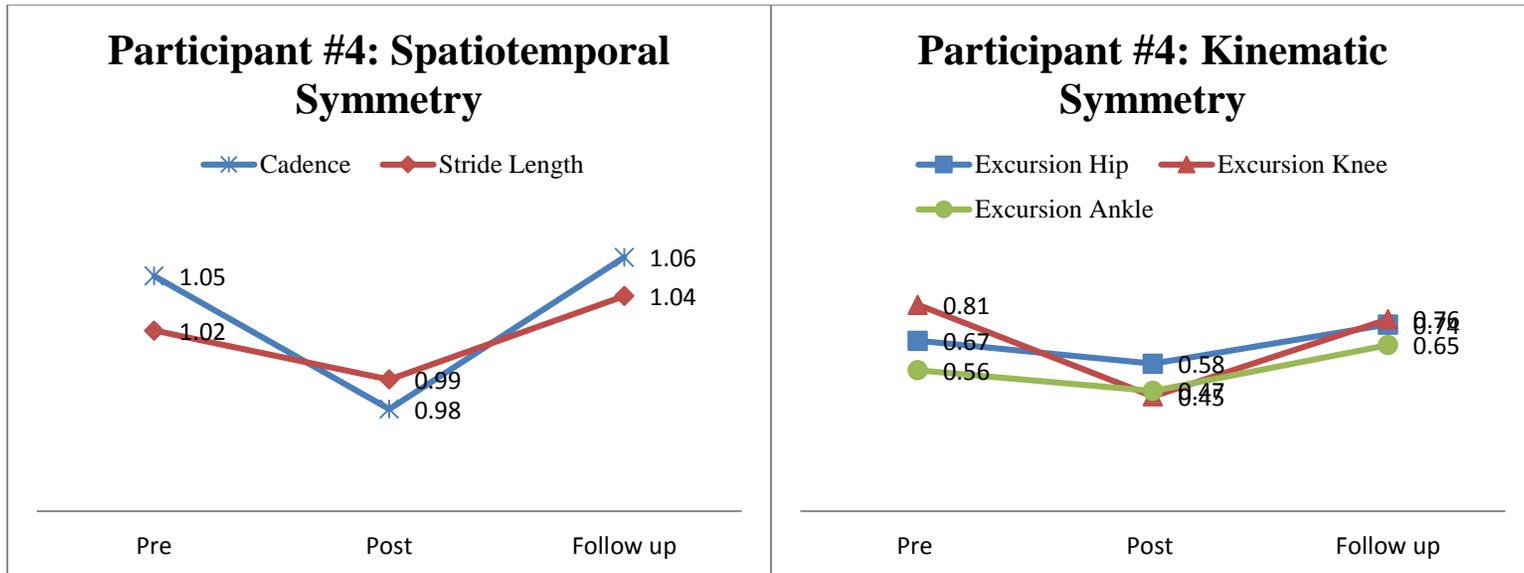


Figure 4. 3- Participant #4: Gait symmetry.

## Participant #5

### *Spatiotemporal Values*

Participant #5 was a 47-year-old male 96 months post stroke and was assigned to the NVF group. Walking speed increased from an original 1.18m/s to 1.22m/s after treatment (Figure 5.1). When measured at follow up, walking speed was 1.27m/s. There was no change in cadence or stride length of the AF and NAF side from pre to post (Figure 5.1).

### *Kinematic Values*

The greatest excursion change was seen in the AF knee and AF ankle. Hip excursion did not change throughout treatment and follow-up (Figure 5.2). AF knee excursion increased from 23.81 to 48.01 degrees after the 8-week intervention (Figure 5.2). At post data collection AF knee excursion decreased to 37.93 (Figure 5.2). NAF ankle did not change. AF ankle displayed an increase from 16.38 pre to 21.72 post and a decrease to 18.03 degrees of excursion at the follow up measure (Figure 5.2).

### *Gait Symmetry*

Symmetry of hip excursion, cadence and stride length did not change. Knee symmetry increased from .43 to .81 at the post measure (Figure 5.3). This symmetry declined with a follow-up measure of .66 (Figure 5.3). Symmetry of the ankle increased from .58 to .76 and a decline to .67 was seen at follow-up (Figure 5.3).

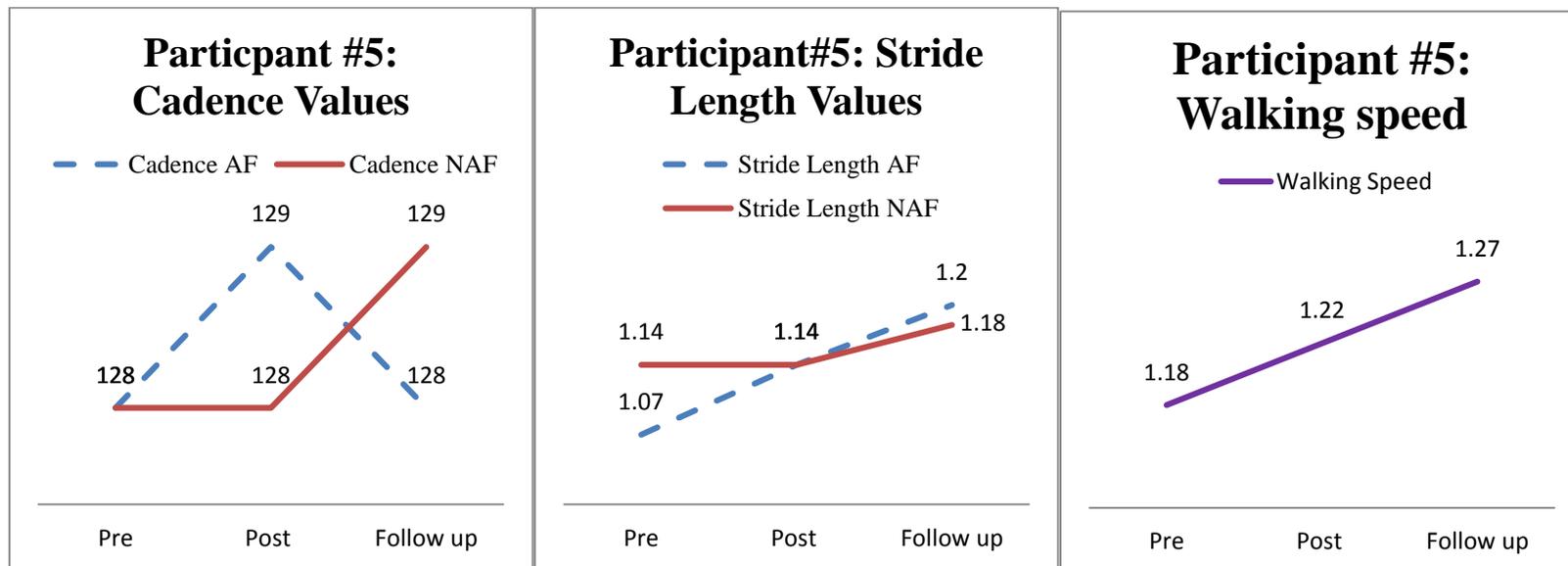


Figure 5. 1-Participant #5: Spatiotemporal Values

Walking speed is in meters per second. Stride length in in meters. Cadence is in steps per minute.

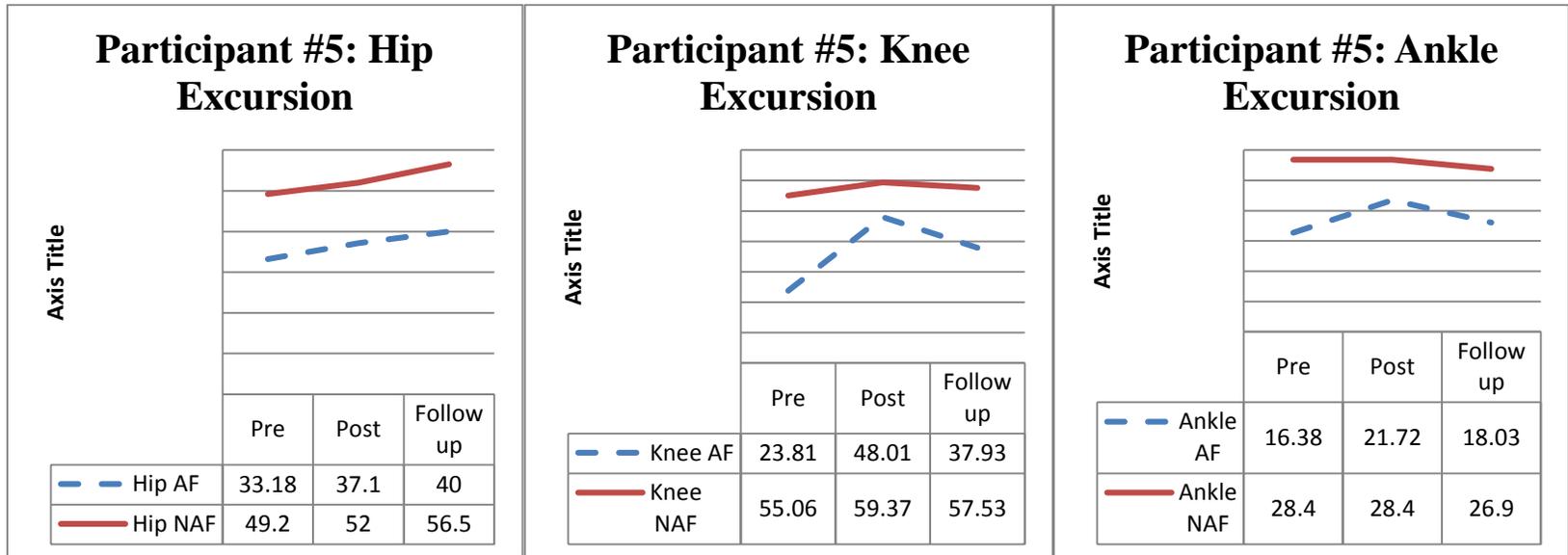


Figure 5. 2-Participant #5: Kinematic Values

All measures are in degrees.

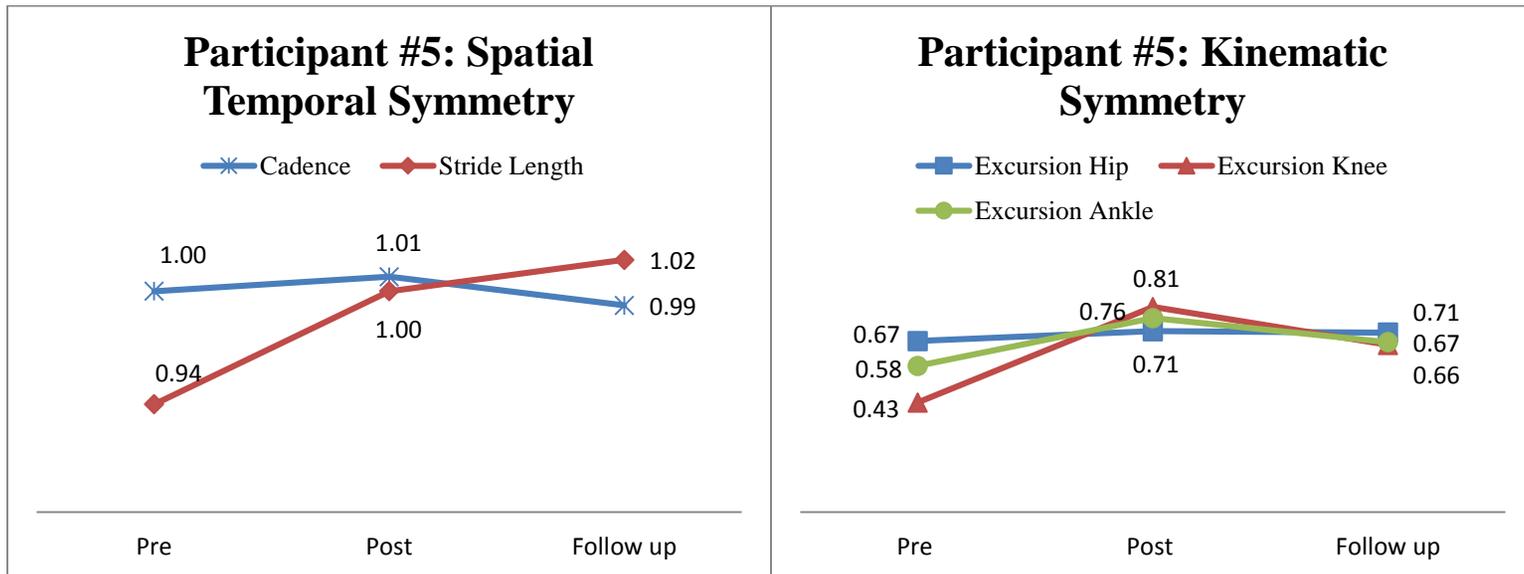


Figure 5. 3-Participant #5: Gait Symmetry

## Participant #6

### *Spatiotemporal Values*

Participant #6 was a 57-year-old female 59 months post stroke and was assigned to the VF group. Walking speed improved from 1.21 m/s to 1.47 m/s after the 8-week intervention. Walking speed was sustained at follow up with a speed of 1.49m/s (Figure 6.1). Cadence increased from 124s/m to 141 s/m on the NAF side, and 120s/m to 141s/m on the AF side (Figure 6.1). These changes in cadence were maintained and slightly improved at follow-up. Stride length showed no change (Figure 6.1).

### *Kinematic Values*

AF and NAF knee excursion changed the most. Hip kinematic excursion did not change (Figure 6.2). Knee excursion for NAF increased from 44.13 degrees to 57.70 degrees after the 8-week intervention (Figure 6.2). At the follow-up 4 weeks later, the NAF knee excursion declined to 49.17 degrees, which is an increase from the initial measure (Figure 6.2). Excursion of the AF knee also increased from 48.20 degrees to 57.94 degrees post (Figure 6.2). This increase was maintained at follow up with an excursion of 54.90 degrees. NAF ankle excursion revealed no change in excursion. Ankle excursion of AF side increased from pre to post, from 20.86 degrees to 26.4 degrees (Figure 6.2). At follow-up, this change was sustained at 23.11 degrees (Figure 6.2).

### *Gait Symmetry*

Cadence and stride length both attained symmetry after treatment with an improvement of .98 to 1.00 and .97 to 1.00, respectively (Figure 6.3). These changes did

not persist at follow-up measure. Symmetry of the hip did not change. Knee symmetry demonstrated minimal improvement from pre to post and returned to initial values after the follow-up (Figure 6.3). Kinematic symmetry of the ankle increased from .73 pre to .93 post (Figure 6.3). Follow-up was maintained with a value of .90 for ankle excursion symmetry (Figure 6.3).

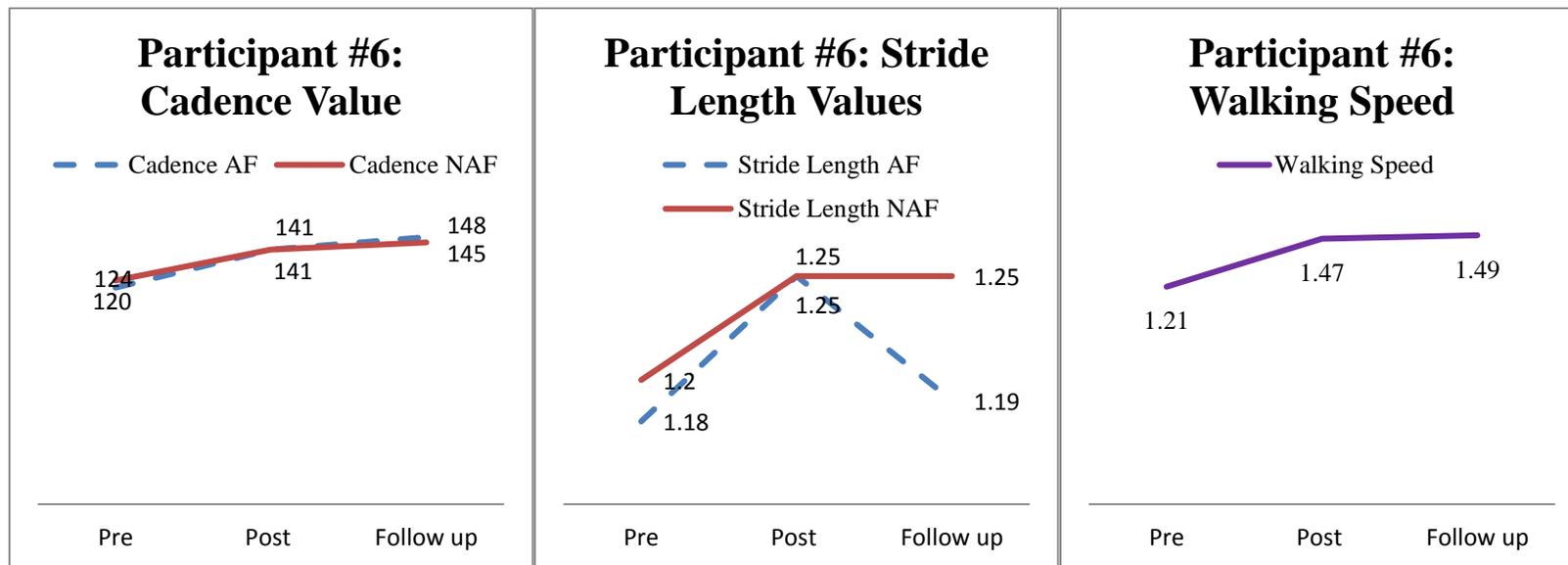


Figure 6. 1-Participant #6: Spatiotemporal values

Walking speed is in meters per second. Stride length in in meters. Cadence is in steps per minute.

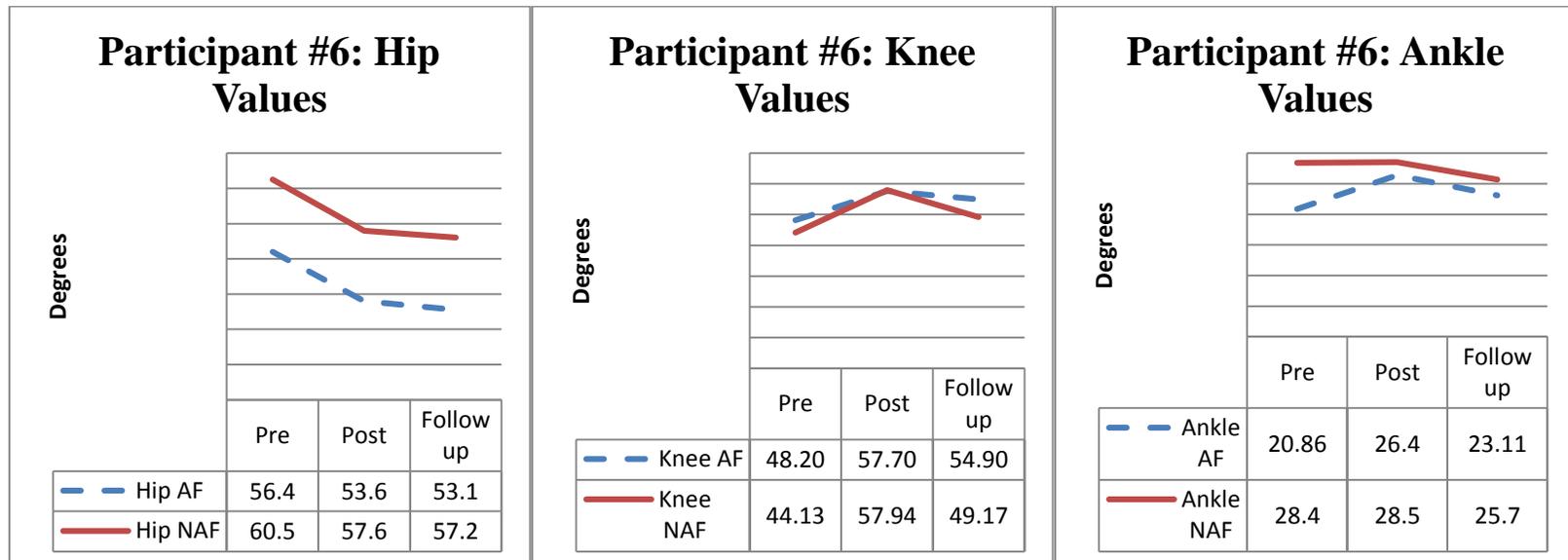


Figure 6. 2- Participant #6: Kinematic values

All measures are in degrees.

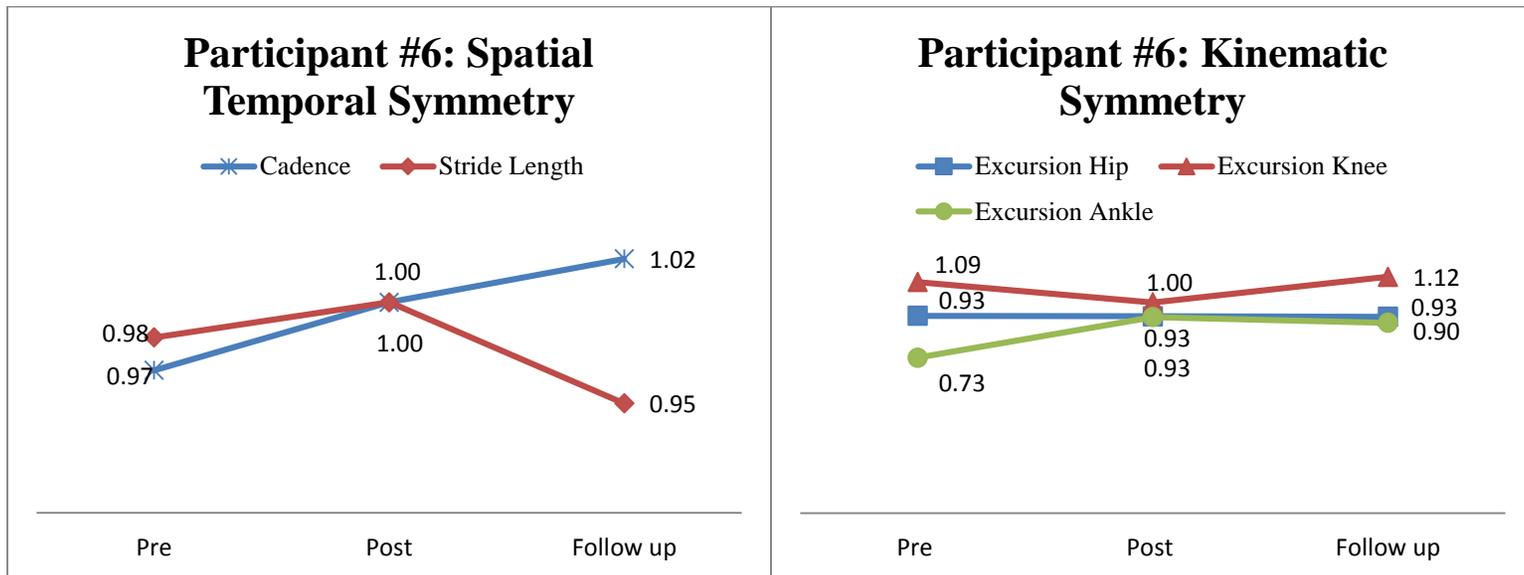


Figure 6. 3-Participant #6: Gait symmetry

## Discussion

The main purpose of this study was to investigate the effects of visual feedback on gait outcomes after an 8-week treadmill training intervention in people post stroke. It was hypothesized that the Visual Feedback (VF) group would show greater changes in spatiotemporal and kinematic variables compared to the Non Visual Feedback (NVF) group. All participants displayed an increase in walking speed, but only the VF group revealed notable changes. Neither group revealed notable change in the kinematic variables. This increase in walking speed after treadmill walking is supported by previous research (Kim et al., 2012; Langhammer and Stanghelle, 2009; Chen et al., 2005). Lack of change in kinematic variables seen in this study was a contrast to previous studies (Tyrell et al, 2011; Mirelman et al., 2010). The primary researcher also hypothesized that the VF group would show significant improvements in spatiotemporal variables and hip excursion. Significant values could not be established because of the small sample size, but the group average did show positive trends.

### Spatiotemporal

Both groups increased in walking speed, with a larger increase in the VF group. NVF group showed a 4.56% increase from pre to post measure. Each participant of the NVF group increased walking speed from pre to post measure (Figure 7.1). All NVF participants were able to sustain the speed increase at follow-up. Only the VF group displayed an increase of 21.7% from pre to post measure (Figure 7.1). Two participants from the VF group were able to sustain and demonstrate positive trends of speed increase. Participant #4 displayed a decline at the follow up measure (Figure 4.1). Participant #3 and

#6 demonstrated an improvement of 12.1% and 1.36%, respectively from pre to post (Figure 3.1 and 6.1).

Stride length of the AF and NAF limb demonstrated a positive trend in all six participants from pre to post measure. NVF group showed the greatest increase of stride length by 6.8% in the AF leg from pre to post data collection (Figure 7.1). This increase was persistent at the follow up measure. Stride length of the NAF leg revealed a 3.4% average change that was sustained at follow up data collection in the NVF group (Figure 7.1).

NVF group did not change in cadence pre to post, while the VF group demonstrated increases in both AF and NAF side (Figure 7.1). NVF group did not change in the AF leg, but showed an increase of 3.6% in the NAF leg (Figure 7.1). AF and NAF limb in the VF group increased steps per minute by 11.7%, from 111.0s/m to 124.0s/m in both groups (Figure 7.1). All participants from the VF group increased from pre to post in both limbs at an equal rate. Participant #4 declined from post to follow, while Participant #3 and #6 improved further (Figure 4.1, Figure 3.1, Figure 6.1).

Spatiotemporal values showed improvement in walking speed for both groups, but no improvement was seen in cadence and stride length for the NVF group. VF group demonstrated the greatest improvement in cadence and walking speed. Stride length showed a small improvement from pre to post and persisted at follow up measure (Figure 7.1). NVF group demonstrated improvements of a smaller magnitude in walking speed. Cadence revealed little to no change, and stride length improved slightly from pre to post with and sustained at follow up measure. These improvements are in agreement with previous findings that support treadmill walking effects on spatiotemporal values (Hesse

et al., 1999; Pohl et al., 2002;Langhammer and Stangehelle, 2009). It is possible that the improvement of spatiotemporal variables is a product of the specific training of the visual feedback in this study. Participants of the VF group were cued to increase or decrease their next step length by the visual feedback provided. This feedback was derived from the previous five steps of each leg in real time. This process encouraged steps per minute and stride length to increase, as each participant strove to meet the step length or sought to time their steps accordingly. It is also possible that increasing the walking speed further encouraged steps per minute, as the participants were stimulated to keep up with the treadmill belt.

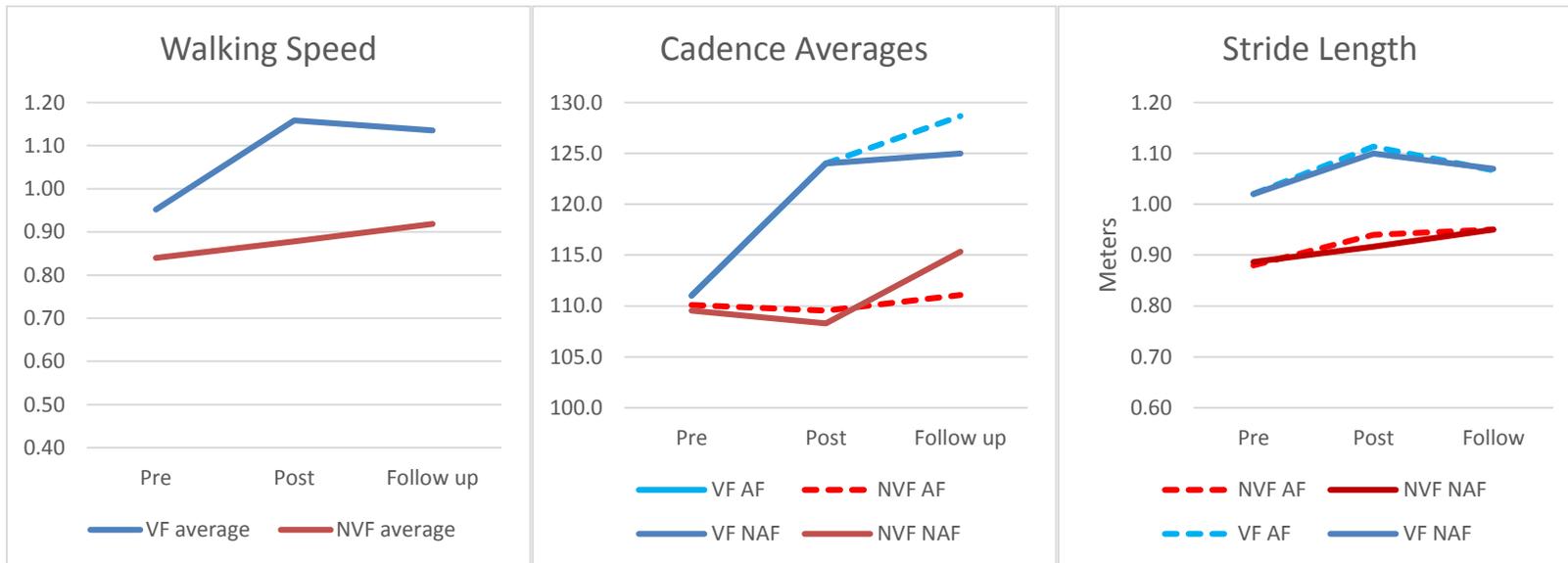


Figure 7. 1-Group Spatiotemporal averages

Walking speed is in meters per second. Cadence is in steps per minute. Stride length is in meters.

## Kinematic

Changes in the kinematic average of the lower extremities in the AF limb were impacted more than the NAF limb in both groups. NVF group revealed an increase in all of the joint excursions with the exception of the NAF hip and NAF ankle from pre to post. AF hip increased 33.4% to 40 degrees of excursion, but this improvement was not sustained at the follow up measure with a decrease of 15.6% to 33.0 degrees of excursion (Figure 7.2). NAF hip did not change from pre to post. Among the NVF group, all three participants improved the excursion on the AF hip. Only Participant #5 improved excursion of the NAF hip, while Participant # 1 and #2 decreased excursion (Figure 5.2, Figure 1.2, Figure 2.2). VF as a group, and as individuals did not demonstrate any change of the AF or NAF hip (Figure 3.2, Figure 4.2, Figure 6.2).

Average knee excursion of both knees in the NVF group improved from pre to post and sustained at follow up (Figure 7.2). AF knee improved 34.0%, from 26.3 degrees to 35.28 degrees, while the NAF knee increased 15.5%, from 37.8 degrees to 43.7 degrees. While Participant #1 did not change in knee excursion, Participant #2 and Participant #5 both displayed increases (Figure 1.2, Figure 2.2, Figure 5.2). Participant #5 alone doubled from 23.8 degrees of AF knee excursion to 48.0 degrees (Figure 5.2). Knee excursion in the VF group increased in the NAF knee, but decreased in the AF side. Participant #3 and #4 decreased pre to post and both increased to the initial excursion measure by follow up (Figure 3.2, Figure 4.2).

AF Ankle excursion did not change in the NVF and VF groups from pre to post. At follow up, NVF NAF ankle excursion increased. This is due to the pain that Participant #1

was experiencing during post data collection. At follow up data collection, Participant #1 was able to improve because of the lack of pain. Participant #2 slightly increased excursion of both ankles and Participant #5 revealed a slight increase of the AF ankle and no change of the NAF ankle (Figure 2.2, Figure 5.2). VF group displayed no change of AF ankle excursion and a slight decrease of NAF ankle excursion (Figure 7.2). This affected the symmetry of the ankle joint, which will be discussed later.

The lack of kinematic change in the VF group could be a result of training and compensation during data collection. While training on the treadmill, VF participants were cued through spatiotemporal variables and focused on improving these variables. This training favored time and distance of each step that was taken by the VF group. During data collection, participants were asked to walk at their “fastest speed” within their safety. This request could have encouraged a compensation technique that relied on the NAF limb in order to increase walking speed. The NVF group did not receive the same feedback and had not been cued through spatiotemporal variables. This explains the previous lack of spatiotemporal change in cadence and stride length, while allowing for compensation of kinematic excursion in the lower extremity joints.

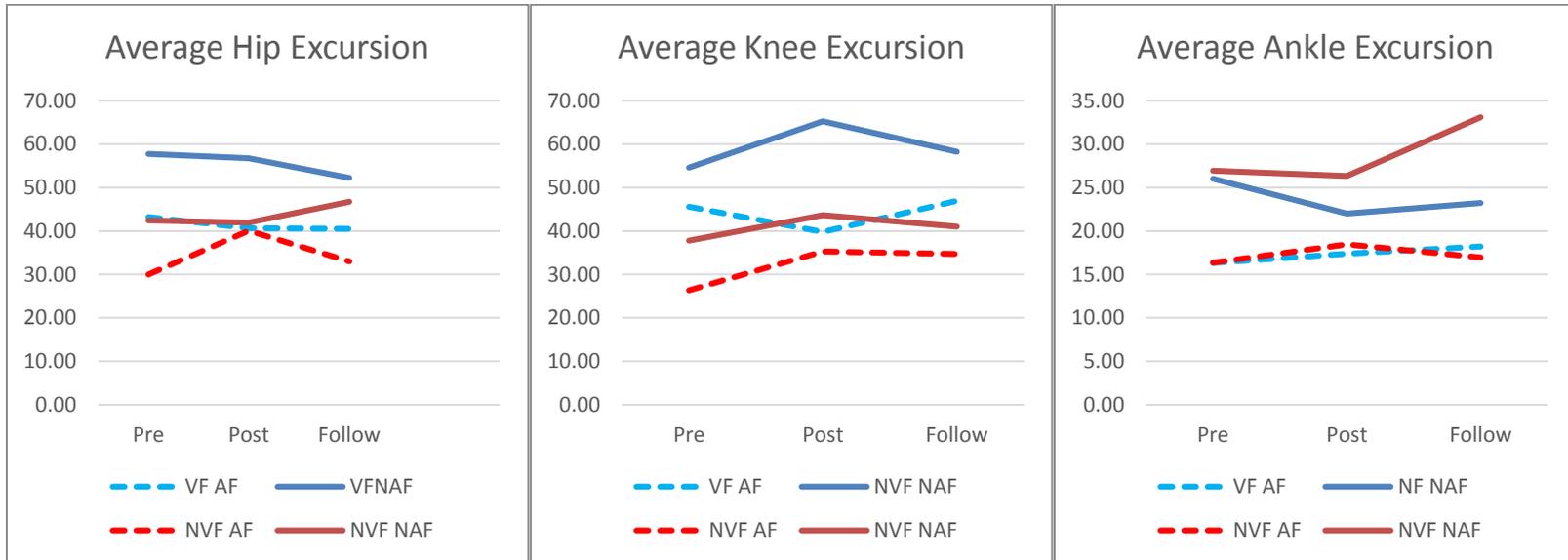


Figure 7. 2- Average Kinematic Excursion

All measures are in degrees.

## Symmetry

Overall cadence symmetry did not change in the VF or NVF group from initial measure to post measure (Figure 7.3). From post to follow up data collection VF and NVF cadence symmetry showed a positive trend. Stride length symmetry of the VF group displayed a positive increase towards symmetry (Figure 7.3). NVF symmetry of stride length decreased from pre to post and increased from post to follow up (Figure 7.3).

Kinematic symmetry changed very little to no change (Figure 7.4). Hip excursion symmetry of the VF group did not change from pre to post, or post to follow up data collection. Hip excursion symmetry of the NVF group improved from .72 pre to .97 post, but declined at follow up to .72 (Figure 7.4). Knee excursion symmetry did not change from pre to post in the NVF group. VF group displayed a decrease of symmetry from .85 pre to .63 post in knee excursion symmetry. At follow up measure, VF knee symmetry returned to .82. Ankle symmetry improved in both the VF and NVF groups from pre to post. Improvement persisted for the VF group, while the NVF declined in symmetry at follow up.

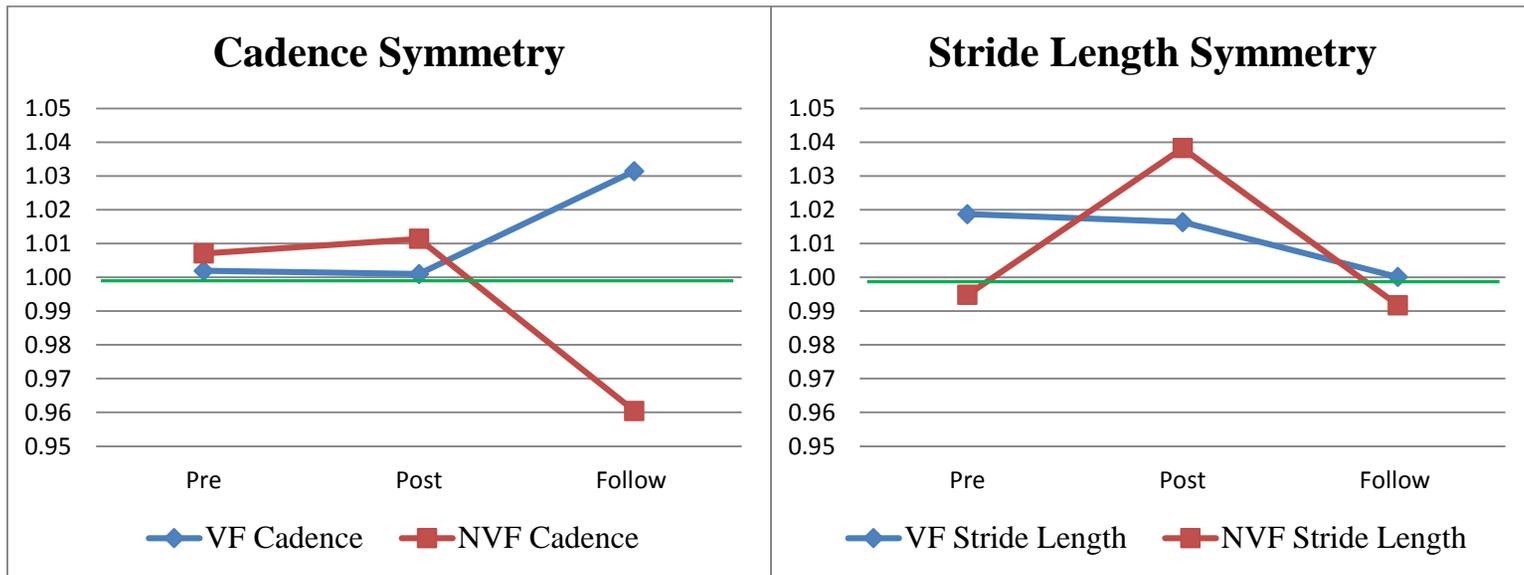


Figure 7. 3- Group Symmetry: Spatiotemporal values. The green line represents perfect symmetry.

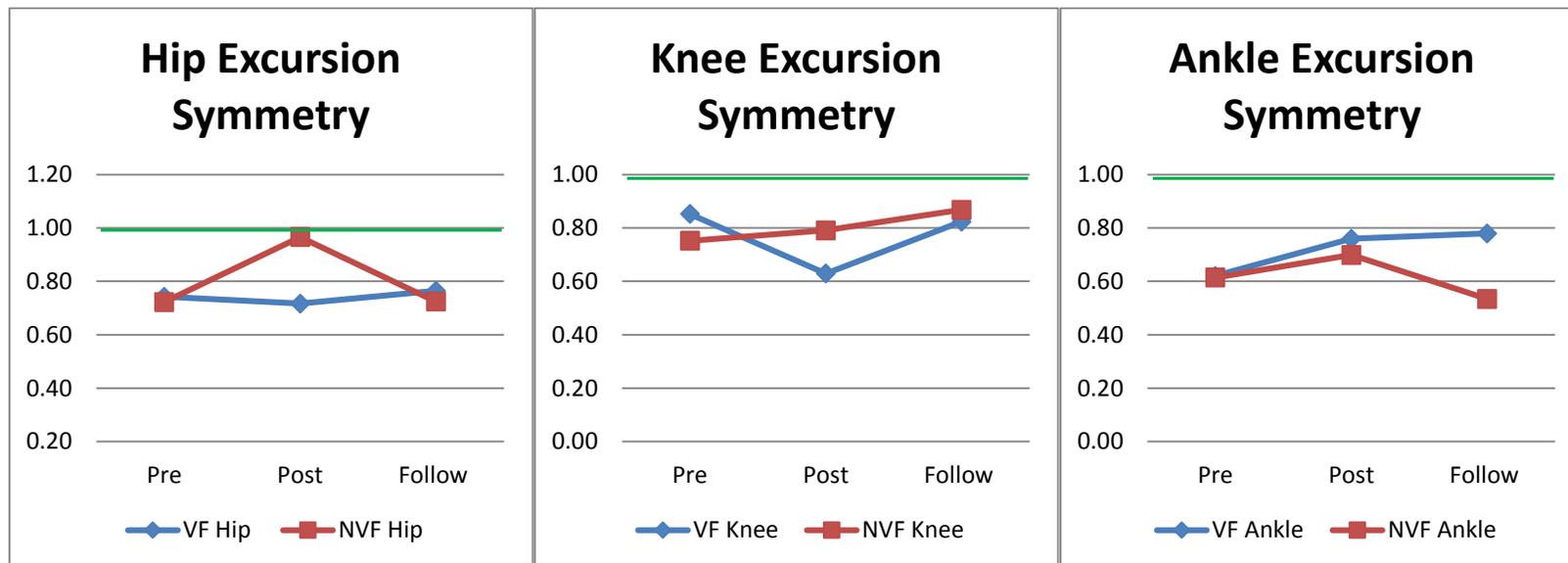


Figure 7. 4- Group Symmetry: Kinematic excursion symmetry. The green line represents perfect symmetry.

### Limitations

Limitations of this study include a small sample size, transportation, and equipment. With a larger sample size, this study could have produced significant values in the spatiotemporal values and more generalized results. Transportation was a very large barrier for people post stroke who were interested in participating. Most people who declined participation did so because of a lack of transportation. Equipment limitations caused schedule conflicts as well as safety issues. There was only one treadmill available to the researcher and it was only available around 7 hours a day. The treadmill used in this study had to be readily available to clients of the facility where the treadmill is housed. This meant that only one participant could perform the intervention at a time and only during certain hours of the day. Most of these hours included early morning (7:00-9:00am), at noon, or early evening (3:00-7:00pm). Minimum speed for gait training with visual feedback is 0.3 m/s and three participants were unable to maintain that speed safely. Those three participants were excluded from this study.

### Future Research

Future research should include a larger sample size to provide more generalized and meaningful outcomes. Because this was one of the first studies to perform visual feedback on the Biodex Gait Trainer treadmill, future studies should be done with a larger sample size to establish the true impact of this training. Providing some form of transportation for the participants with funding would be a large help to the participants and the researcher. Multiple treadmill access would also be a benefit to any future study.

This would allow for a more flexible schedule that could accommodate several more participants. A future study could also compare the auditory and visual feedback components of this machine to determine which modality would benefit participants the most.

### Conclusion

In summary, results from this study suggest that visual feedback training with individual who are similar to the participants in this study can improve cadence and walking speed. Utilizing the Biodex Gait Trainer treadmill training with visual feedback should be recommended for clinical use, as it can provide improvements while reducing the amount of work for clinicians. Therefore, VF treadmill training should be suggested for people post stroke as part of their acute and chronic rehabilitation.

## References

- Almeida, Q. , & Bhatt, H. (2012). A manipulation of visual feedback during gait training in parkinson's disease. *Parkinsons Disease*, 2012, 508720-508726.
- Chen, G. , Patten, C. , Kothari, D. , & Zajac, F. (2005). Gait differences between individuals with post-stroke hemiparesis and non-disabled controls at matched speeds. *Gait & Posture*, 22(1), 51-56.
- Chen, G. , Patten, C. , Kothari, D. , & Zajac, F. (2005). Gait deviations associated with post-stroke hemiparesis: Improvement during treadmill walking using weight support, speed, support stiffness, and handrail hold. *Gait & Posture*, 22(1), 57-62.
- Combs-Miller, S. , Kalpathi Parameswaran, A. , Colburn, D. , Ertel, T. , Harmeyer, A. , et al. (2014). Body weight-supported treadmill training vs. overground walking training for persons with chronic stroke: A pilot randomized controlled trial. *Clinical Rehabilitation*, 28(9), 873-884.
- Khallaf, M. , Gabr, A. , & Fayed, E. (2014). Effect of task specific exercises, gait training, and visual biofeedback on equinovarus gait among individuals with stroke: Randomized controlled study. *Neurology Research International*, 2014, 693048.
- Kim, C. , Lee, J. , Kim, H. , & Kim, J. (2015). The effect of progressive task-oriented training on a supplementary tilt table on lower extremity muscle strength and gait recovery in patients with hemiplegic stroke. *Gait & Posture*, 41(2), 425-430.
- Hesse, S. , Uhlenbrock, D. , & Sarkodie-Gyan, T. (1999). Gait pattern of severely disabled hemiparetic subjects on a new controlled gait trainer as compared to assisted treadmill walking with partial body weight support. *Clinical Rehabilitation*, 13(5), 401-410.
- Harris-Love, M. , Forrester, L. , Macko, R. , Silver, K. , & Smith, G. (2001). Hemiparetic gait parameters in overground versus treadmill walking. *Neurorehabilitation and Neural Repair*, 15(2), 105-112.
- Hamacher, D. , Bertram, D. , Folsch, C. , & Schega, L. (2012). Evaluation of a visual feedback system in gait retraining: A pilot study. *Gait & Posture*, 36(2), 182-186.
- Hesse, S. , Werner, C. , Bardeleben, A. , & Barbeau, H. (2001). Body weight-supported treadmill training after stroke. *Current Atherosclerosis Reports*, 3(4), 287-294.

- Hsu, A. , Tang, P. , & Jan, M. (2003). Analysis of impairments influencing gait velocity and asymmetry of hemiplegic patients after mild to moderate stroke. *Archives of Physical Medicine and Rehabilitation*, 84(8), 1185-1193.
- Kang, H. , Kim, Y. , Chung, Y. , & Hwang, S. (2012). Effects of treadmill training with optic flow on balance and gait in individuals following stroke: Randomized controlled trials. *Clinical Rehabilitation*, 26(3), 246-255.
- Kim, C. , Lee, J. , Kim, H. , & Kim, J. (2015). The effect of progressive task-oriented training on a supplementary tilt table on lower extremity muscle strength and gait recovery in patients with hemiplegic stroke. *Gait & Posture*, 41(2), 425-430.
- Knarr, B. , Reisman, D. , Binder-Macleod, S. , & Higginson, J. (2013). Understanding compensatory strategies for muscle weakness during gait by simulating activation deficits seen post-stroke. *Gait & Posture*, 38(2), 270-275.
- Langhammer, B. , & Stanghelle, J. (2009). Improving gait after stroke--treadmill or walking; quantity or quality. *Journal of CyberTherapy and Rehabilitation*, 2(3), 191.
- Lewek, M. , Feasel, J. , Wentz, E. , Jr, F. , & Whitton, M. (2012). Use of visual and proprioceptive feedback to improve gait speed and spatiotemporal symmetry following chronic stroke: A case series. *Physical Therapy*, 92(5), 748-756.
- Nadeau, S. , Arsenault, A. , Gravel, D. , & Bourbonnais, D. (1999). Analysis of the clinical factors determining natural and maximal gait speeds in adults with a stroke. *American Journal of Physical Medicine & Rehabilitation*, 78(2), 123-130.
- Patterson, K. , Parafianowicz, I. , Danells, C. , Closson, V. , Verrier, M. , et al. (2008). Gait asymmetry in community-ambulating stroke survivors. *Archives of Physical Medicine and Rehabilitation*, 89(2), 304-310.
- Pohl, M. , Mehrholz, J. , Ritschel, C. , & Ruckriem, S. (2002). Speed-dependent treadmill training in ambulatory hemiparetic stroke patients - a randomized controlled trial. *STROKE*, 33(2), 553-558.
- Signal, N. (2014). Strength training after stroke: Rationale, evidence and potential implementation barriers for physiotherapists. *New Zealand Journal of Physiotherapy*, 42(2), 101.
- Roerdink, M. , Lamoth, C. , Kwakkel, G. , Wieringen, P. , & Beek, P. (2007). Gait coordination after stroke: Benefits of acoustically paced treadmill walking. *Physical Therapy*, 87(8), 1009-1022.

Roth, E. , Merbitz, C. , Mroczek, K. , Dugan, S. , & Suh, W. (1997). Hemiplegic gait - relationships between walking speed and other temporal parameters. *American Journal of Physical Medicine & Rehabilitation*, 76(2), 128-133..

Stroke Facts. (2015, March 24). Retrieved November 1, 2015, from <http://www.cdc.gov/stroke/facts.htm>

Understanding Stroke Risk. (n.d.). Retrieved November 1, 2015, from [http://www.strokeassociation.org/STROKEORG/AboutStroke/UnderstandingRisk/Understanding-Stroke-Risk\\_UCM\\_308539\\_SubHomePage.jsp](http://www.strokeassociation.org/STROKEORG/AboutStroke/UnderstandingRisk/Understanding-Stroke-Risk_UCM_308539_SubHomePage.jsp)

Walker, C. , Brouwer, B. , & Culham, E. (2000). Use of visual feedback in retraining balance following acute stroke. *Physical Therapy*, 80(9), 886-895.

von Schroeder, H. , Coutts, R. , Lyden, P. , Billings, Jr, E. , & Nickel, V. (1995). Gait parameters following stroke: A practical assessment. *Journal of Rehabilitation Research and Development*, 32(1), 25.

## Appendix A

### Participant Characteristics

<b>Group</b>	<b>Age</b>	<b>Months post stroke</b>	<b>Sex M / F</b>	<b>AF R / L</b>	<b>Adherence</b>
VF	60.00 +/- 3	105 +/- 140	2 / 1	1 / 2	97.22% +/- 2.78%
NVF	58.67 +/- 24	55.67 +/-44	1 / 2	2 / 1	94.45% +/-11.1%

Table 8. 1-Group Characteristics

<b>Participant</b>	<b>VF / NVF</b>	<b>Age</b>	<b>Months post stroke</b>	<b>Sex</b>	<b>AF</b>	<b>Adherence</b>
#1	NVF	58	11	F	R	83.33%
#2	NVF	71	60	M	R	100%
#3	VF	63	11	M	L	100%
#4	VF	60	245	F	L	95.83%
#5	NVF	47	96	M	L	100%
#6	VF	57	59	F	R	95.83%

Table 8. 2- Individual Characteristics

## Appendix B

### NVF and VF Group Raw Data

Nonvisual Feedback Group					
		#1	#2	#5	Average
Cadence AF	Pre	92.3	110	128	110.10
	Post	89.6	110	129	109.53
	Follow	95.2	110	128	111.07
Cadence NAF	Pre	89.6	111	128	109.53
	Post	88.9	108	128	108.30
	Follow	106	111	129	115.33
Stride Length AF	Pre	0.43	1.14	1.07	0.88
	Post	0.49	1.19	1.14	0.94
	Follow	0.46	1.19	1.20	0.95
Stride Length NAF	Pre	0.43	1.09	1.14	0.89
	Post	0.45	1.16	1.14	0.92
	Follow	0.48	1.19	1.18	0.95
Walking Speed	Pre	0.33	1.02	1.18	0.84
	Post	0.35	1.07	1.22	0.88
	Follow	0.40	1.10	1.27	0.92

Table 8. 3- NVF Group: Spatiotemporal Values

Visual Feedback Group					
		#3	#4	#6	Average
Cadence AF	Pre	103	110	120	111.00
	Post	112	119	141	124.00
	Follow	128	110	148	128.67
Cadence NAF	Pre	104	105	124	111.00
	Post	109	122	141	124.00
	Follow	126	104	145	125.00
Stride Length AF	Pre	0.77	1.11	1.18	1.02
	Post	0.92	1.17	1.25	1.11
	Follow	0.88	1.13	1.19	1.07
Stride Length NAF	Pre	0.73	1.13	1.20	1.02
	Post	0.87	1.18	1.25	1.10
	Follow	0.87	1.09	1.25	1.07
Walking Speed	Pre	0.65	1.00	1.21	0.95
	Post	0.83	1.18	1.47	1.16
	Follow	0.93	0.99	1.49	1.14

Table 8. 4- VF Group Spatiotemporal Values

Non Visual Feedback Group					
		#1	#2	#5	Average
Hip AF	Pre	20.29	36.6	33.18	30.02
	Post	22.85	60.2	37.1	40.05
	Follow	24.42	34.6	40	33.01
Hip NAF	Pre	25.3	52.9	49.2	42.47
	Post	22.7	51.1	52	41.93
	Follow	29.65	54	56.5	46.72
Knee AF	Pre	17.18	38	23.81	26.33
	Post	14.53	43.3	48.01	35.28
	Follow	19.69	46.5	37.93	34.71
Knee NAF	Pre	22.57	35.8	55.06	37.81
	Post	20.08	51.52	59.37	43.66
	Follow	23.47	42.06	57.53	41.02
Ankle AF	Pre	13.91	18.79	16.38	16.36
	Post	13.64	20.02	21.72	18.46
	Follow	11.87	21.01	18.03	16.97
Ankle NAF	Pre	27.9	24.5	28.4	26.93
	Post	20.37	30.2	28.4	26.32
	Follow	38.9	33.5	26.9	33.10

Table 8. 5- NVF Group Kinematic Excursion

Visual Feedback Group					
		#3	#4	#6	Average
Hip AF	Pre	31.4	41.9	56.4	43.23
	Post	32.1	36.31	53.6	40.67
	Follow	27.9	40.6	53.1	40.53
Hip NAF	Pre	50.3	62.4	60.5	57.73
	Post	50.2	62.5	57.6	56.77
	Follow	44.3	55.2	57.2	52.23
Knee AF	Pre	35.07	53.5	48.2	45.59
	Post	24.04	37.6	57.7	39.78
	Follow	34.67	51.2	54.9	46.92
Knee NAF	Pre	53.8	65.8	44.125	54.58
	Post	54.76	83.1	57.94	65.27
	Follow	57.88	67.72	49.17	58.26
Ankle AF	Pre	16.94	11.13	20.86	16.31
	Post	17.31	8.43	26.4	17.38
	Follow	16.52	15.01	23.11	18.21
Ankle NAF	Pre	29.6	20.05	28.4	26.02
	Post	19.73	17.78	28.5	22.00
	Follow	21.06	22.94	25.7	23.23

Table 8. 6-VF Group Kinematic Excursion

NVF Group Symmetry			#1	#2	#5	Average
Spatial Temporal	Cadence	Pre	1.030134	0.990991	1	1.007042
		Post	1.007874	1.018519	1.007813	1.011402
		Follow	0.898113	0.990991	0.992248	0.960451
	Stride Length	Pre	1	1.045872	0.938596	0.994823
		Post	1.088889	1.025862	1	1.03825
		Follow	0.958333	1	1.016949	0.991761
Excursion	Hip Excursion	Pre	0.801976	0.691871	0.67439	0.722746
		Post	1.006608	1.178082	0.713462	0.966051
		Follow	0.823609	0.640741	0.707965	0.724105
	Knee Excursion	Pre	0.761187	1.061453	0.432437	0.751692
		Post	0.723606	0.84045	0.808658	0.790904
		Follow	0.838943	1.105563	0.659308	0.867938
	Ankle Excursion	Pre	0.498566	0.766939	0.576761	0.614089
		Post	0.669612	0.662914	0.764789	0.699105
		Follow	0.305141	0.627164	0.67026	0.534189

Table 8. 7- NVF Group Symmetry

VF Group Symmetry			#3	#4	#6	Average
Spatial Temporal	Cadence	Pre	0.990385	1.047619	0.967742	1.001915
		Post	1.027523	0.97541	1	1.000978
		Follow	1.015873	1.057692	1.02069	1.031418
	Stride Length	Pre	1.054795	1.018018	0.983333	1.018715
		Post	1.057471	0.991525	1	1.016332
		Follow	1.011494	1.036697	0.952	1.000064
Excursion	Hip Excursion	Pre	0.624254	0.671474	0.932231	0.742653
		Post	0.639442	0.58096	0.930556	0.716986
		Follow	0.629797	0.735507	0.928322	0.764542
	Knee Excursion	Pre	0.651859	0.81307	1.092351	0.852427
		Post	0.439007	0.452467	0.995858	0.62911
		Follow	0.598998	0.756054	1.116534	0.823862
	Ankle Excursion	Pre	0.572297	0.555112	0.734507	0.620639
		Post	0.877344	0.474128	0.926316	0.759263
		Follow	0.784425	0.654316	0.899222	0.779321

Table 8. 8- VF Group Symmetry

## Appendix C

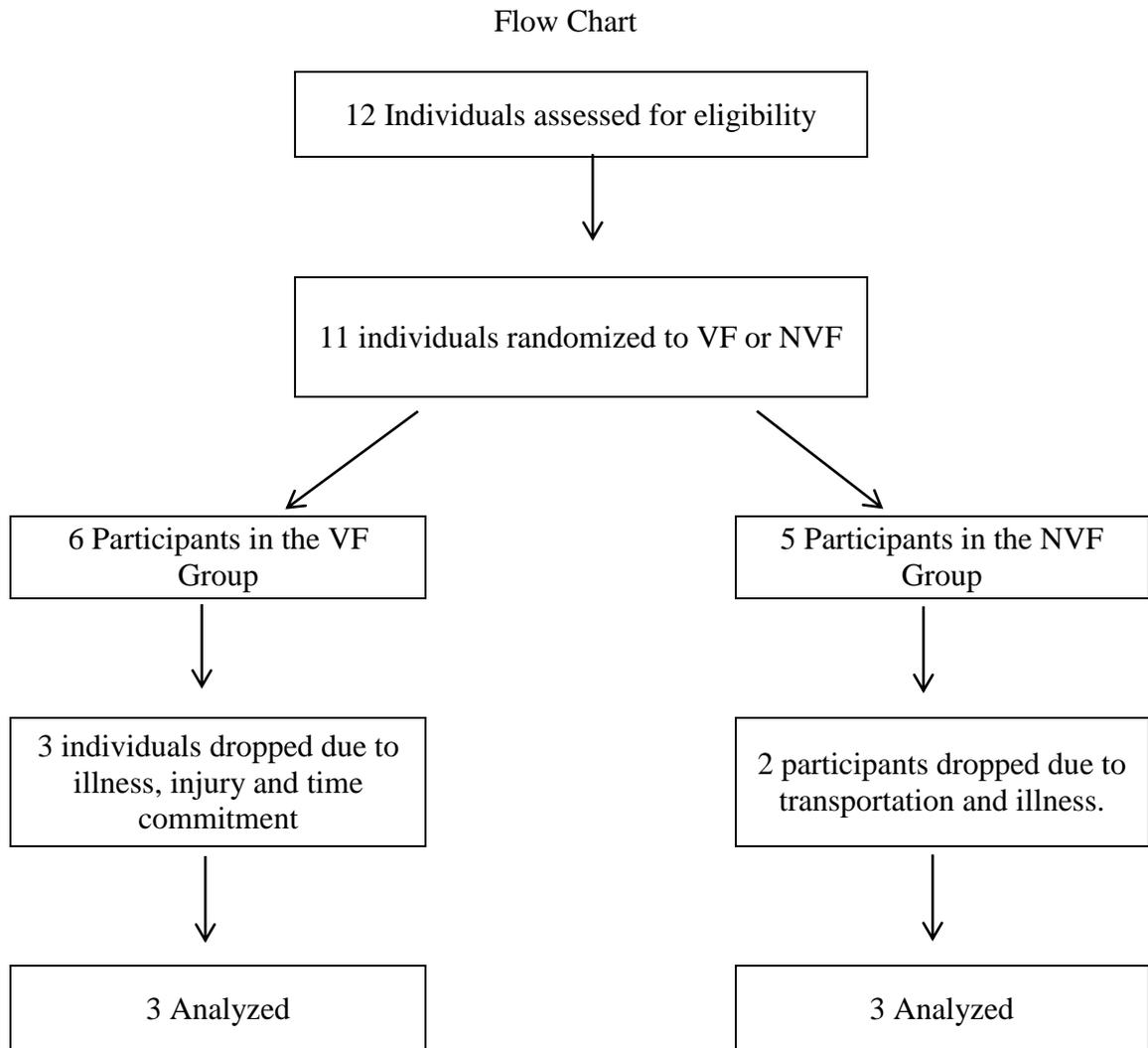


Figure 8. 1 - Flow chart of Participants

## Appendix C

### California State University, Northridge CONSENT TO ACT AS A HUMAN RESEARCH PARTICIPANT

#### *To Investigate the Effects of Visual Feedback Gait Training on Gait Outcomes in People Post Stroke*

You are being asked to participate in a research study titled “Comparing walking outcomes of training with and without visual feedback while treadmill walking in people post stroke”, a study conducted by Ileana Hurtado as part of the requirements for the M.S. degree in Kinesiology at California State University, Northridge. Participation in this study is completely voluntary. Please read the information below and ask questions about anything that you do not understand before deciding if you want to participate. A researcher listed below will be available to answer your questions.

#### **RESEARCH TEAM**

##### **Researcher:**

Ileana Hurtado  
Department of Kinesiology  
18111 Nordhoff St.  
Northridge, CA 91330- 8287  
805-279-4907  
ileana.galindo.494@my.csun.edu

##### **Faculty Advisor:**

Dr. Taeyou Jung  
Department of Kinesiology Adapted Physical Activity  
18111 Nordhoff St.  
Northridge, CA 91330-8287  
818-677-5709  
taeyou.jung@csun.edu

## **PURPOSE OF STUDY**

The purpose of this research study is to examine the effects of treadmill walking with real-time visual feedback on gait outcomes in people post stroke.

## **SUBJECTS**

### **Inclusion Requirements**

You are eligible to participate in this study if you have a confirmed diagnosis of Stroke more than 6 months prior, are older than 18 years of age, are able to walk more than 10 yards unassisted, are able to walk on a treadmill for 30 minutes, are able to read communicate and follow directions in English.

### **Exclusion Requirements**

You are not eligible to participate in this study if you have a musculoskeletal or neurological condition that could inhibit your ability to participate in gait training, inability to walk 10 yards without assistance, visual impairment, current participation in another research study, do not meet the age requirement, and or cannot communicate in English.

### **Time Commitment**

This study will involve approximately 30 minutes of treadmill walking, 3 times a week, for 8 weeks. There will be one testing sessions before and one testing session after the 8-week training.

The testing will take approximately one hour. Measurements of limb length, joint width, height, and weight will take about 20 minutes. Marker placement will take about 10 to 20 minutes depending on the need to change clothing. Walking trials will take approximately 15 minutes. Marker removal will take about 5 minutes.

Total time commitment is 14 hours over 8 weeks, including 2 hours for three test sessions and 12 hours for treadmill training sessions.

## **PROCEDURES**

### Recruitment:

Upon being recruited for this study, you will be required to obtain medical clearance from your primary physician prior to any treadmill walking. Once medical clearance has been obtained, you will be randomly assigned to either the treadmill walking with visual feedback group or the treadmill walking without visual feedback group.

### Initial Meeting:

After you have obtained medical clearance you will be directed to come to the Center of Achievement through Adapted Physical Activity (COA) on the California State University, Northridge (CSUN) campus for a 30-minute one-on-one explanation of the treadmill training and three-dimensional analysis system. You will also receive an explanation of which group you have been assigned into and what participation in that group entails. During this initial meeting the first data-collection will take place.

### Data Collection Procedures:

All data collection and treadmill walking exercise sessions will be held at the COA, CSUN. There will be three data collection sessions. One will occur before any treadmill walking occurs, while the second will occur after the completion of treadmill walking. Four weeks after the completion of the second session, you will be asked to return for a third and final session of data collection. Each data collection procedure will last approximately 30 minutes and will include:

1. Measurements of your height, weight, leg length, as well as the width of your ankles, knees and hip bones. (5 minutes)
2. Placement of 15 markers on the skin of your legs. (5 minutes)
3. Standing for 3 seconds
4. Walking twice in the walkway for practice.
5. Walking while being recorded by a video camera and motion capture system cameras. (15 minutes)
  - a. Three times comfortably
  - b. Three times at a quick pace
6. All markers will be removed and you will be free to go (5 minutes)

### Intervention Procedures:

You will perform approximately 30 minutes of treadmill walking 3 times a week for 8 weeks.

If you are randomly assigned to the visual-feedback group, you will perform the intervention while watching a screen that will provide feedback regarding the placement of your foot.

If you are randomly assigned to the non-visual feedback group, you will still visit the same facility and walk on the same treadmill. The only difference being that you will not view the screen.

### **RISKS AND DISCOMFORTS**

- You may experience fatigue
- You may experience exhaustion
- You may experience pain
- You may experience difficulty Breathing
- You may experience falling
- You may experience injury
- You may experience muscle Cramps
- You may experience anxiety/fear while walking on treadmill and during data collection
- You may experience potential relapse
- You may experience fainting
- You may experience cardiac arrest
- You may experience skin irritation/rash due to the adhesive from the motion analysis markers
- You may experience in rare instances, sudden death

To minimize Potential risks:

- In order to avoid risks associated with exercise, medical clearance will be obtained from your primary physician prior to their participation.
- You will be advised to drink water during rest period to avoid dehydration during the exercise or test sessions.
- To minimize fatigue and exhaustion due to repetitive exercise, rest periods are systematically provided during the intervention and testing procedures. Additionally, if you are unable to attend an exercise session due to said fatigue or exhaustion, your exercise session will be rescheduled.
- To minimize the risk of falling during the treadmill walking, there will always be an active spotter who will hold an emergency stop button in the hand.
- There will be first aid CPR/AED certified staff/intern members of the Center of Achievement in order to assist the procedures of the experiment.
- Anxiety or fear of treadmill and data collection will be mitigated through reassurance that there is a research assistant present who will be actively spotting you in order to reduce risk of falling. If such a fall will occur, proper protocol will take place such as calling emergency services if deemed necessary.
- If you show any signs or symptoms, such as pain or difficulty in breathing, the data collection will be ceased immediately and emergency services should provide medical services.
- Emergency services (911) will be contacted if deemed necessary and you will be referred to your primary physician for proper treatment at your own costs.

## **BENEFITS**

### **Subject Benefits**

Although there are no direct benefits, you may experience improved walking and improved confidence in walking.

### **Benefits to Others or Society**

The study findings can contribute to building scientific evidence for treating individuals who have experienced a stroke.

## **ALTERNATIVES TO PARTICIPATION**

The only alternative to participation in this study is not to participate.

## **COMPENSATION, COSTS AND REIMBURSEMENT**

### **Compensation for Participation**

You will not be paid for your participation in this research study.

You will be provided a parking pass. This pass will be provided upon arrival at the beginning of each study related visit and is to be returned at the end of each visit.

**Costs**

There is no cost to you for participation in this study.

**Reimbursement**

Since there is no cost to you there will be no need for reimbursement.

**WITHDRAWAL OR TERMINATION FROM THE STUDY AND CONSEQUENCES**

You are free to withdraw from this study at any time. **If you decide to withdraw from this study you should notify the research team immediately.** The research team may also end your participation in this study if you do not follow instructions, miss scheduled visits, or if your safety and welfare are at risk.

**CONFIDENTIALITY****Subject Identifiable Data**

All identifiable information that will be collected about you will be removed and replaced with a code. A list linking the code and your identifiable information will be kept separate from the research data.

**Data Storage**

All electronic research data will be stored on an external hard drive or desktop computer that are both password protected.

All audio/video recordings will be stored on an external hard drive or desktop computer that are both password protected

All paper research data will be stored in a locked file cabinet at the Center of Achievement through Adapted Physical Activity in Dr. Taeyou Jung's office. Only the primary investigator, Ileana Hurtado, and faculty advisor, Dr. Taeyou Jung have access.

All forms of your data will remain accessible to the primary researcher and the faculty advisor up to three years after the completion of the study after which all data will be destroyed.

**Data Access**

The researcher and faculty advisor named on the first page of this form will have access to your study records. Any information derived from this research project that personally identifies you will not be voluntarily released or disclosed without your separate consent, except as specifically required by law. Publications and/or presentations that result from this study will not include identifiable information about you.

**Data Retention**

The researchers intend to keep the research data for approximately 3 years and then it will be destroyed.

**Mandated Reporting**

Under California law, the researchers are required to report known or reasonably suspected incidents of abuse or neglect of a child, dependent adult or elder, including, but not limited to, physical, sexual, emotional, and financial abuse or neglect. If any researcher has or is given such information, he or she may be required to report it to the authorities.

**IF YOU HAVE QUESTIONS**

If you have any comments, concerns, or questions regarding the conduct of this research please contact the research team listed on the first page of this form.

If you have concerns or complaints about the research study, research team, or questions about your rights as a research participant, please contact Research and Sponsored Projects, 18111 Nordhoff Street, California State University, Northridge, Northridge, CA 91330-8232, or phone 818-677-2901.

**VOLUNTARY PARTICIPATION STATEMENT**

You should not sign this form unless you have read it and been given a copy of it to keep. **Participation in this study is voluntary.** You may refuse to answer any question or discontinue your involvement at any time without penalty or loss of benefits to which you might otherwise be entitled. Your decision will not affect your relationship with California State University, Northridge. Your signature below indicates that you have read the information in this consent form and have had a chance to ask any questions that you have about the study.

**I agree to participate in the study.**

- I agree to be photographed
- I do not wish to be photographed
- I agree to be video recorded
- I do not wish to be video recorded

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Participant Signature

---

Date

---

Printed Name of Participant

---

Researcher Signature

---

Date

---

Printed Name of Researcher

## Appendix D

CALIFORNIA STATE UNIVERSITY, NORTHRIDGE

# EXPERIMENTAL SUBJECTS BILL OF RIGHTS

The rights below are the rights of every person who is asked to be in a research study. As an experimental subject I have the following rights:

- 1) To be told what the study is trying to find out,
- 2) To be told what will happen to me and whether any of the procedures, drugs, or devices is different from what would be used in standard practice,
- 3) To be told about the frequent and/or important risks, side effects or discomforts of the things that will happen to me for research purposes,
- 4) To be told if I can expect any benefit from participating, and, if so, what the benefit might be,
- 5) To be told the other choices I have and how they may be better or worse than being in the study,
- 6) To be allowed to ask any questions concerning the study both before agreeing to be involved and during the course of the study,
- 7) To be told what sort of medical treatment (if needed) is available if any complications arise,
- 8) To refuse to participate at all or to change my mind about participation after the study is started. This decision will not affect my right to receive the care I would receive if I were not in the study.
- 9) To receive a copy of the signed and dated consent form.
- 10) To be free of pressure when considering whether I wish to agree to be in the study.

If I have other questions I should ask the researcher or the research assistant, or contact Research and Sponsored Projects, California State University, Northridge, 18111 Nordhoff Street, Northridge, CA 91330-8232, or phone (818) 677-2901.

X

Signature of Subject

Date