J. Phys. Ther. Sci. 32: 85–91, 2020

The Journal of Physical Therapy Science

Case Study

Monitoring of the human body and brain behavior using optical motion capture system and EEG utilizing horseback riding simulator: an extended case study

Alina Byzova, PhD[1)*], Hamid Roozbahani[1)], Heikki Handroos[1)], Nils Hakansson[2)], Hamid M. Lankarani[3)]

1) Mechanical Engineering, Lappeenranta-Lahti University of Technology LUT: Yliopistonkatu 34, Lappeenranta 53850, Finland
2) Biomedical Engineering, Wichita State University, USA
3) Mechanical Engineering, Wichita State University, USA

Abstract. [Purpose] Hippotherapy is an unusual type of treatment and has been found to be effective for diseases of the musculoskeletal system and rehabilitation. Horseback riding simulator is used as a beneficial alternative to the real horse with utilizing an optical motion capture system and EEG. [Participants and Methods] The idea is to monitor body and brain behaviour of the professional rider and non-professional rider utilizing a horse simulator, using optical motion capture system to identify differences in pelvic region activity between professional and non-professional riders and EEG to investigate the brain effect of professional rider utilizing horseback riding simulator. [Results] For the monitoring body and brain behaviour of the professional rider and non-professional rider, two types of experiment were handled, the first experiment represents body behaviour and the second experiment represents brain behaviour. [Conclusion] The study shows, that inexperienced rider may make mistakes of pelvis movements that leads to the asymmetry in hip external rotation and back region. Also, the study of EEG provides that while horseback riding mostly frontal lobe is active, that refers to concentration, body movements and intelligence. Moreover, temporal and parietal lobes are highlighted that relates to sensor-motor cortex and moving which are needed during riding.
Key words: Horseback riding simulator, Electroencephalography, Motion capture system

(This article was submitted Aug. 23, 2019, and was accepted Oct. 17, 2019)

INTRODUCTION

The positive effect of horseback riding as a therapy mostly used for elder people and children with some health issues to improve posture, balance, energy expenditure, and health state[1)] and gross motor function in children with Cerebral Palsy[2)]. The most common musculoskeletal disease, which can be healed by horseback riding therapy sessions is low back pain. Asymmetry leads to the chronic back pain as both human and horse bodies are symmetrical[3)]. In therapy, horseback riding recommends in the treatment of coronary heart disease, metabolic disorders, bronchial asthma, vegetative-vascular dystonia, functional bowel disease, rectal diseases[4)]. At the same time, there are no increased loads on the heart muscle. Riding is very beneficial for those people who undergo rehabilitation after a stroke or heart attack, because the pulse of the rider during horseback riding can reach 170 beats per minute, blood circulation is increased in 5 or even 10 times[5)].

In neurological and psychiatric practice riding is indicated as a treatment of peripheral and central nervous system patholo-

*Corresponding author. Alina Byzova (E-mail: alina.byzova@lut.fi)

gies to eliminate the effects of stroke, epilepsy, autism, some forms of schizophrenia, oligophrenia, down syndrome, as well as multiple sclerosis, various depression, neuroses, mental retardation, alcoholism, drug addiction, social adaptation, and, especially cerebral palsy[6]. Cerebral palsy is a term that combines a group of chronic non-progressive symptoms of motor disorders secondary to lesions or abnormalities of the brain that occur in the perinatal period[7].

There were numerous studies investigating posture and asymmetry of the rider during horseback riding in the literature[8–11] but more commonly using inertial motion capture system. The study by Hobbs uses optical motion capture system and concludes that rider asymmetry is recognized as a negative feature[12]. Also, studies were carried out using horseback riding simulator to monitor trunk muscle activation and balance on elder people[13] and to maintain the postural control in children with cerebral palsy[14]. There are several studies related to the human's and the horse's brain behaviour. Kim analyzes effects of horseback riding therapy on background electroencephalograms (EEG) of elderly people[15], the study of Cho is aimed to identify the effects of real horseback riding and horseback riding using horse simulator on the relative alpha power spectrum in the elderly[16] and Crews considers the existing bond between the rider and the horse using EEG and reading data from the horse and human concurrently[17]. In Crews study, it was suggested, that there is a possibility of synchronizing brain patterns between the rider and the horse while interaction.

The aim of this study is to reveal a proof-of-concept prototype of a novel horseback riding physiotherapeutic simulator system. The idea is to monitor body and brain-behaviour of the professional rider and non-professional rider utilizing a horse simulator, using optical motion capture system to identify differences in pelvic region activity between professional and non-professional riders and EEG to investigate the brain effect of professional rider who never had experience of using horseback riding simulator.

PARTICIPANTS AND METHODS

The horseback riding simulator (Fig. 1) was designed and created at the Lappeenranta University of Technology. An electrical drive Mevea (Mevea LTD., Lappeenranta, Finland) motion platform (Fig. 1) served as the motion core of the simulator and was used to generate horseback riding motions for the simulator[18]. The Mevea motion platform is 6 degrees of the freedom motion platform, operated with six electrical servo actuators that received control signals from a standard PC in combination with a Beckhoff PLC equipped with a Beckhoff basic CPU module CX2030 and Beckhoff CX2100 power supply and UPS module. The control software was written in Matlab/Simulink and TwinCat and contained a custom interface to provide real-time control of the motion platform via an ethernet connection. The motion platform works in the different modes which vary in speed. Each mode reflects the movement of a real horse implemented into the motion platform. The signals to drive the motion platform were based on sensor data collected while a participant rode a real horse (Fig. 1).

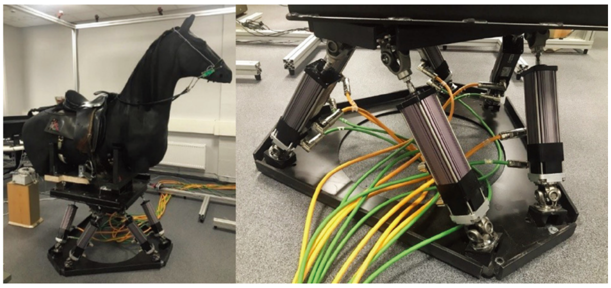

Fig. 1. Horseback riding simulator and Mevea motion platform.

A 6 degree-of-freedom wireless sensor (Inertia-Link, Microstrain, Williston, VT, USA) was used to determine the saddle motion dynamics for several horse gaits, i.e., walk, trot, and gallop. Mode "walk" is active at speed from 1 to 8 km/h, mode "trot" is active at speed from 9 to 20 km/h, and mode "gallop" is active at speed from 21 to 35 km/h. The sensor was rigidly mounted on the back of the rider's saddle to measure the dynamics that the rider sensed during the different gaits. The sensor measured three orthogonal translational accelerations and three orthogonal angular velocities at 100 Hz using accelerometers (±10 g) and gyros (±1,200°/s), respectively. The horse used for the measurements was of the Haflinger breed[19].

Mode "walk" is active at speed (km/h) from 1 to 8, mode "trot" is active at speed from 9 to 20, and mode "gallop" is active at speed from 21 to 35. Measured data was filtered and transformed to the global Cartesian coordinate system and the principle of Bryant's angles is used to handle rotational motions. In order to convert the recorded sensor data into a format to drive the horse simulator, the acceleration and angular velocity data were filtered using the classical washout filter which consists of a band-pass filter, high-pass filter and a double integrator. Parameters of filters are the band-pass filter with filter order 2 and frequency 1–30 Hz; the high-pass filter with filter order 1 and frequency 0.5 Hz; the low-pass filter with filter order 2 and frequency 0.1 Hz. After filtering the acceleration and angular velocity data were transformed into the global Cartesian coordinate system using the principle of Bryant's angles. Inverse kinematics was used to address the parallel technique of the motion platform. Inverse kinematics can be used to calculate the actuator lengths needed to simulate a particular gait based on input position data, see of Eq. 1.

$(BM) \rightarrow =P \rightarrow +R\cdot(r\_e) \rightarrow -r \rightarrow$ (1)

in which BM is the vector of a single actuator with respect to the base coordinate system, P is the vector of positions (x, y, z) of the movable plate in the base coordinate system, r is the joint location vector of a single actuator in the base coordinate system, and re is the joint location vector of the actuator in the local coordinate system on the movable plate[19]. The PID

Table 1. Experimental participant characteristics

Participant	Gender	Age (years)	Height (cm)	Weight (kg)	Experience (years)
1	Male	20	180	77	0
2	Male	22	176	72	0
3	Female	18	165	47	0
4	Female	22	165	58	13
5	Female	24	163	60	15
6	Female	21	155	48	13

controller with a feed-forward controller was chosen to make the platform motions smoother and enabled generation of a continuous motion sensation.

The experiment was conducted in the simulation laboratory of Lappeenranta University of Technology where horseback riding simulator is located. The study protocol adhered to the Declaration of Helsinki guidelines and the study complies with the ethical standards of the Declaration of Helsinki 1964. Ethical committee of the LUT University approved the study and written informed consent of publication had been obtained from each participant individually. Six people participated in the experiment—three non-professional (two male; average age: 20.0 years; height: 173.7 cm; weight: 65.3 kg) and three professional riders (three female; average age: 22.3 years; height: 161.0 cm; weight: 55.3 kg) (Table 1). Participants from non-professional rider group had little horseback riding experience whereas the participants from professional rider group had an average of 13.7 years of horseback riding experience. Electroencephalography (EEG) data was collected during the experiments from one of the professional riders (Participant 6).

Each participant completed the experimental protocol consisting of one trial for each of the six simulated horseback riding gait modes in a single testing session. Each trial consisted of two laps of the simulated ride of a particular gait mode. The six gait modes were comprised of three gaits (walk, trot and gallop) at two speeds (low and high). Specifically, the six gait modes selected for data collection were slow walk at 1 km/h, fast walk at 5 km/h, slow trot at 10 km/h, fast trot at 20 km/h, slow gallop at 25 km/h, and fast gallop at 35 km/h performed in sequential order. The simulator moves with given speed due to the ability of the motion platform. Data were recorded for 10 sec for each trial.

The same six gait modes were used for the trials in which EEG data were collected. At the beginning and at the end of the experiment the rider was asked to sit on a chair and the simulation horse without movements and with eyes closed to collect baseline data. The experimental EEG data were collected with the rider on the simulation horse as it performed gaits from slow walk to fast gallop in forward order and back from a fast gallop to slow walk in reverse order. Data were collected for 25 minutes and 45 seconds with a time step of 1 second during recording and approximately 1 minute for each gait mode.

An optical infrared marker-based motion capture system NaturalPoint OptiTrack (Planar Systems, Inc., Hillsboro, OR, USA) was used for data acquisition. Professional rider was equipped with markers placement on the body (Fig. 2). Nineteen millimeter markers with rubber base were placed to the clothes of riders with second side tape. The camera system, including twelve Flex 3 V100R2 cameras, was placed in the self-made metal frame and calibrated before the experiment started. The system has a sampling rate of 100 Hz.

For EEG data recording, a Neuroelectrics Enobio 32-electrode EEG system (Neuroelectrics, Barcelona, Spain) cap with standard electrode placement, was used (Fig. 3). The electrodes attached to the head detected the voltage fluctuations associated with brain activity and were sampled at 500 Hz. The default positions for the 32 EEG electrodes, which are approved by the American Electroencephalographic Society[20], were used.

The data, presented in this paper, is cumulative data from six riders. Rigid bodies were created, they consist of at least three markers placed around joints and measure the position (in millimetres) by three axes x, y, z. Position data needed to be filtered, filtering was made by exporting the project to Microsoft Excel where it was sorted by trackable name to observe and normalized into the equal time strides for each mode. For the professional and non-professional riders time strides account 1,000 points. After, the data was filtered using self-written MATLAB script with a low-pass filter.

RESULTS

The load from riding depends on the gait of the horse. For instance, the horse's gait trot is equal to an active walking of a human, gallop is equal to a run. During quiet riding, a person experiences much less impact on the joints and spine than with fast walking or running. It is seen from all graphs that the position of the pelvis of the professional rider changes on a smoother trajectory with lower curves amplitude compared to the non-professional rider, for example, on Figs. 4 and 5 during slow and fast trot.

Position in this case is Offsets the translation the position of the model relative to the centroid of the rigid body[21, 22]. This is due to the fact that the professional rider has more experience in riding, knows how to find a correct position in the saddle and is able to maintain upright trunk position. Also, professional rider knows how to control the body and how to interact with the horse while riding. Especially, lower amplitude of the professional rider compared to the non-professional can be observed during the slow trot.

Fig. 2. Professional rider with markers placement, front and back view.

Fig. 3. Professional rider during EEG experiment.

Fig. 4. Slow trot position for professional and non-professional riders.

Fig. 5. Fast trot position for professional and non-professional riders.

Curves colour combination on the figures means:
• for professional rider the x-axis –blue, the y-axis –red, the z-axis –yellow;
• for professional rider the x-axis –purple, the y-axis –green, the z-axis –light blue.

Every rider's measured physical value (position, velocity, acceleration, etc.) shows in the software recording as three points using a Cartesian coordinate system with its single value according x, y and z axes. Main X and Y axes are: X –number of measured points for a period of time, Y –points value.

On the slow and fast walk acceleration modes, the movements of the simulator are sharp what leads to the increase of amplitude. During walking both real horse's and simulator's movements are sharp because of the physical structure of the horse and gait type. While walking the horse's hip lifts and pushes the rider's pelvis forward and backwards, which leads to the increasing of hip's movements velocity that can be observed from Figs. 6 and 7.

The results of the slow and fast gallop velocity (Figs. 8 and 9) are very similar with a slight difference for professional and non-professional riders. The conclusion could be made based on that for the non-professional rider it is easier to balance on the horse during a gallop due to the high speed of the gait, whereas this gait is similar to the running condition of the human.

The target of this experiment is to investigate the brain effect of professional rider who never had experience of using horseback riding simulator. As horse gaits for the simulator were recorded from a real horse and implemented to the simulator and the experienced rider has better understanding of riding algorithm, we were curious about brain behaviour of professional rider while experiencing horseback riding simulator for the first time in the life. Before, rider was only get used to riding real horse and started the experiment with having no idea how the simulator works and behave.

In all investigated frequencies occipital and temporal lobes are highlighted in P4 domain, which is responsible for vision.

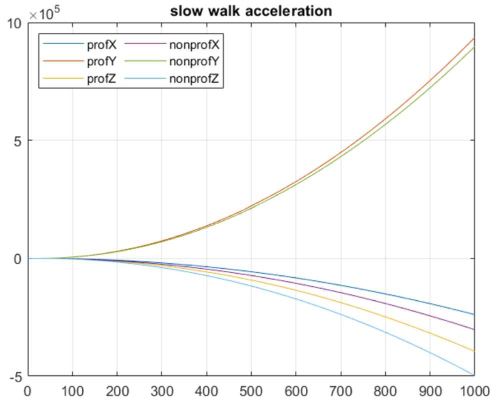

Fig. 6. Slow walk acceleration for professional and nonprofessional riders.

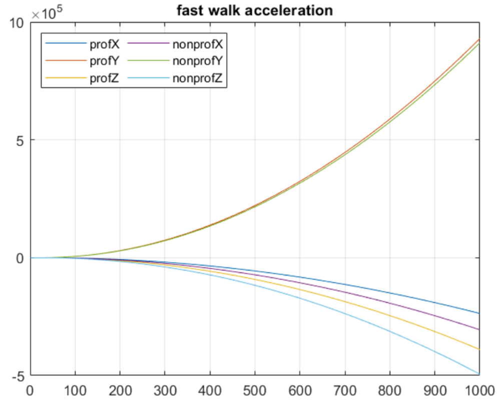

Fig. 7. Fast walk acceleration for professional and nonprofessional riders.

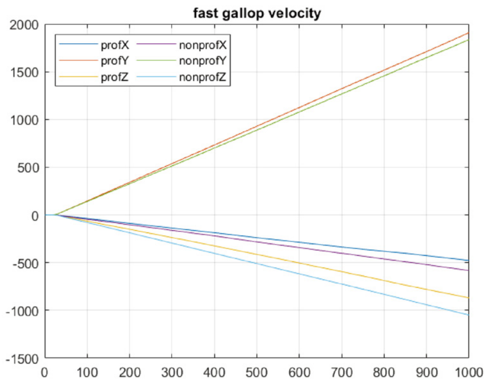

Fig. 8. Slow gallop velocity for professional and nonprofessional riders.

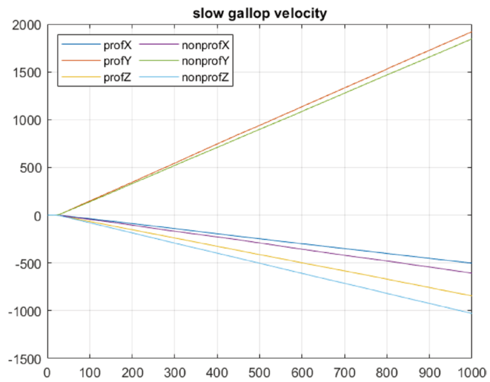

Fig. 9. Fast gallop velocity for professional and nonprofessional riders.

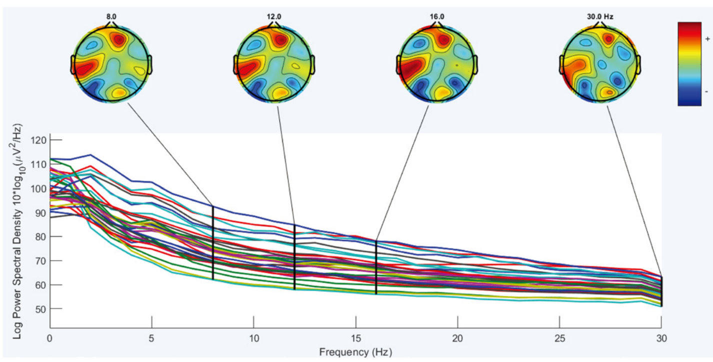

Fig. 10. Scalp map.

Lobes, responsible for hearing, are highlighted in green and yellow (Fig. 4), it shows that there was no distraction during the experiment except the noise from the working horseback riding simulator[23]. On a scalp map, higher activation accrues in the F4 domain in the frontal lobe, which refers intelligence, concentration, body movements, speaking, and emotions. Domains C3, CP5 that relates to sensor-motor cortex and moving are highlighted in red.

There is no significant difference between brain scalps on 8 and 12 Hz frequencies (Fig. 10). That can be explained by the skills of the professional rider who knows how to control the body and horse and who is familiar with all horse gaits. Greater concentration is observed at 16 Hz frequency, activation in the F4 domain in the frontal lobe is even higher and coloured in dark red that can be caused by changing of horse gait and increasing the speed. Occipital and temporal lobes in P4 domain, which are responsible for vision are highlighted brighter and frontal lobe responsible for concentration is highlighted lighter at 30 Hz frequency.

DISCUSSION

This study shows, that the rider who has never experienced horseback riding before may make mistakes of pelvis movements in the saddle that can lead to the asymmetry in hip external rotation and back (Figs. 4 and 5). It is very essential to the rider to pay attention to the kinematic, especially, the position of the pelvis during riding a horse. All the movements that a rider receives from the horse are absorbed mostly by the lower region of the body such as the pelvis and hip joints. If the rider loss any mobility at the pelvic region, then all force from the horse's movements will transfer to the lumbo-pelvic region. Incorrect absorption of movements can cause injuries in the upper part of the body, especially back injuries as it is the most vulnerable area. The rider should keep the pelvis in a neutral position without any rotation to avoid lumbar lordosis or anteriorly rotated pelvis. Scientifically proven, that professional riders keep their pelvis closer to the centre of the saddle and further forward then non-professional riders, which tilt pelvis to the left or right and more backward[24].

The preliminary study suggests that optical based motion capture method has several drawbacks related to the size of whole equipment used in the experiment. The optical motion capture method is not portable. Camera placement and camera calibration using wanding tool take a very long time to record every piece of future captured volume. Marker placement, also, is a time-consuming process, that requires basic knowledge of the human's body anatomy and additional equipment using for markers binding. The structure of markers is fragile, markers are easy to break, what does not correspond the price for one single marker. The price of the special suit that could be purchased is too high for a laboratory experiment.

The future perspective of the following research is currently being held by LUT Laboratory of Intelligent Machines. A new platform is being designed to maintain higher frequencies. A new horse is being measured to apply the new data to the last version of a motion platform. New optical based motion capture software and equipment are being installed in the laboratory to contribute with a high-quality measurement and assist with easier handing and user-friendly interface.

This study, additionally, investigates electroencephalography of the brain activity while riding a horseback simulator. Low and high frequencies affect to the brain activity in a different range. Low frequency corresponds to relaxation and sleeping time, while high frequency is responsible for awaking time and activities such as sport, mathematics, concentration[25]. Thus, every brain lobe represents different brain activity. While horseback riding mostly frontal lobe is active, that refers to concentration, body movements and intelligence that are needed during riding. Also, temporal and parietal lobes are highlighted that relates to sensor-motor cortex and moving.

Funding and Conflict of interest

The authors declare that they have no competing interests and that they have no funding.

ACKNOWLEDGEMENT

The authors would like to express very great appreciation to all professional and non-professional riders, who participated in the experiment and helped with their big impact to the research. The authors must also express special thanks to Amin Hekmatmanesh for his huge contribution made with experiment, guidance and help with signal processing and neuroscience. The authors acknowledge the help provided by Juha Koivisto with technical support in the laboratory.

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