Horses and Humans Research Foundation
Final grant reporting

A final report should be submitted when the entire project, as described in the approved grant application, is completed (including any assessment results, statistical analysis, etc.). A final invoice should be attached as well. Please contact HHRF immediately with an extension request if the report will not be submitted by the due date.

Final grant report should include the following:

1. A full summary of research project results and findings.
   Equine-assisted therapy (EAT) is a form of physical, occupational and speech therapy that uses horse movement. In today's society, there exists a need for EAT for patients with cerebral palsy in spite of a limited understanding of scientific evidence-based effects of EAT. This pilot study evaluated the impact of EAT between children with cerebral palsy and horses in terms of kinetics. This study included 4 children with spastic cerebral palsy aged between 3 and 14 years. There were 3 data collection sessions in 8 sessions of 20-minute of EAT for 3 subjects and in 7 sessions of 20-minute of EAT for 1 subject. Functional mobility was measured using timed up and go test for 3 subjects and 10-meter walk test for 1subject two times before EAT and two times after EAT. Six Inertial Measurement Units (IMU) devices were used to measure the acceleration of the children and horses during the EAT. The IMU sensor data was analyzed using fast Fourier transformation (FFT) and cross-correlation with a time shift. The study is to determine the rationale behind success of EAT. The results have shown that as the therapy progressed, subjects showed a significant decrease (i.e., enhancement) in time for the functional mobility tests and the subjects' movement synchronized (i.e., interaction) with the horse's movement in up and down direction. In conclusion, this study provides evidence that EAT can be leading to improved functional mobility of the children with cerebral palsy and the positive interaction between the movements of the children with cerebral palsy and the horse. Future work includes analyzing data in the other direction and evaluating causality between improved functional mobility and positive interaction.

   As a result of this study, one master student is obtaining a MS degree. Please see the included thesis (modified for the HHRF report).

2. A summary that can be posted to the research page of the HHRF web site (if different than #1)
   Same as #1.

3. State both your final conclusions and how you feel these findings should inform/influence equine assisted activity practices.
   This study is a pilot study investigating the relation between functional improvement due to equine therapy and the interaction between the horses and the patients with CP. Due to the limited sample size (n=4), we couldn't definitely make the conclusion. However, the following conclusion is drawn: Walking functional improvement of children with CP is

related to the level of interaction between the children with CP and horses. Even though the causal relation is not found yet, it is suggested that encouraging the children with CP the interaction with horses will have positive effect in their functional enhancement.

4. Time line, show completed items and any changes/difficulties in completing the listed items from the original application noted and explained.
   2017 Dec: Award notification
   2018 Jan: Set up the account at Texas A&M, IRB application
   2018 Feb-Aug: Preparation of sensors and experiments, recruitments
   2018 Sep-2019 Apr: Data collection with 4 subjects
   2019 May-2019 Oct: Data analysis, and manuscript writing.

5. Budget: final budget expenditures, with any variations from the original submitted application budget noted and explained.

Original	Actual	Memo
Student worker salary: $8,966	Student worker salary (total): $7692.63 1310 Salary-Faculty-Non-Teaching: $884.86 1325 Sal-Gar – Professional: $2,859.09 1920 Fica Contributions (Oasi Matching): $165.78 1945 Worker's Compensation Assessments: $7.80 1950 Unemployment Compensation Insurance: $2.69 1955 Orp Base: $58.41 6032 Sponsored Projects-Tuition & Fees: $3,714.00	There is a variation of 14%. We used 14% less (-$1273.37) than the budget. This is because student salary, benefits, and other costs vary every year.
Consumable supplies: $1,034	Consumable supplies (total): $1732.29 4013 Supplies – Research: $1,672.13 4075 Shop And Industrial Supplies: $28.16 5765 Educ Books, Film & Ref - $32.00	There is a variation of 67%. We used $698.29 more since we needed to purchase more parts (IMUs and batteries) to meet the performance requirements.
Total: $10,000	Total: $9424.92	Overall, we used 94.2% of the total budget.

6. Summary of any complications or challenges that have been encountered and how they have been addressed.
   Recruiting subjects was a complication. However, other than that, we didn't have any other complication.

7. Share detailed plans for submitting material for publication; summaries of findings with the public.
   The research finding will be presented at Professional Association of Therapeutic Horsemanship International (PATH Intl.) in Denver, CO in Nov 8-10 as a poster. The finding will also be presented at American Society of Biomechanics at Atlanta, GA in Aug 2020. A manuscript for journal article will be prepared and submitted in November, 2019 either for Pediatric Physical Therapy or Archives of Physical Medicine and Rehabilitation.

8. Invoice signed by grant manager for expenses incurred (for the remaining 50% of grant award)
   See the attached.

9. Photos from research project activities that can be used in HHRF public marketing and outreach materials (such as newsletters, annual report, press release, etc.) Include a photo

release form from all participants that includes HHRF in the listing of those permitted to us the photos for public outreach (sample can be supplied upon request).
See below.

Exploring how functional improvement is related to interaction between children with cerebral palsy and horses during equine-assisted therapy: A pilot study

ABSTRACT

Equine-assisted therapy (EAT) is a form of physical, occupational and speech therapy that uses horse movement. In today's society, there exists a need for EAT for patients with cerebral palsy in spite of a limited understanding of scientific evidence-based effects of EAT. This pilot study evaluated the impact of EAT among children with cerebral palsy and horses in terms of kinetics. This study included 4 children with spastic cerebral palsy aged between 3 and 14 years. There were 3 data collection sessions in 8 sessions of 20-minute of EAT for 3 subjects and in 7 sessions of 20-minute of EAT for one subject. Functional mobility was measured using timed up and go test for 3 subjects and 10-meter walk test for one subject two times before EAT and two times after EAT. Six Inertial Measurement Units (IMU) devices were used to measure the acceleration of the children and horses during the EAT. The IMU sensor data was analyzed using fast Fourier transformation (FFT) and cross-correlation with a time shift. The study is to determine the rationale behind the success of EAT. The results have shown that as the therapy progressed, subjects showed a significant decrease in time for the functional mobility tests and the subjects' movement synchronized with the horse's movement in up and down direction. In conclusion, this study provides evidence that EAT can be leading to improved functional mobility of the children with cerebral palsy and the positive interaction between the movements of the children with cerebral palsy and the horse. Future work includes analyzing data in the other direction and evaluating causality between improved functional mobility and positive interaction.

1. INTRODUCTION

1.1 Background

Cerebral palsy is an umbrella term that is a group of brain injury or malformation disorders affecting a person's ability to move [1]. In the United States, approximately 800,000 people including children and adults have at least one symptom of cerebral palsy and around 10,000 babies are born each year with cerebral palsy. One in 323 children in the U.S is diagnosed with cerebral palsy. Even though many children are suffering from cerebral palsy, there is no known cure [2]. Cerebral palsy is caused by damage to the motor control centers of the developing brain, which can happen while the brain is developing. More than 70% of children with cerebral palsy have spasticity that is a condition in which certain muscles appear stiff and tight [1]. There are a variety of different symptoms of cerebral palsy depending on different levels of severity. The common signs of cerebral palsy are: i) problems with movement on one side of body, ii) stiff muscles, iii) exaggerated or jerky reflexes, iv) involuntary movements or tremors, v) lack of coordination and balance, vi) drooling, vii) problems swallowing or sucking, viii) difficulty with speech (dysarthria), ix) seizures, x) contractures (shortening of muscles), xi) delayed motor skill development, xii) incontinence. Among them, the most significant problem in children with cerebral palsy is the lack of postural control and dynamic balance related to functional mobility of the children with cerebral palsy [3].

A variety of therapies exist in treating cerebral palsy and they are designed for different kinds of symptoms of cerebral palsy. Recently, the benefits of EAT over the other therapies for cerebral palsy has been elucidated. It is believed that EAT has the potential to cover the various problems for cerebral palsy and has become increasingly popular for patients with cerebral palsy [4]. According to Equine-Assisted organization (EAGALA), there are more than therapy programs practicing EAT for patients with a broad range of psychological and physical conditions and 60,000 clients were served worldwide in 2018 [5].

EAT is a form of physical, occupational and speech therapy treatment strategy using the characteristic movements of a horse [6]. EAT involves not only riding on the horse's back but also interacting with a well-trained horse (e.g, patting, talking). This therapy can improve the patient's: i) overall strength, ii) trunk and core strength, iii) gross and fine motor control, iv) balance, v) posture, vi) muscle tone for both hypotonia and hypertonia, vii) the ability to give and receive visual cues, viii) sensation, ix) communication skills, x) social skills, xi) confidence and self-esteem [7].

Especially, the benefits of EAT result in building trunk and head stability which are related to functional mobility and it is commonly used for children with neuromuscular disabilities [8, 9]. In EAT, the movement of the horses offers a variety of changes to the rider, which may be used to facilitate improved contraction, joint stability, weight shift, and postural equilibrium responses in children with cerebral palsy [10].

1.2 Literature review

Previous studies have described the benefits of the movement of horses for children with cerebral palsy, including improved gross motor function, dynamic balance, and trunk postural coordination. In general, researchers employed Gross Motor Function Measure (GMFM) and Pediatric Evaluation of Disability Inventory (PEDI) as outcome measures for children with cerebral palsy because both are recognized, validated measures used for gross motor function and functional mobility [11]. The EAT intervention for children with cerebral palsy typically focused on maximizing potential through improving gross motor skill and functional mobility [12].

For instance, Park et al. [13] used GMFM and PEDI-FSS to evaluate the effects of EAT on gross motor function and functional performance of children with cerebral palsy. This study was designed with large sample sizes, 34 children as the EAT group and 21 children as the control group. After 8-weeks of intervention of EAT, significant improvements in walking, running, and jumping of GMFM and in self-care, mobility, and social functioning of PEDI were shown in the EAT group, but not in the control group. These results demonstrated the positive effects of EAT on gross motor function and functional performance of children with cerebral palsy.

A different method for a better understanding of the effects of EAT was conducted. McGibbon et al. [14] focused specifically on adductor muscle activity using surface electromyography. The asymmetric adductor muscle activity of children with cerebral palsy might cause reduced hip range of motion and possible dislocation and lead to poor dynamic balance and inefficient walking [15]. This study examined the relationship between the improvements in adductor symmetry and functional mobility. Absolute differences in mean EMG values between the left and right sides of individual muscle groups during each task were calculated and recorded as asymmetry scores. After 12 weeks of weekly EAT, 4 out of 6 subjects showed improvement in adductor muscle symmetry during walking but all 6 subjects improved in the GMFM scores. The study demonstrated EAT might be improving adductor muscle asymmetry and functional mobility, but improved adductor symmetry alone did not represent the improvement because the other two subjects also showed improvement in their motor skills even though their adductor symmetry did not improve over time. The positive changes in functional skills might occur due to multiple factors related to postural control and dynamic balance [14].

The above studies showed the positive outcome of EAT. However, they could not explain the influence of the horse's movements on the rider's body. Some researchers attempted to examine the influence of the horse's movement on children with cerebral palsy during EAT in the kinematic way.

It can be hypothesized that additional investigations may result in better performance. There exists a published study on the long-term effects of EAT on a child with cerebral palsy. Shurtleff et al. [8] investigated the changes in head and trunk stability in a child with cerebral palsy over 36 weeks of weekly EAT. In this study, video motion capture allowed precise tracking of kinematic trunk movements during EAT. The result demonstrated a reduction in the subject's average anterior-posterior movement after 12 weeks of EAT compared to the first week. However, the result did not show any improvement after 12 weeks of EAT. Besides, the limitation of this study was an extremely small sample size (n=1). It was not enough to draw a conclusion about the impact of EAT on children with cerebral palsy from this study.

Haehl et al. [16] examined the influence of EAT on the kinematic performance of children with cerebral palsy. It suggested the existence of a kinematic relationship between the patient and the horse during EAT. Also, a rider would show a movement pattern in response to the horse's movement. The study used a 60 Hz camcorder set up in an indoor arena to collect kinematic data. Markers were used to calculate the children's upper trunk, lower trunk and horse's caudal angles shown in Figure 1. The changes in angels of the children with cerebral palsy per horse stride exhibited smooth movement patterns and specifically, the angles of children's upper and lower trunk followed similar trajectories in response to the horse's movement. However, the trunk angles could not be explained as trunk control alone because there's a possibility of using their trunk and arm muscles together. The limitation of this study is the lack of explanation of how the movements were interacted during horse riding.

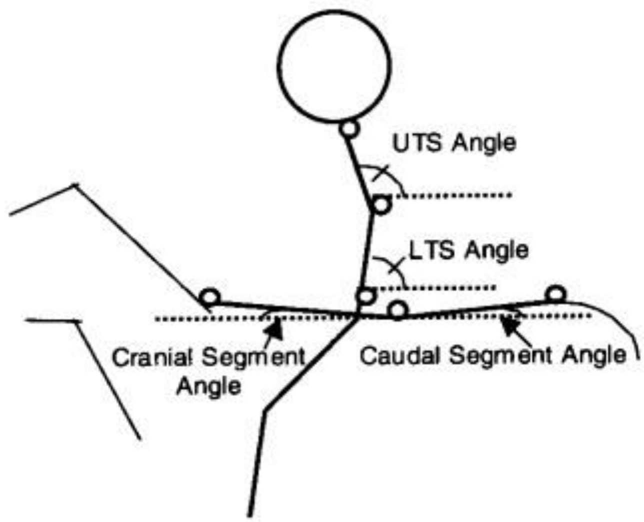

Figure 1: Measurements of postural orientation of the subjects

Similar to the above study, MacPhail et al. [17] determined whether the patient would react to the horse's movement while riding in kinematics. The study conducted a kinematic analysis of the lateral trunk movement of the patient with respect to the movement of the horse. The subjects were classified depending on the presence of cerebral palsy. The displacement angles of the subject's trunk and horse's pelvis were calculated from the data to determine the movements of the rider and horse in Figure 2. The markers allowed the evaluation of the lateral movement of the trunk. All nondisabled children showed a similar and steady pattern of trunk movement compared with the horse's movement. In addition, children who were nondisabled were easy to respond to the low-frequency event, with minimal delay. On the other hand, children with cerebral palsy responded inconsistently and the movement of the children with cerebral palsy was poorly coordinated to horse pelvic movement. It implied that all nondisabled children produced a consistent pattern of trunk movement in response to the horse's pelvic movement and the synchronization between the movements of the children and horse occurred during EAT. On the other hand, the synchronization between the movements of the children with cerebral palsy and horse was hardly seen during EAT.

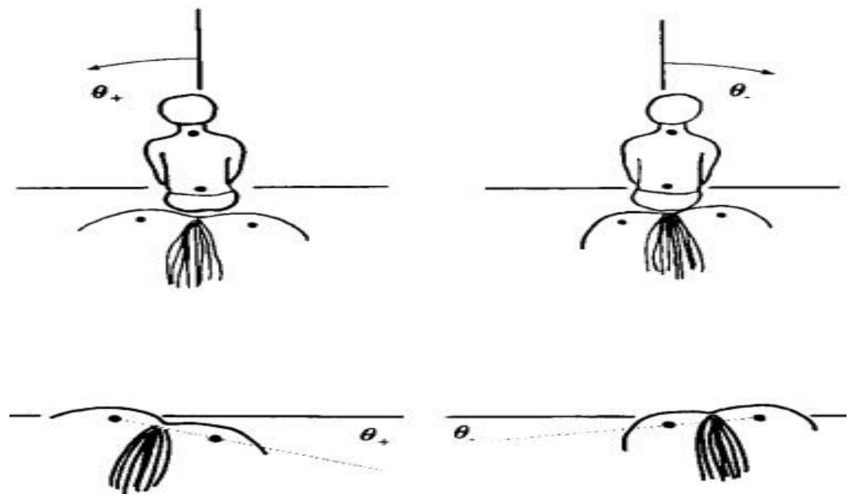

Figure 2: Joint Marker Placement and angle definition

The different type of data was used for analyzing the impact of EAT on children with cerebral palsy. Uchiyama et al. [18] used the acceleration data to evaluate the similarity between the movements of the children and horse based on the hypothesis that the horse's pelvis movement during EAT is similar to the human pelvic movement while walking. Normal walking acceleration data for humans and horses for 3 min, respectively were collected, and the stride-phase data was generated according to the walking cycle. The data was converted into its corresponding to the frequency domain. The results have shown that the frequency peaks of human walking corresponded with those of horse walking. Especially, the frequency spectra of human walking and horse walking in the Z-axis (up and down) were more correlated than in the X and Y-axis. It might imply horse walking gait during EAT offers the stimulation of a walking exercise as a normal human does.

With the literature review of the effects of EAT on children with cerebral palsy, no studies have focused on kinetics-related interaction between the rider and horse in EAT. Considering the concept of the kinetics, whenever there is an interaction between two objects, there is an interaction force upon each other [19]. Therefore, interaction should be examined through a force concerning with kinetics, along with kinematics. Even though acceleration data is considered as kinematic data, it was used for kinetics because acceleration represented force normalized by mass through the equation that force is mass times acceleration. This study focused on the force by interaction between the rider and horse in term of kinetics, not kinematics.

1.3 Motivations for the research

Previous researches on the effects of EAT on cerebral palsy emphasized the importance of providing evidence to support the benefits of EAT. There have been various attempts by researchers to examine the positive influence of EAT on cerebral palsy and interaction between movements of patients and horses during EAT. Most studies on the influence of EAT on cerebral palsy focused on the functional performance, not on the mechanism of how horse movement affects the movement of the children with cerebral palsy. A few researchers provided kinematic evidence-based effects of EAT but the fundamental mechanism in the kinetics of EAT has not been fully elucidated. Specifically, the relationship between the kinetic changes during EAT and functional performance need to be examined.

On the background of EAT, the growing demand for EAT has brought about the establishment of more than 600 programs practicing EAT in the world. It is believed to be a strategy for coping with the problems of children with cerebral palsy. Therefore, it has become important to prove the positive effects of EAT on cerebral palsy.
In sum, there is a dearth of research on the kinetic relationship between the movements of children with cerebral palsy and horse during EAT. Besides, there is a need to enhance the relevance of EAT to the improvement in functional mobility and positive interaction between horse's and patient's movements.

1.4 Research goals and objectives

The long-term goal of this thesis is to identify the determinants of the positive effects of EAT on children with cerebral palsy. It has been stated that most studies on EAT focus on trunk stability, posture, and pelvic mobility for improvement in gait and balance, not on the interaction between patients and horses. There is a need for more reliable research on the kinetic relationship between the movements of children with cerebral palsy and horse during EAT. Based on the current situation of EAT, it is believed that this study would be helpful not only for therapists but also for patients with cerebral palsy.

This objective of the study is the observation of changes in the functional mobility of the subjects and kinetic changes during EAT over time. This thesis aimed to observe the improvement in functional mobility as therapy progressed. Also, this study aimed to observe how the movements of subjects and horses interact during EAT. The changes in the interaction between the movements of subjects and horses over time should be observed for the study.

Based on these objectives, the following hypotheses for the study were formulated:

I. The functional mobility of children with cerebral palsy would improve as the number of EAT sessions increases.

II. In terms of the interaction, the movements of children and horses during the therapy would be more correlated as EAT progresses.

III. The movement of children in EAT would follow the movement of horses.

2. METHODS

2.1 Subjects

Four children were recruited through physical therapists who reviewed the Texas A&M University waiting list for applications. Subjects in the study consisted of 1 boy and 3 girls aged range of 3-12 years and diagnosed with spastic cerebral palsy. The inclusion criteria for children with cerebral palsy were as follows: i) age 4 to 12 years, ii) gross motor function classification system (GMFCS) level I, II, and iii) the ability to signal pain, fear, or discomfort. The exclusion criteria were as follows: i) botulinum toxin treatment, orthopedic, or neurosurgery in the previous 6 months, i) severe intellectual disability, iii) scoliosis, and iv) poor visual or hearing acuity. Subjects in the study have a different type of spastic cerebral palsy: The first, second, and third subjects have spastic hemiplegia cerebral palsy, which affects only one side of a person's body, and the last subject has spastic quadriplegia cerebral palsy, which affects all four limbs, the trunk, and the face [20]. The information of subjects is shown in Table 1.

Table 1. Profiles of the subjects in this study

Subject #	Type of Spasticity	Sex	Age(y)	Height(cm)	Weight(kg)
1	Hemiplegia	Female	3	87.6	12.3
2	Hemiplegia	Female	12	128.3	23.4
3	Hemiplegia	Male	4	N/A	18.6
4	Quadriplegia	Female	10	127.0	22.7

Before performing tests, a full explanation of all procedures was provided not only to children but also to parents or caregivers. This study has been approved by the Internal Reviewer Board of Texas A&M University (2018-0064, 2018-0028).

2.2 Experimental protocols

All testing processes were designed to examine the objective and hypotheses for the study. All tests were conducted under the direction of the physical therapists or equine specialists and were recorded on video for data analysis. The three subjects received weekly therapies for 8 weeks but the last subject received 7 EAT sessions in 5 weeks because of the bad condition of the subject during the sessions. All subjects received no other physical therapy to avoid the possible factors affecting the functional performance of the children with cerebral palsy in the study. As shown in Figure 3. there were 3 data collection sessions in 8 weeks sessions. None of the subjects dropped out of the study.

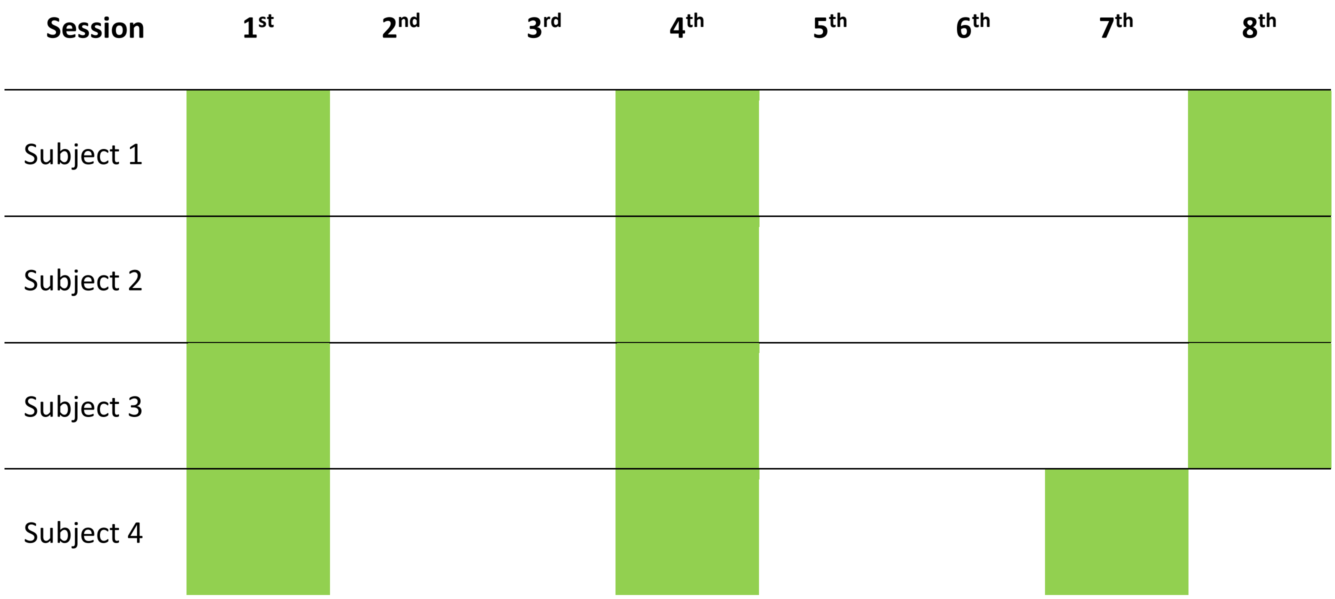

Figure 3. Timetable for EAT and data collection

Data collection sessions were designed to observe the changes in functional mobility before and after EAT. Data collection sessions involved 3 parts: i) functional mobility tests before EAT, ii) EAT, and iii) functional mobility tests after EAT. Figure 4 represents the overall flow of the experiment in the study.

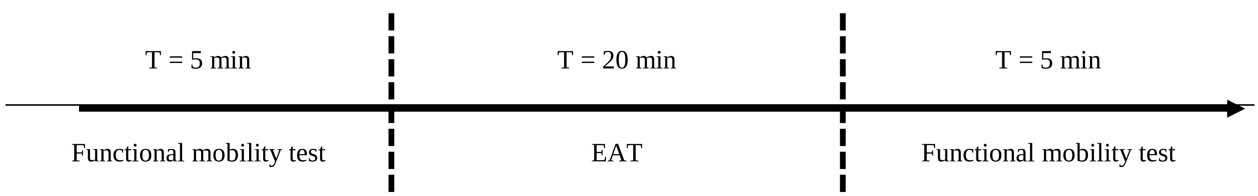

Figure 4. Flowchart in data collection session

EAT was performed at the riding arenas in Georgetown and College Station, Texas. Information for size and user of the horse arena is shown in Table 2. Considering the difference in size among the arenas, the trajectories of the horse and walking distances were controlled as they were done in Ride on Center for Kids (ROCK) at Georgetown, TX.

In EAT, the subjects were not required to control the horse. The horses were all trained for riding programs and controlled by a horse handler who was accompanied by a therapist and an assistant. Horse walking speed in the study was 1.03 m/s, which is similar to the average human walking speed (1.0 m/s) [21]. It was expected to provide the subjects with the stimulation of exercise as a normal person does. The horses were fitted with a saddle pad and surcingle, and the subjects were fitted with a safety helmet and were placed sitting in a forward astride position.

Table 2. Description of horse arenas used in the study. Three arenas were used for the data collection: i) Ride on Center for Kids (ROCK) at Georgetown, TX, ii) Parsons Mounted Cavalry (PMC) at College Station, TX, and iii) Freeman Arena at College Station , TX.

Name	Size (m x m)	User
ROCK	31 x 61	Subject 1, 3
PMC	46 x 55	Subject 2
Freeman	61 x 106	Subject 4

A 20-minute EAT session in the study consisted of two 10-minutes parts in Figure 5: In the first part, a horse was led on a designated path, which is shown in Figure 6, at a steady speed (1.03 m/s) without stopping for 10 minutes. In the second part, the horse walked at a steady pace for 10 minutes as it did in the first part but stopped for a second every minute during which the children were holding a ring-shaped toy in their hand. Holding a toy in both hands prevented them from using their arms when maintaining their balance [22]. The rationale for dividing into two parts was to see diverse reactions to different situations. The first part focused on stability through the whole body while the second part focused on stability through their trunk. Figure 5 shows that the rough sketch of the EAT session.

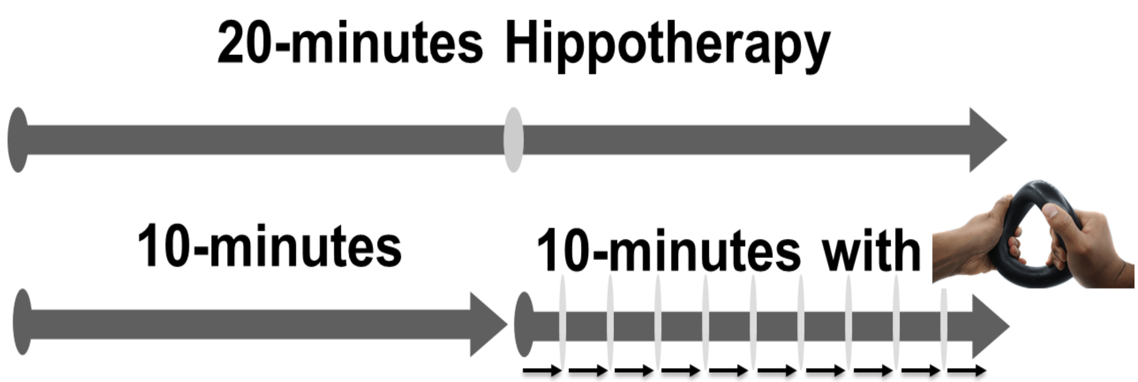

Figure 5 Rough sketch of the EAT session

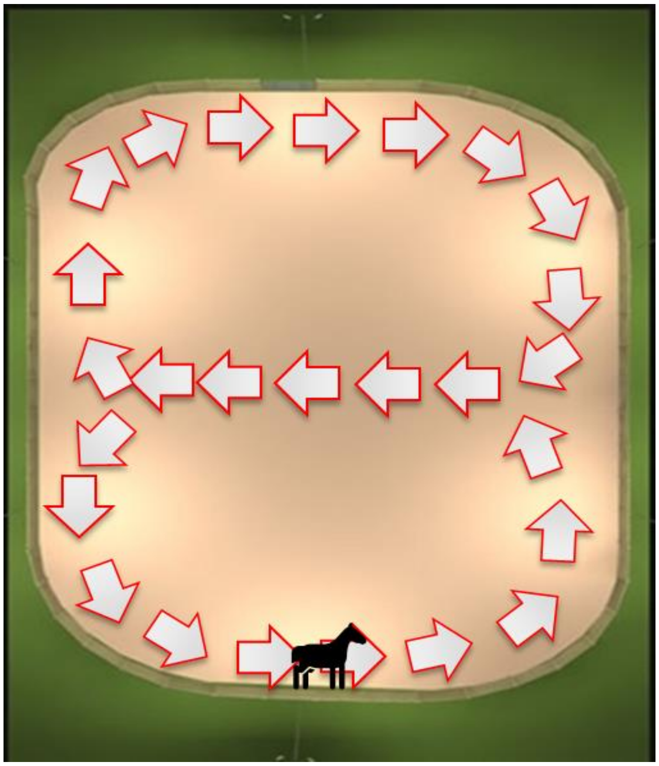

Figure 6. Trajectory of a horse in the arena during the EAT

Although subjects were not tested by the same horse handler or in the same arena, all subjects experienced the same activities, aiming to encourage subjects to move rhythmically with the horse while stimulating active postural control, trunk strength, balance, and trunk/pelvic dissociation.

2.3 Functional mobility measurement

Mobility is one of the central issues for cerebral palsy. On the review of literature, Gross Motor Function Measure (GMFM) and Pediatric Evaluation of Disability Inventory (PEDI) as outcome measures are widely employed to evaluate the functional mobility of children with cerebral palsy. However, those measurements might not be sensitive for detecting the functional change in children with cerebral palsy and they cannot assume that a unit of change has the same meaning across the scale. This study used an observational research method for the subjects over a period of time. Therefore, functional mobility measurement in this study was expected to show the recognizable and measurable changes in functional mobility over a period of time.

Timed up and go and 10-meter walk tests are valid objective measures for evaluating functional mobility over a period of time [23, 24]. These measures display validity and clinical utility while they are simple, quick, cost-effective and user-friendly. Functional mobility tests were conducted and administered by a therapist while the children's parents or caregivers were present. According to the subject's ability to walk and move, the first 3 subjects were selected to use timed up and go test and the fourth subject was selected to use a 10-meter walk test as shown in Table 3. The last subject had severe coordination disabilities that prevented the subject from completing the tasks for timed up and go test. Both timed up and go and 10-meter walk tests were repeated twice before EAT and twice after EAT.

Table 3. Functional mobility tests for subjects

Test	Subject #
Timed up and go	1, 2, 3
10-meter walk	4

2.3.1 Timed up and go

Timed up and go is a quick test used in clinical practice as an outcome measure to assess functional ambulatory mobility or dynamic balance. Timed up and go test is a reliable and responsive measure of dynamic balance and functional mobility for children with cerebral palsy between 3 and 12 years of age [25].

Timed up and go test began with the subject sitting on a chair, which was selected depending on the height of subjects. The chair was not moved when the subject moved from sitting to standing. The subject was seated in a way that hip and knee remained at 90° of flexion. A piece of tape was placed on the floor to mark the line at a distance of 3-m from the chair. The subject was asked to stand up, walk to the line on the floor, turn around, walk back to the chair, and sit down. Figure 7 represents the principles of the timed up and go test.

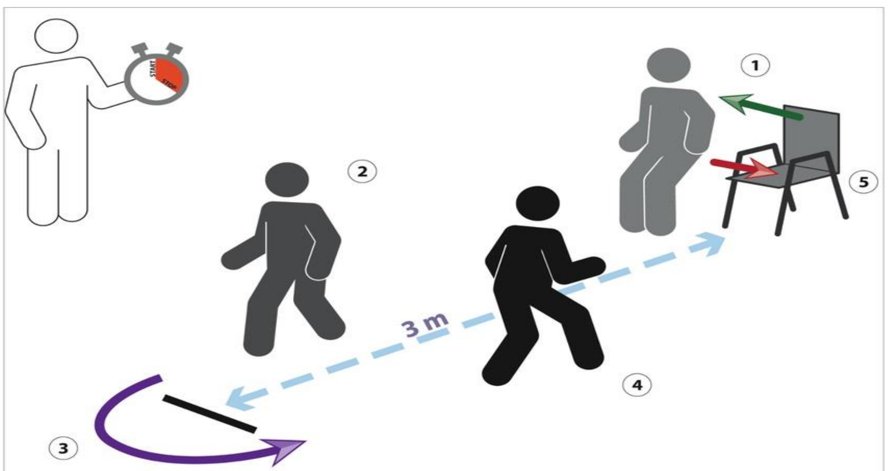

Figure 7. Principles of the timed up and go test

2.3.2 10-meter walk test

The 10-meter walk test is a performance measure used to assess walking speed in meters per second over a short distance (10-meter). This test is safe and cost-effective in cerebral palsy patients with motor function disorders [24].

In the 10-meter walk test, the last subject was allowed to use an assistive walking device because the subject was not able to stand and walk without the aid of the device. The test was conducted in comfortable gait speed following a verbal start. The time was measured for the intermediate 6 meters to allow for acceleration and deceleration. Figure 8 represents the principles of the 10-meter walk test.

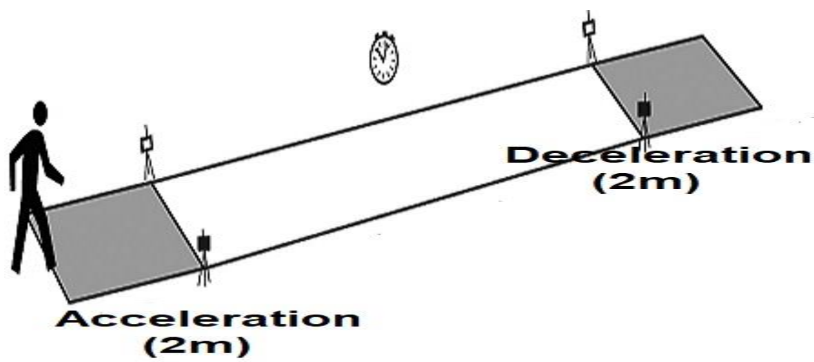

Figure 8. Principles of the 10-meter walk test

2.4 IMU calibration

An inertial measurement unit (IMU) is a tool used to measure and report a body's specific acceleration, angular velocity, and the orientation. SparkFun 9DoF Razor IMU in Figure 9 was selected because it was small enough for children so that the subjects do not get distracted by the sensors and do not become uncomfortable during the session. SparkFun 9DoF Razor IMU consisted of a microprocessor, 9DoF sensor, microSD card socket, and LiPo battery charger.

Figure 9. SparkFun 9DoF Razor IMU (size: 3cm by 3cm)

In the EAT, locations of 6 IMU sensors were designed to analyze the movement of children and horses: 3 sensors on the children’s head, upper back, and lower back and 3 sensors on the horses’ head, pelvis, and torso as shown in Figure 10. The location of the children’s sensors aimed to evaluate the head and trunk stability that is essential for limb movements and functional mobility [26]. The reasons why the sensors were placed in those places on the horse were:

1) It was the most safe and convenient place to attach to a horse.
2) Horse’s walking movement is a sinusoidal wave-like pattern.

Figure 10. Location of the sensors during the therapy sessions

The microprocessor calibrated each of acceleration, gyroscope, and magnetometer with the sampling rate at 100 Hz, which was the maximum sample rate of magnetometer. The data were logged to a microSD card.

The IMU device was programmed to collect data as soon as it was turned on. Each sensor had to be synchronized with time to compare with data from other sensors. In this project, the IMU devices did not use the remote communication system to limit the size of the sensor assembly. Instead, a switch box was designed and was connected with all IMU devices. Whenever the switch was pressed, the input pin of each IMU sensor turned from HIGH to LOW. This approach allowed all IMU data to display the same starting point, indicating the beginning of the therapy.

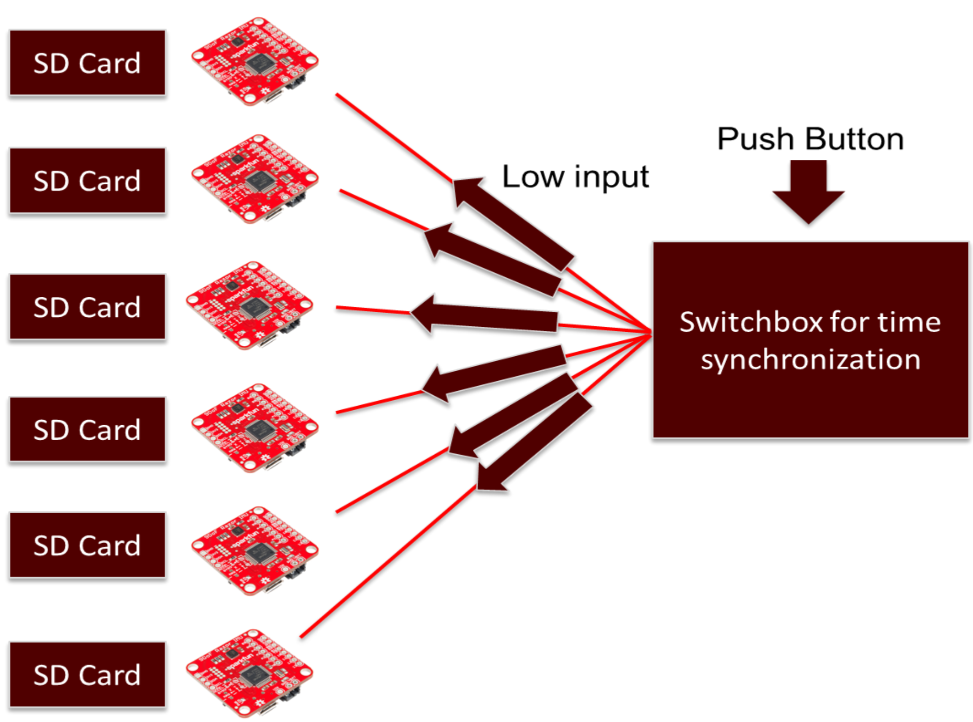

Figure 11. How the time synchronization works for the 6 IMU devices

2.5 Data processing

2.5.1 Data trimming

The IMU data obtained during the therapy session was sampled irregularly at about 11ms, and data losses happened because the data was not sampled for about 40ms each time data was logged to the SD card. For a nonuniformly sampled data set, raw data was resampled at 100Hz using interpolation of spline in conjunction in order to get a better output signal [27]. There was a need to trim the data from multiple IMU sensors. First, data before the button was pressed was deleted to have the same start time and timestamps. Second, the resampled data was divided into the first part (time instances with continuous movement) and the second part (time instances when the horse was stationary) based on the time of recorded video and analysis of time-domain data. 360,000 continuous data for 10 min in the first part was obtained from the entire data set.

2.5.2 Data selection

Acceleration data provides changes in gravity, generating physical changes in movements of the body [28]. The use of acceleration data in the study helps figure out the change in movements of the subjects and horses during EAT.

This pilot study is the first step for the evaluation of the interaction between the movements of horses and children with cerebral palsy. In order to discover kinetic relationships during EAT, the scope of data was narrowed. Uchiyama et al [18] reported that the movements in the Z-axis (up and down direction) have a strong correlation in the frequency spectra of human and horse walking. Data in the other directions will be analyzed for future study. Therefore, the acceleration data only in the up and down direction in this study was investigated. Data in the first part consisting of the continuous movement was used because it might include a lot of repetitive and rhythmic patterns of movement compared to the data in the second part consisting of the discontinuous movement.

In horse riding, the human is in direct contact with the saddle affected by the horse’s pelvic movement. The horse pelvic movement is directly affecting the human movement during EAT. The horse’s head and torso sensor data are also meaningful, but the horse’s head and torso movements are not directly affecting the rider’s movement compared to the horse’s pelvic movement. Therefore, the horse's pelvis acceleration data was selected for the kinetic relationship between horse and human during EAT. The horse's head and torso acceleration data will be examined in the future. For those reasons, this study planned to use IMU data in the up and down direction in the first part. Besides, the horse's pelvic acceleration data was selected as the representation of the horse's movement for the kinetic relationship.

2.5.3 Fast Fourier Transform

Two signal processing methods were used to analyze the data from the IMU sensors. Fast Fourier Transform (FFT) was used to convert a signal into its corresponding frequency domain to analyze variations in data, such as an event over a period of time. FFT produced the frequencies at which the high peaks of magnitude converted by FFT were generated [29]. Through Fast Fourier Transform, repetitive pattern of each signal can be displayed, and specific frequencies would be dominant.

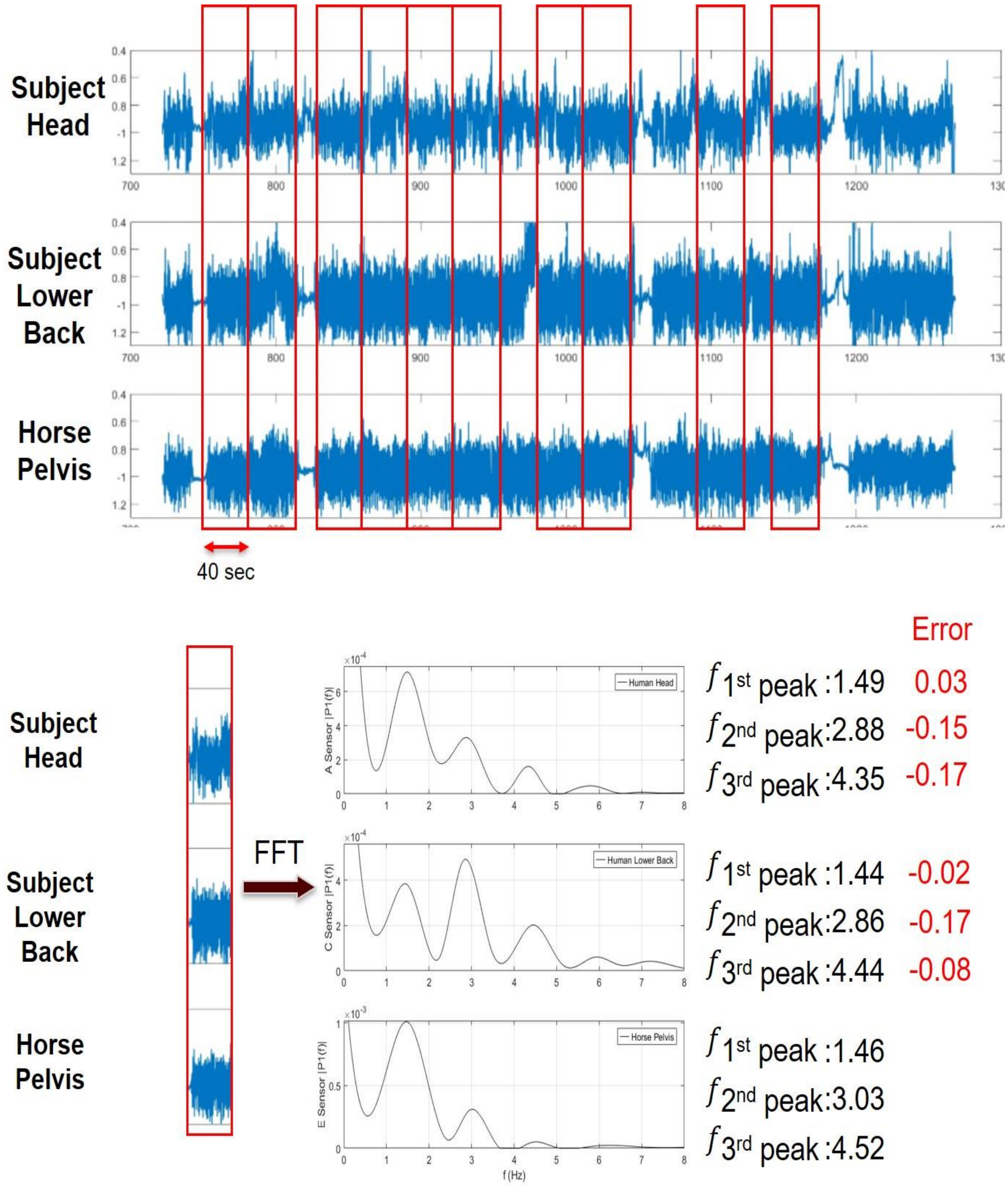

Figure 12. Example of calculation process for the frequency error between signals of subject and horse's pelvis

For accurate analysis of correlation in frequency between the horse's pelvis and subject's movements, the frequency error between those movements was calculated. Figure12 shows how to calculate the frequency error between signals of the subject and the horse's pelvis. First, each 10-minutes data was split into 10 data with 40sec, which consisted of a continuous movement without a stop or noise. Second, each acceleration data with the same timestamps was converted into its corresponding frequency domain by FFT. Then the first three frequency peaks of each acceleration data were found. The frequency peaks of the acceleration data of the subject were compared with the frequency peaks of the acceleration data of horse pelvis to produce error. The set of error within sessions was calculated into root mean square error. This method aimed to observe the changes in frequency peaks of acceleration data as the number of sessions increased.

2.5.4 Correlation by a time shift

Correlation computed a measure of similarity between two inputs. Any time delay between the signals was accounted for with an added time shift. In this study, all signals pertaining to the subject were processed with respect to signal from the horse’s pelvic movement. The correlation method investigates the relationship between two random variables. The correlation coefficient is the statistical measure that is going to allow us to quantify the degree of correlation between two random variables A and B [30].

$$\rho_{AB} = Corr(A, B) = \frac{Cov(A,B)}{\sigma_A \sigma_B} = \frac{\sigma_{AB}}{\sigma_A \sigma_B}$$

where σ_{AB}, σ_A, and σ_B are the square root of covariance of A,B, standard deviations of A and B, respectively.

To find the time delay, correlation was modified by applying a time shift. The fixed signal was correlated with another one moved by some elements to the left and to the right. In this study, the signal from the pelvis of a horse was set as the fixed one and the signals from subjects are moved to the left and to the right. This method is the same as the principle of cross-correlation. In this method, the highest correlation values are shown at positive time values, which means the signals from the subject are shifted to the right. In other words, the signals from the subject follow the signal from the horse and the movement of the pelvis of the horse.

3. RESULTS AND DISCUSSION

3.1 Functional mobility test

Comparison of results of the functional mobility test between before and after HPOT was not meaningful because children with cerebral palsy were entirely tired and fatigued by the end of the experiment and the results of functional mobility tests might vary between before and after HPOT. Considering the fatigue levels of the subjects, the results before EAT and after EAT were not compared. In Figure 13, all 4 subjects in the last session resulted in better improvement in functional mobility compared to the first session. Especially, in case of the subject 4, there were around 20 seconds decrease in 10-meter walk test between the first and last sessions.

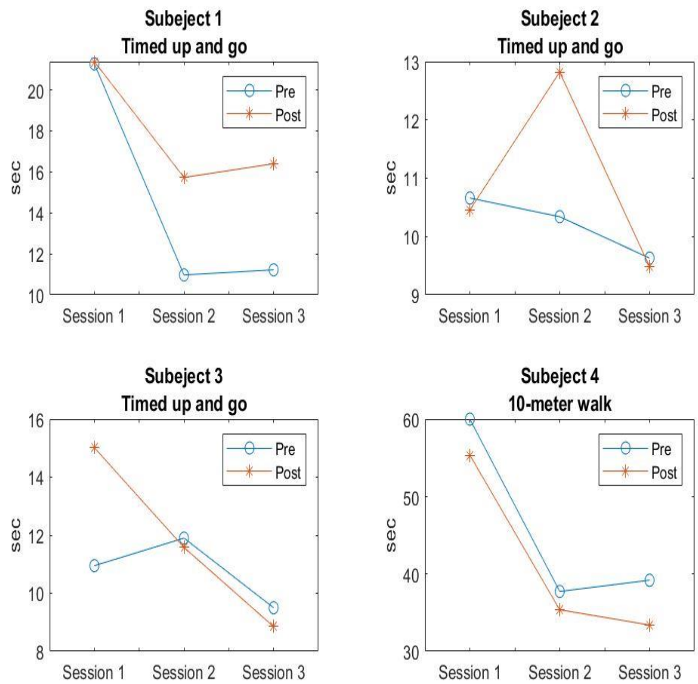

Figure 13. The outcomes of functional mobility tests for each subject

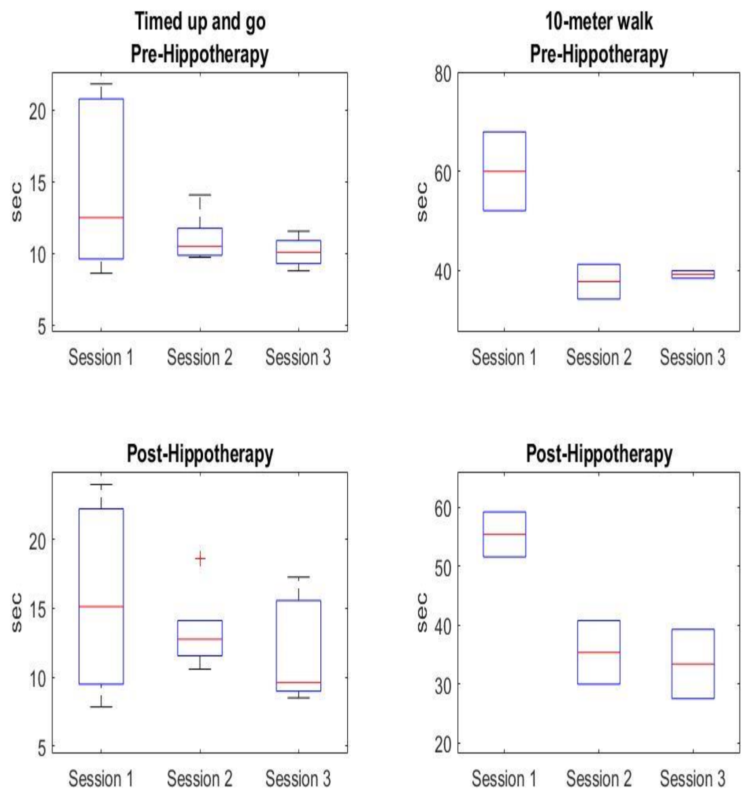

Figure 14. Boxplot of outcomes of functional mobility tests

For a better understanding of the results of the functional mobility tests, a box plot for the outcomes of the functional mobility tests was made depending on the type of test and before and after intervention. Observation has shown that the mean values of all subjects apparently dropped as the number of sessions increased. A range of variations in the results of the tests before EAT decreased as the number of sessions increased. A range of variations in results of the tests after EAT is not consistent rather is increasing over sessions. It might be explained that the fatigue levels of the subjects led to inconsistent variation of the outcomes. Despite the factor affecting the results, there is a strong trend that the progress of EAT sessions resulted in improvements in functional mobility. The results show that there was a decrease in the mean value of outcomes of functional mobility tests as therapy progressed. Also, a comparison in mean value and range of variation between the first and last sessions supports the hypothesis of this study that there would be positive changes in the functional mobility of children with cerebral palsy as the therapy progressed.

3.2 Fast Fourier Transformation

The acceleration spectra of subject 2 and horse are shown in Figure 15. The direction of acceleration used for data analysis was up and down (Z-axis). In the study, the frequency of the acceleration of the movements of subjects and horses was calculated by FFT. Frequency peaks of movements of subjects and horse pelvis were compared to find the similarity between those of subjects and horse pelvis. The frequency peaks of subject 2’s movement and horse’s pelvic movement were 1.5, 3, and 4.5 Hz. As shown in Figure 15, the frequency peaks of movement of subject 2 corresponded with those of the movement of horse pelvis during EAT.

Figure 16 represents the average spectral patterns of movements of all subjects and horse pelvis. Like the patterns shown in Figure 15, average spectral patterns of movements of all subjects and horse pelvis show the same frequency peaks of movements of all subjects and horse pelvis. The power spectra of acceleration data of the horse and subjects in the up and down direction were strong at the low frequency and were weak at the high frequency. Thus, 3 frequency peaks of movements of all subject and horse pelvis were noticeable.

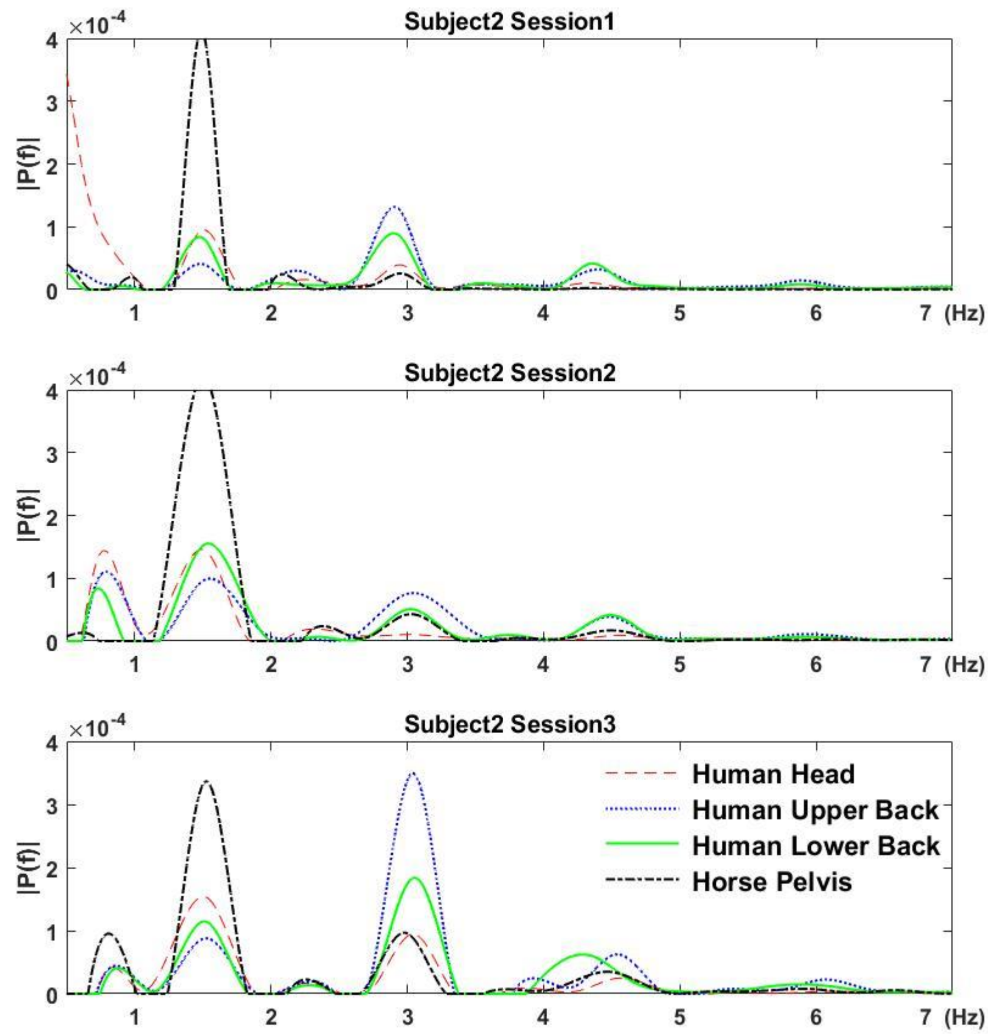

Figure 15. Spectral patterns of movements of subject2 and horse pelvis in the up and down direction during therapy each session

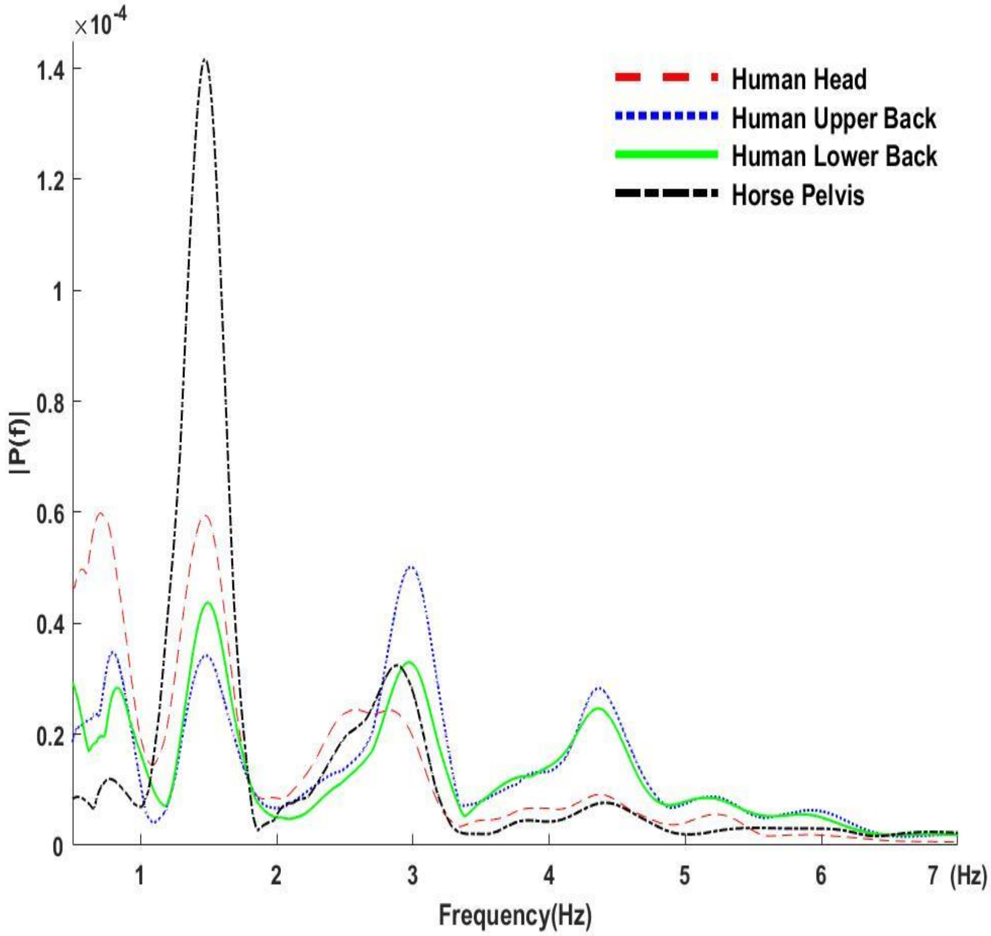

Figure 16. Average spectral patterns of movements of all subject and horse pelvis in the up and down direction

Observation has shown that the frequency peaks of movements of all subjects corresponded with those of movement of horse pelvis during EAT at 1.5, 3, and 4.5 Hz. There might be a close correlation between the movements of subjects and horses during therapy.

As shown in 5.3.2, the frequency error calculation was done to observe the changes in frequency peaks of acceleration data as the number of the sessions increased. Figure 17 exhibits the boxplot of frequency error between movements of the subjects and horses each session. It was obvious that frequency error between movements of the subjects and horse's pelvis decreased as the number of sessions increased. The mean values and the range of variation in the frequency error dropped significantly as EAT progressed. The dominant frequencies of the movement of children with cerebral palsy synchronized with those of horses. The boxplot of frequency error between movements of the subjects and horses each session provides stronger evidence to support the hypothesis of study that the movements of children and horses during the therapy would be correlated as EAT progresses.

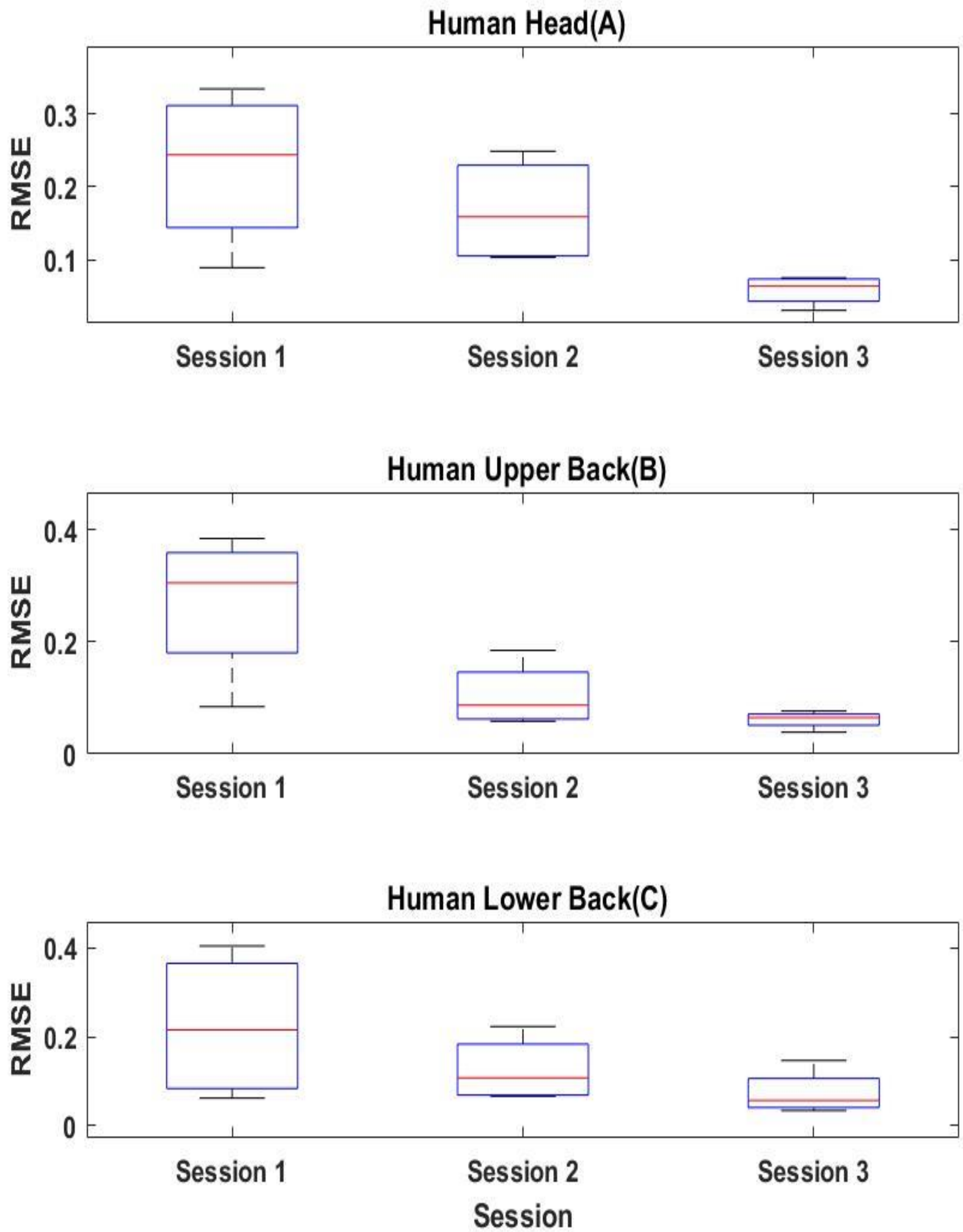

Figure 17. The boxplot of frequency error between movements of the subjects and horses each session

3.3 Correlation by a time shift

To evaluate the time delay between two signals, the correlation by applying a time shift in MATLAB was used for the acceleration in the up and down direction of subjects 4. The highest correlation values were shown at positive time values, which means the signals from the subject followed the signal from the horse’s pelvis. Figure 18 shows the correlation between the horse's pelvis and subject by a time shift for the acceleration in the up and down direction of subject 4. There were no significant changes in time delay at which the highest correlation value was generated over sessions. However, there was an increase in the highest correlation between the horse's pelvis and the subject as therapy progressed. The more synchronization between the movements of the horse’s pelvis and subject during EAT happened over sessions at a specific time delay.

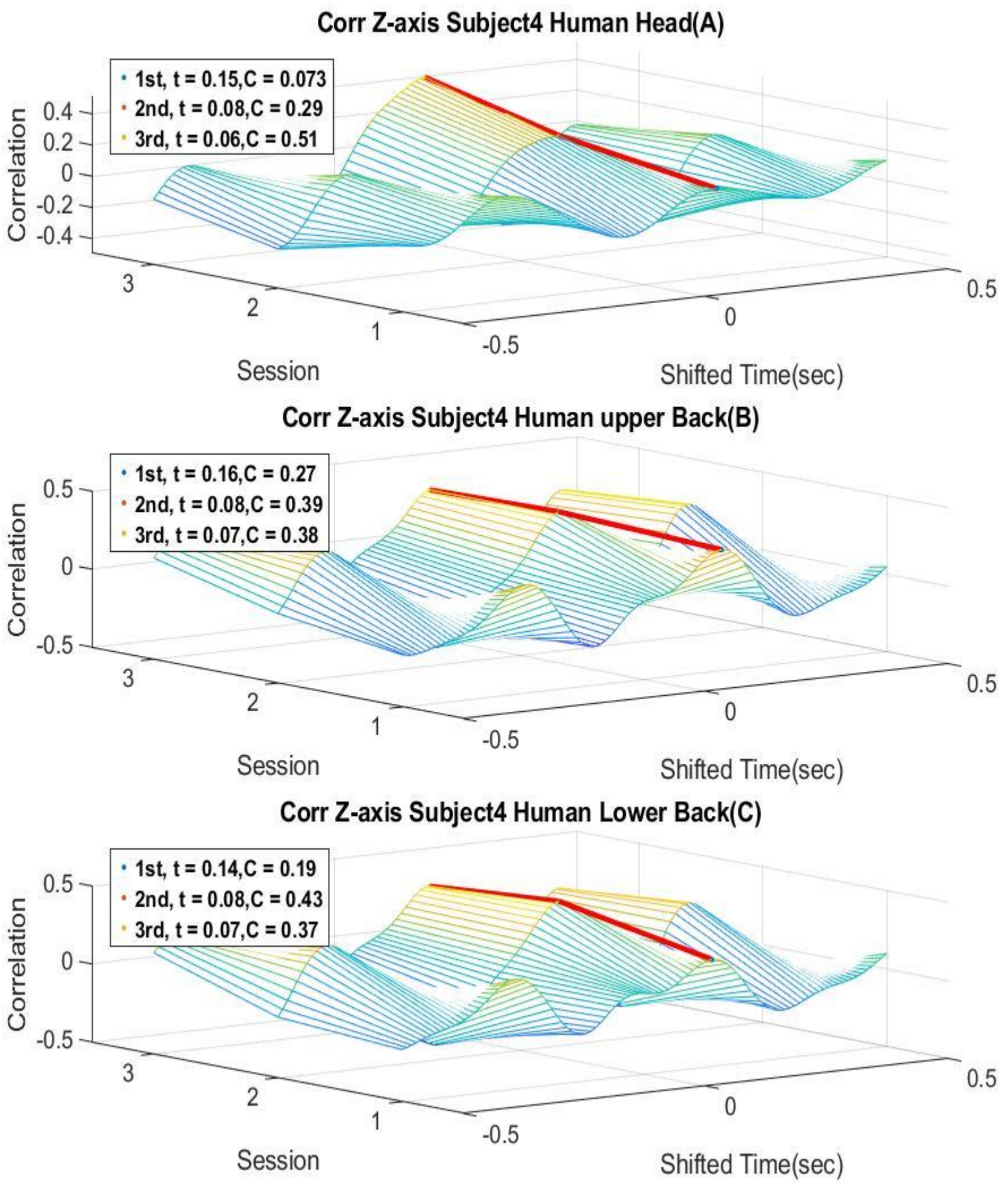

Figure 18. Correlation between horse’s pelvis and subject by a time shift for the acceleration in the up and down direction of subject 4

There was a need for analysis of data for all subjects thus box plot of the highest correlation between movements of all subjects and horse pelvis during EAT and time delay by cross-correlation method for acceleration in the up and down direction was made. Figure 19 exhibits that the correlation values of all subject sensors with horse pelvis increased as EAT progressed. The time delay values of all subject sensors with horse pelvis neither increased nor decreased over sessions. Despite inconsistent time delay, the time delay was positive at the highest correlation value and it represented the subject's signals followed the pelvis signal. As the number of sessions increased, the mean values in the correlation value increased while the range of variation in the correlation value was not consistent.

The result explains the trend that continued EAT allowed the children with cerebral palsy to become familiar with the horse's movement over time. There was a trend the children's movement synchronized with the horse's movement over sessions. Positive interaction between the movements of children with cerebral palsy and a horse occurred during EAT and improved over sessions.

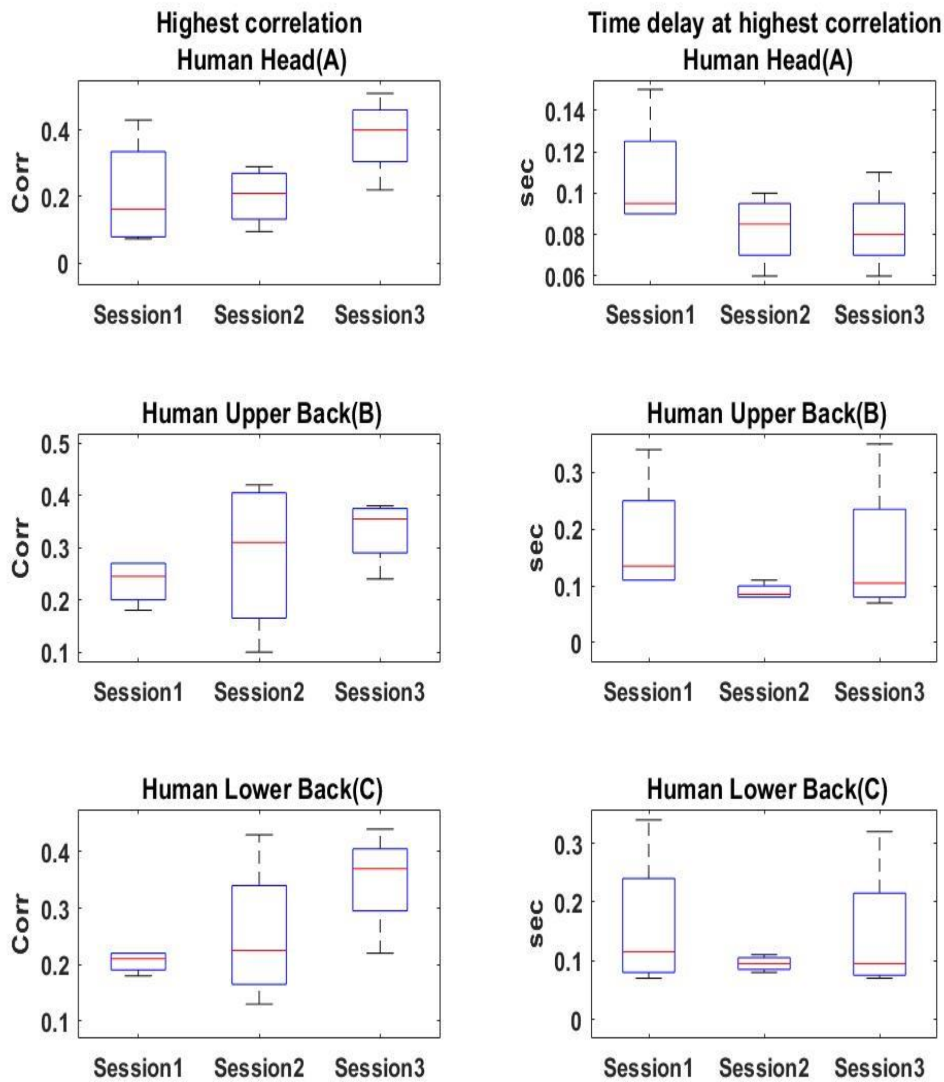

Figure 19. Box plot of highest correlation between movements of all subjects and horse pelvis during EAT and time delay by cross-correlation method for acceleration in the up and down direction

4. CONCLUSION

This study investigated how the improvement in functional mobility is linked with the interaction between children with cerebral palsy and horses during EAT. Observation has shown that the progress of EAT led to improvements in the functional mobility of children with cerebral palsy and positive interaction between movements of children with cerebral palsy and horse during EAT. EAT displays a definite trend that outcomes of functional mobility test and synchronizations between movements of children with cerebral palsy and horse have improved. Despite the limited scope of the pilot study, all results obtained from the experiment support the benefits of EAT.

Park et al [13] demonstrated the positive effects of EAT on gross motor function and functional performance of children with cerebral palsy. In this study, although different functional mobility measurement was used, the improvements in functional mobility in children with cerebral palsy through EAT were observed. Also, Uchiyama at el [18] examined the similarity between the accelerations of the horse and human gaits, indicating that horse riding could provide the motor input received from walking. This study showed that children with cerebral palsy were able to produce a positive reaction to the input from horse walking during EAT.

EAT has the potential to be a valuable treatment intervention that maximizes the functional mobility of children with cerebral palsy. EAT can be referred to as the interaction with a horse. This study is expected to lay the foundation for a better understanding of the interaction between patients and horses. The synchronization between the patient's and the horse's kinetics implies a positive response to the therapy. If successful, therapists can use the synchronization metrics, proposed in the study, to justify any improvement seen in the patients. It is hoped that designing therapeutic activities that target these synchronization metrics can result in accelerated rehabilitation.

5. FUTURE WORKS

As mentioned in the research goal and objective, there was a limited scope of research. Future work includes analyzing acceleration data in the forward and side direction, the second part data (time instances when the horse was stationary), and data of horse's head and torso. There was an interesting result of correlation for acceleration data in the side direction. Figure 20 shows the higher correlation values than the result of correlation for acceleration in the up and down direction and consistent time delay. Therefore, it is worth attempting to examine the different data that was not used in this pilot study.

Although the study provides the positive effects of EAT on functional mobility of children with cerebral palsy and positive interaction during EAT, the causality between improvements in functional mobility and positive interaction between the movements of children with cerebral palsy and horse cannot be explained using results in this study. To figure out the causality, two different environments would be designed. One is riding a horse with interaction and another is riding a horse without interaction. Those two situations help understand the effect of interaction on the improvements in functional mobility.

There will be an evaluation of the frequency difference in normal walking between children with cerebral palsy before and after EAT. Functional mobility measurement is reliable and recognizable but functional mobility needs to be analyzed in changes in the walking frequency. More studies are required to determine the impact of EAT on children with cerebral palsy.

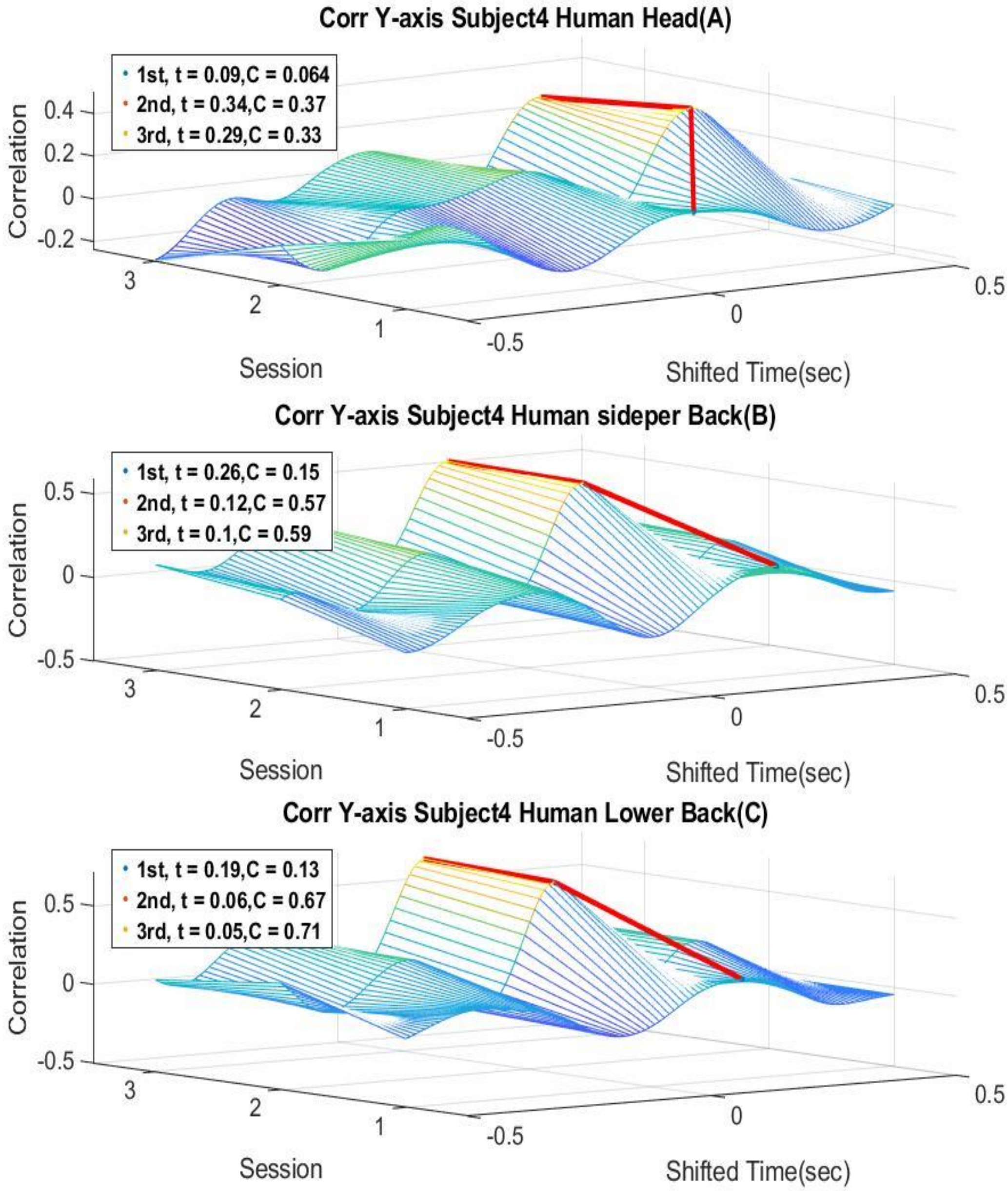

Figure 20. Correlation between horse's pelvis and subject by a time shift for the acceleration in the side direction of the subject

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