IEEE Access
Multidisciplinary ⋮ Rapid Review ⋮ Open Access Journal

Received August 4, 2020, accepted September 1, 2020, date of publication September 4, 2020, date of current version September 17, 2020.

Digital Object Identifier 10.1109/ACCESS.2020.3021746

Real-Time Human Body and Brain Monitoring During Horseback Riding Simulator by Means of Inertial Motion Capture and EEG Systems

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ABSTRACT One type of effective muscular disorders therapy is horseback riding. The main objective of the present study is developing a physiotherapeutic simulator (concept proof) instead of a real horse though employing the Electroencephalography (EEG) amplifier and inertial motion capture system (IMCS). In the experiment, the professional and non-professional rider's body movements and brain-behaviors monitored during the horseback riding simulator. The computational analysis for identifying the alterations of the pelvic area activity among two group riders were considered based on the IMCS. The EEG system was used for investigating the brain signals of the experienced horseback rider who had never experienced using horse simulator. For this purpose, the following experiments were handled, representing body and brain-behavior. As a result, it was concluded, that inexperienced horseback riders tend to make movement mistakes while riding a simulator, which may cause asymmetry shift in external hip and back regions. The study of EEG shows that the frontal lobes, which are responsible for intelligence and concentration were activated. Also, the temporal and the parietal areas of the brain which are responsible for movements and vision were activated significantly, respectively.

INDEX TERMS Electroencephalography (EEG), horse simulator, horseback riding therapy, motion capture system.

I. INTRODUCTION

Horseback riding is known as a type of therapy (i.e., hippotherapy) for some macular disabilities in medical studies. Research has shown that horseback riding is an impressive therapy for muscular disturbances, which is based on the advantages of horseback riding for enhancing the human balance, disposition, energy consumption, motor function development, mental health and emotional states [1], and the general state of human health [2]. The beneficial impact has been noted in folks suffering from back pain and who have movement difficulty. For instance, in the past decay it has been shown that the hippotherapy is an impressive method for improving posture [3] and developing brain motor function [4] in children with cerebral palsy, a condition affecting approximately two in every 2000 live births in the western world [5]. Also, it is been reported that the patients who suffered from Parkinson in the early stages (balance problem and multiple sclerosis) have been improved [6]. It is estimated that 380,000 individuals suffering from multiple sclerosis in European countries. Additionally, the costs associated with multiple sclerosis – €12.5 billion for direct costs, informal care, and indirect costs – could be reduced if accessible appropriate therapy became more widely available [7]. European Agency for Safety and Health at Work [8] released a report of work-related low back problems that 15%-42% of folks are suffering from low back pain and about 60%-90% of folks will have low back difficulties in their lifetime. Since this initial report, a follow-up survey (2010) has resulted in confirmation of these findings in addition to identifying

The associate editor coordinating the review of this manuscript and approving it for publication was Mohammad Zia Ur Rahman.

trends in the occurrence of work-related musculoskeletal disorders [9].

There are multiple areas of research that have sought to investigate and assess the therapeutic benefits of hippotherapy. One group of studies was directed toward researching rider's body position and laterality while experiencing horseback riding using inertial sensing technology for detecting inertial sensors prospective and restrictions to consider the rider's pelvis motion three types of movements such as canter, trot and walk with certain precision for repeatability [10], to indicate the incommensurability in horse riders, which is seen by the measured differences in the external rotation angle of the hip joint [11], to consider the interplay factors in the rider–horse system for various skill in horse movement levels such as canter gaits, sitting trot, and walk [12]. Horseback riding simulators have also been used in studies focused on monitoring trunk muscle activation and balance in older adults [13] and body position control in children suffering from cerebral palsy [14]. Another area of research focused on the rider's mind and the horse's brain-behavior. Kim *et al.* analyzed influence of physical therapy using horseback riding with EEG for old people [15]. EEG signal analyzing is a noninvasive method for considering neuron activities. Depend on the tasks and regulations in an experiment, specific neurons are activated and generate stronger signals than other locations. In our experiment, we focus on the locations related to a task related to horseback riding. During horseback riding body movements (specifically hand movements, sensory motor cortex area), high mental focus (frontal lobe of brain) is required [16]. The locations for considering sensory motor cortex area are C3, C4 and Cz. Also, for considering the frontal lope FP1, FP2, AF3 and AF4 signals are monitored and analyzed.

Whereas Cho *et al.* attended to compare the impacts of the physical therapy horseback riding with an alternative horseback riding simulator [17]. In the experiment, the alpha power spectrum is investigated as a measurement parameter in the elderly participants. As stated by Vulckovic *et al.*, motor imagination brain-computer interface has been used as a part of therapy to restore motor functions [18]. Furthermore, Electroencephalography (EEG) data from a real horse and a participant human rider recorded by Crews simultaneously for researching the bond between them [19]. The result of the research is a suggestion that there is a possible synchronizing brain pattern as a bond between the pair during riding.

Despite the breadth of research demonstrating the benefits of horseback riding as a therapeutic activity, access to hippotherapy is limited, particularly in high population density areas. Therefore, a substitute for a real horse such as a horse simulator will be beneficial. Whereas the mentioned research has shown a connection between postural control and brain waves when riding a real horse, limited research has been done to a assess the potential therapeutic benefits (i.e., the rider's motion and brain activity) associated with riding a horseback riding simulator. Because no studies are

FIGURE 1. The employed horseback riding simulator in the experiments and designed Mevea motion platform for the experiment.

proving that the therapeutic benefits are similar between a real horse and simulator, the first aim of the present paper is assessing and comparing the benefits of therapeutic riding a real horse with a simulated horse (i.e., pelvic region motion). The second objective of the present study is suggesting a new prototype as a proof-of-concept for the physiotherapeutic simulator system, which is a horseback riding simulator. The outcome of this component of the study will determine whether the test model simulator can serve as a suitable option to replace a real horse for therapeutic sessions. The second objective is to determine whether a professional horseback rider exhibits the same body motion and EEG activity when riding a real horse and the horse simulator system.

The current paper represents the second experimental part in research studying the body and brain-behavior utilizing horseback rider simulator at the Lappeenranta University of Technology (LUT) (See Appendix A). The same horseback riding simulator was used to conduct the experiment. Also, the participants in both studies remain the same, as well as, the experimental protocol. The main difference between the studies is a motion capture approach detecting the body movements. The EEG part analysis presented in the article was processed from a different point of view, taking into account the growth in future independent research.

II. METHODS

A. HORSEBACK RIDING SIMULATOR

Laboratory of Intelligent Machines in LUT has developed the concept and design of the horseback riding simulator (Fig. 1). The motion core of the simulator is an electrical drive Mevea motion platform [20] (Fig. 1).

The horseback riding movements were generated using the Mevea platform. The platform has six degrees of freedom motion and operates by activating six servo actuators. The servo actuators receive a control signal from a basic personal computer with connected a BECKHOFF PLC. The electrical parts of the simulator are equipped with the BECKHOFF PLC that includes CPU CX2030, power supply CX2100 and UPS[19]. The control software of the platform is Matlab/Simulink and BECKHOFF TwinCat. The software provides a custom interface for the motion platform identification in real-time control using an ethernet connection. In the platform computations, the motion platform integrates three main movements of a real horse in different speed modes.

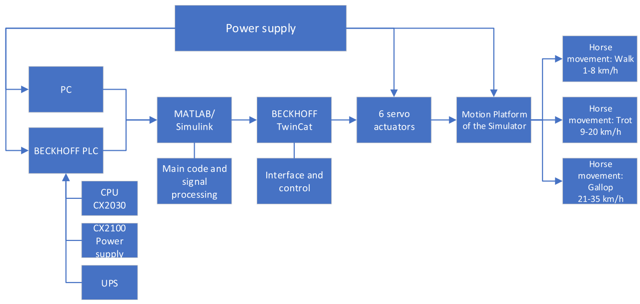

FIGURE 2. The block diagram of the operational principals of the designed horse simulator.

Driven signals and patterns of the motion platform are the imitations of the recorded patterns from a real horse, which are measures using different sensors. The block diagram (FIGURE 2) represents the operational principals of the designed horse simulator.

The saddle motion dynamics from the real horse was recorded using a Microstrain Inertia-Link with 6 degree-of-freedom which is equipped with a wireless sensor. Three horse gaits were recorded: walk, trot and gallop. The speed for the movements varied as follows: 1km/h to 8km/h regarding the "walk" movemement [21]; 9km/h to 20km/h regarding "trot" movemement [21]; and 21km/h to 35km/h regarding the "gallop" movemement [21]. The wireless Inertia-Link sensor was motionlessly located at the rider's saddleback for measuring the movement dynamics of the rider experienced at different horse's gaits. Through six sensors the real horse movements were measured in which included three orthogonal sensors for measuring the vertical acceleration and three sensors for measuring the vertical angular velocities. The data collection was conducted at 100 Hz using accelerometers (± 10 g) and gyros ($\pm 1200°/s$), for measuring acceleration and angular velocity, respectively. The Haflinger breed horse was used for the experiment.

In the angular velocity and acceleration data processing algorithm, the data was denoised using a combination of two filters: band-pass filter and high-pass filter. In the next step, a double integrator is employed for transforming the measured values from a sensor to steer the horseback riding simulator platform. Filtered data was transformed into the Cartesian coordinate system by means of Bryant's angles principle [22]. By using the inverse kinematics, the parameters of the future platform were calculated, using the equation (1). All parameters are chosen concerning the base and local (r_e) coordinate system. The PID controller was chosen as an instrument to enable a continuous motion sensation and smooth the platform's motion [23].

$$\overrightarrow{BM} = \overrightarrow{P} + R \cdot \overrightarrow{r}_e - \overrightarrow{r} \quad (1)$$

where:

BM – is the single actuator vector;

P – is the movable plate position (x, y, z) vector;

r – is the single actuator joint location vector;

r_e– is the actuator joint location vector on the movable plate [23].

TABLE 1. Participants details information.

Participant	Sex	Age (years)	Height (cm)	Weight (kg)	Experie nce (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

B. PARTICIPANTS

In the study, six participants have participated in the experiment with the following details (shown in Table 1): two males as professional riders: average age: 20.0yrs; weight: 65.3kg; height: 173.7cm. Three professional riders with the following details: three females; average age: 22.3yrs; weight: 55.3kg height: 161.0cm [22]. Non-professional riders had never experienced horseback riding before and the professional horseback rider participants had an experience of 13 to 15 years. The EEG signals were recorded while the professional riders (Participant 6) were performing the task. The present paper followed the Declaration of Helsinki principals. Authors confirm that oral and written informed consents of participation and publication were obtained from all participants [22].

C. EXPERIMENT PROTOCOL

The experimental task was accomplished by individual participants. Each trail includes six simulated horseback riding gait fashions, which is placed in a single testing session. According to the protocol, six chosen gait modes were completed during the experiment. The gaits at the lowest and highest speed each were operated inconsistently following order: I- Slow and fast "walk": 1km/h and 5km/h, respectively; II- slow and fast "trot": 10km/h and 20km/h, respectively; and III- slow and fast "gallop": 25km/h and 35km/h, respectively [21]. Data were recorded for 10 sec during single trial [22].

The EEG was recorded while the horse gait modes were presented in the experimental protocol as follows. At the beginning of the experiment, the participants have to sit and close their eyes for relaxing on a chair, and then on the switched-off simulator. The measurements were carried out as simulator performed gaits from a slow walk to fast gallop in forward and reverse order. Data was collected for 30 minutes with a one-second time step during recording and 45 seconds for each gait mode [22].

D. DATA ACQUISITION

For motion capture data acquisition, a wireless inertial measurement system (MTw Awinda and Xsens MVN, Xsens, Enschede, Netherlands) was used. The MTw wireless motion tracker, built-in the suit, provided position, orientation, velocity, angular velocity and acceleration data. Initially, the inertial motion capture system was calibrated according to the manufacturer referenced N-pose [24]. The inertial system data were sampled at 240 Hz and recorded for further analysis.

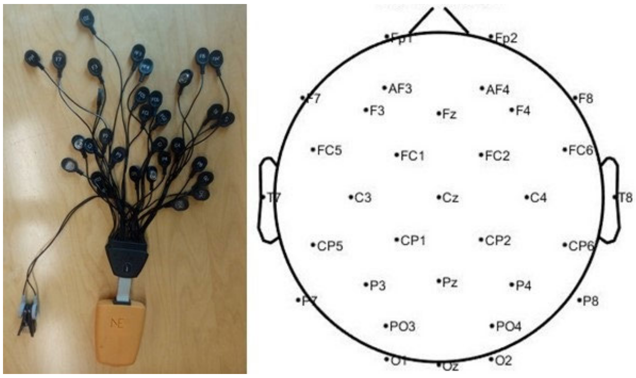

FIGURE 3. The portable EEG device and the topography of the electrode's placement.

FIGURE 4. Professional rider during EEG experiment.

The Employed EEG amplifier in the experiment was the Enobio 32-electrode that the electrodes placed regarding the 10-20 standard (FIGURE 4). The sample rate for recording the brain wave was detrended and set to 500 Hz. The 32 EEG electrodes placement was illustrated based on the 10-20 standard used in the experiment as a recommendation approved by the American Electroencephalographic Society (Fig. 3) [25]. Also, the topography of electrodes installation is depicted in Fig. 3.

E. DATA PROCESSING

Presented data is cumulative from all participants with acceleration, angular velocity, velocity, position, and orientation parameters analyzed. All parameters were analyzed in anterior-posterior directions and parameters such as acceleration, angular velocity, velocity needed to be filtered. In the algorithm, a low-pass filter with frequency 40-100Hz was used for filtering.

For EEG data processing, Neuroelectrics NIC OFFLINE software was used. In the filtering approach, a lowpass Butterworth filter with the edge of 0.1 to 30 Hz is designed in MATLAB to remove noise.

III. ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Written informed consent to participate was obtained from all participants. The study does not deviate from the principle of informed consent because all participants gave their consent for participation and publication. Ethics approval was unnecessary according to national regulations of Human Sciences in Finland and guidelines issued by the Finnish National Board on Research Integrity (TENK) [26].

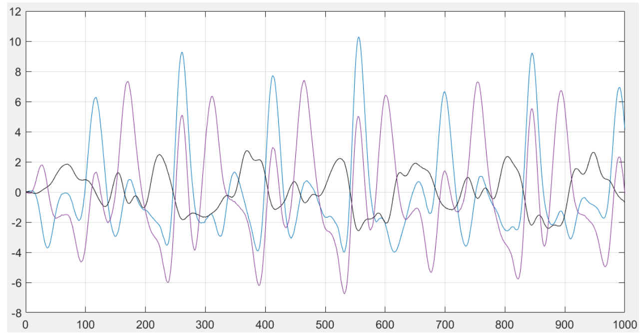

FIGURE 5. Unexperienced rider slow trot acceleration data representation (purple – x, black – y, blue – z axes).

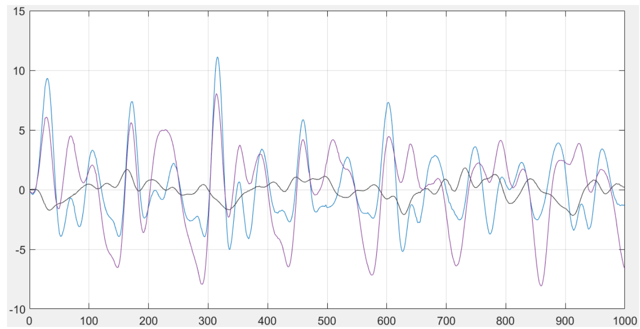

FIGURE 6. Experienced rider slow trot acceleration data representation (purple – x, black – y, blue – z axes).

IV. RESULTS

A. ACCELERATION

All acceleration data graphs have a similarity on a higher speed of all gaits including fast walk, trot and gallop. Measured acceleration, velocity and angular velocity indicate the recorded physical values in the Cartesian coordinate system as a single value at x- (purple curve color on the figure), y- (black) and z-axes (blue). Horizontal and vertical axes on the coordinate grid show the number of measured points value and point a period, respectively. The reaction of a professional rider to horseback riding simulator movements is softer and smoother in contrast to the inexperienced rider at the same gait. The movements of the experienced rider, representing the pelvic region acceleration have less curved tranquilly direction of changes indistinctive for the inexperienced rider. It is seen that the amplitude along the z-axis of the non-professional rider is higher and uneven, there is no sequence in movements. Results of the slow trot (Fig. 5 and 6) show the most different values, while at fast trot there are almost no differences along with graphs. For the rider with no experience faster gait of the horse (e.g. fast trot, gallop) is easier to maintain as it has analogous patterns which occur while the human is running [27]. Besides, it may be caused by addictive to the horseback riding simulator's movements.

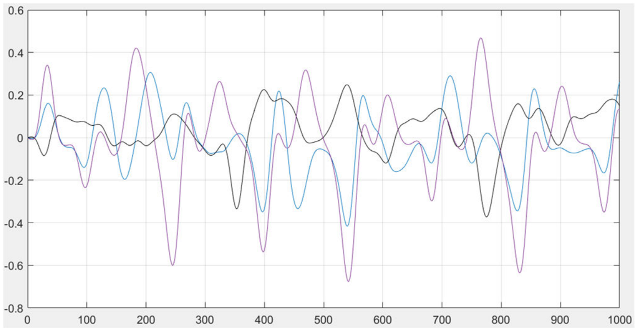

FIGURE 7. **Unexperienced rider slow trot velocity data representation (purple – x, black – y, blue – z axes).**

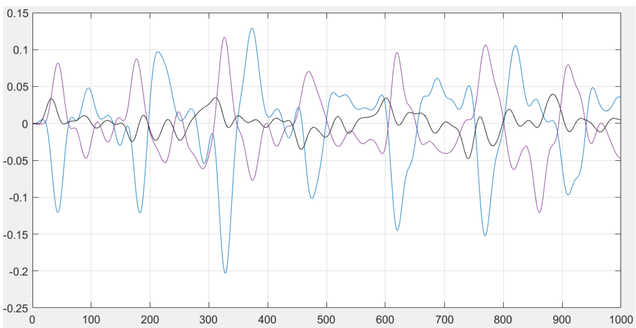

FIGURE 8. **Experienced rider slow trot velocity data representation (purple – x, black – y, blue – z axes).**

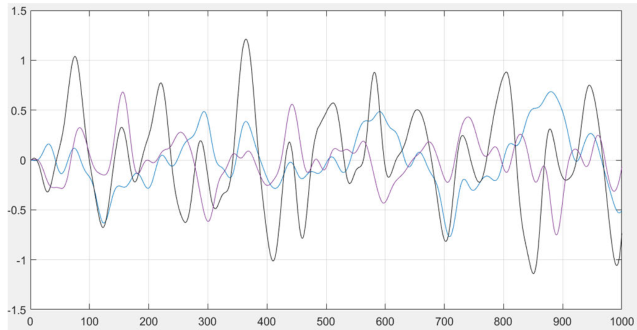

FIGURE 9. **Unexperienced rider fast walk angular velocity data representation (purple – x, black – y, blue – z axes).**

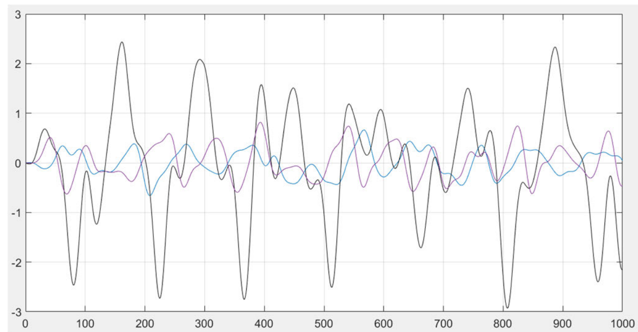

FIGURE 10. **Experienced rider fast walk angular velocity data representation (purple – x, black – y, blue – z axes.**

B. VELOCITY

Comparable amplitude can be noted only at slow and fast walk gait. At slow and fast walk gait it is seen that professional rider velocity synchronizes with horseback simulator's gait speed and movements with every step. Velocity data of non-professional rider has chaotic behavior at every mode of horseback riding simulator, especially, at the slow and fast walk and slow trot (Fig. 7 and 8).

From slow trot mode amplitude of non-professional rider starts to change from the z-axis to the x-axis and increases with every following mode of the simulator [28]. At a fast trot, the amplitude of the velocity data on the figure has the most chaotic behavior along the x-axis three axes without any tendency. At slow and fast gallop there is a similar pattern for velocity data of the non-professional rider riding horseback simulator.

C. ANGULAR VELOCITY

The physical properties, meaning and description of angular velocity provide a great explanation for the tendency of minimal changes along the x- and z-axes for the experienced rider and provide a trace of higher amplitude along the y-axis at slow walk gait mode. At the fast walk (Fig. 9 and 10) there is the same trend for the rider as the previous gait, but the amplitude of the non-professional rider increases, and the amplitude of z-axis is extremely different from other cases [29]. At the slow and fast trot, the amplitude along with y-axis increases, that makes the scenario of angular velocity data graphs more similar with a professional rider.

At a slow gallop, the amplitude rises along x- and y-axes for non-professional rider and only along y-axes for the professional rider that can be explained by the level of experience of the riders. At a slow gallop, the amplitude rises along x- and y-axes for both non-professional and professional riders that can be explained that the fast gallop gait forces to balance the body position attentively due to presence of higher concentration and the perception of force given from the horse [30].

D. POSITION

During all gaits, the results of the professional rider are steady without any significant changes and oscillation axes of x, y and z. At slow walk gait for non-professional rider changes only along z-axes are small and more or less stable, but curves along with x-axis decrease, y-axis increase. At fast walk gait, there is displacement along all three axes, the curve along with the x-axis decreases, and the amplitude of the x-axis is major for the non-professional rider. The amplitude of the professional rider slightly increased. During slot trot of the non-professional rider there are almost no changes along z-axis although oscillation is high, and curves along with the x-axis decrease, y-axis increase. At the fast trot of the non-professional rider, the x and z-axes stable, the curve along with the y-axis increases, although amplitude and oscillation are moderate. There are significant changes in the values at y-axis and between the figures for professional and non-professional riders at a slow and fast gallop. For non-professional rider at slow and fast gallop gait curves along with x-axis decrease, y-axis increase, and the z-axis is stable.

E. ORIENTATION

The results of the professional rider among all gaits show good quality and understanding of the riding process. There is no sensible representation of the data results at slow walk mode gait for the unexperienced rider due to chaotic behavior of the curves. At the fast walk, the amplitude of x- and z-axes increases for the non-professional rider, and changes along y-axis look more than experiencing horseback riding compared to slow walk gait. The amplitude rises for the professional rider that can be explained as increasing of the speed [31].

During slow and fast trot gaits there is no significant difference along x- and z-axes. The amplitude of the y-axis of the non-professional rider increases, but the amplitude of the professional rider is much higher. At slow gallop gait, the main drawback among all results of the non-professional rider is that x-axis is very smooth. The amplitude of the z-axis is extremely high, and the amplitude of the y-axis is slightly less compared to the professional rider. The results at fast gallop gait are mostly similar to slow gallop except that the amplitude of y-axis is lower, the z-axis is higher for the professional rider compared to slow gallop gait [32]. For the non-professional rider the amplitude of z-axis increases, but the y-axis is stable.

F. STATISTICAL ANALYSIS

For statistical analysis, the two-way analysis of variance (ANOVA) was used to determine whether the speed (acceleration, angular velocity and velocity) and gaits of the simulator have an effect on the rider's level of experience. The statistical analysis was performed in Matlab and Excel. The statistically significant difference was found in the experience of the riders by both speed ($F = 36.66$, $p = 0.006$) and gaits ($F = 19.56$, $p = 0.0013$). The significance level is assumed to be 0.05, p-values are less than the level of significance, though the interaction between speed and gait is not significant as F-values are bigger than F-critical value (F critical $= 1.625$). The graphical result of the two-way ANOVA is shown in Fig. 11, where group 1 (blue) – professional riders and group 2 (red) – nonprofessional riders.

The results of the statistical analysis show the effectiveness of the conducted experiments as it was statistically proven that the experienced riders show better performance than inexperienced ones in terms of utilizing horseback riding simulator at various speeds and gaits. The significant difference in results proves the advantageous effect of having basic principles and understanding of horse riding.

G. EEG

The EEG is employed to consider the horse simulator effects on a professional rider's brain. In the experiment, the rider did not have experience of simulator horseback riding. The question is, does the effects of a real horse on the brain is the same as a horse simulator, that the behavior is recorded based on a real horse [33]?

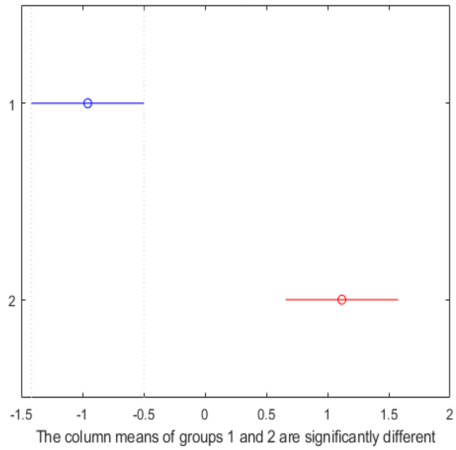

FIGURE 11. Graphical representation of two-way ANOVA.

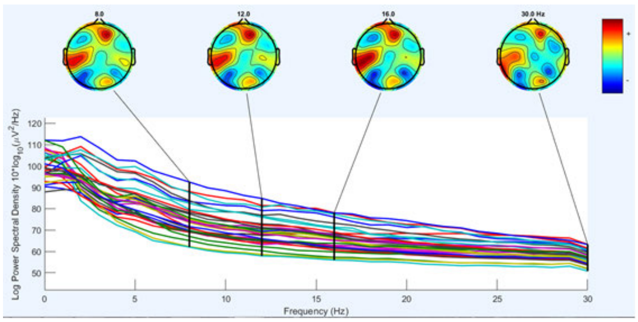

FIGURE 12. Sculp map.

In the experiment, we know that the parietal (P4), Occipital (O1 and O2) are the activated areas for the task, which are relative to the vision and illustrated in sculp map Fig. 12. In the sculp map, it is shown that the hearing areas have small affection by horse simulator noise and highlighted by green/yellow colors [34]. Regarding Fig. 12, the most affected area of the brain is the frontal lobe, seen in F4 area, which means higher neurons activation for rider's movements, concentration, intelligence, emotion and speaking. Also, C3 and CP5 domains are highlighted in red which are related to the sensor-motor cortex of the brain.

V. DISCUSSION

The positive effect of horseback riding is based on a complex effect on the human body as the rider is given the rhythm of the horse's movement. A horseback riding simulator is an alternative approach to hippotherapy. In some ways, the alternative approach is able to show an even better performance. The simulator helps to strengthen all muscles of the body, supports its functions in tone and increases endurance.

Despite a small amount of research, the horseback riding simulator is recognized as an effective form of treatment for muscle activation and balance on elder people [15], [49], posture control in children with cerebral palsy [14], and riding lessons and therapeutic use [50], [51].

The simulator allows a child or an adult to safely learn the basics of horseback riding. The combination of the horseback riding simulator together with an inertial motion capture system allows to monitor and record the body behavior of the rider. Thus, with a recorded and analyzed data of professional rider utilizing the simulator and with an understanding of the correct movements pattern it is easier to prevent the inexperienced rider from critical mistakes.

There are studies investigating the difference between a human brain signal from the simulator and real horse. The higher increase in brain patterns of participants experienced real horseback riding was noted. However, the activation of all EEG domains was observed with rising concentration and restfulness [17]. Thus, the brain activity of an experienced rider obtained in present research provides the same sensations as when horseback riding. Especially when the movements are similar between a mechanical simulator and a real horse.

The horseback riding simulator as an alternative method of therapy attracts more and more attention due to its proved efficiency and easy use. Depending on the program, results of the therapy may vary from horse to horse, from patient to patient. For instance, patients with cerebral palsy or mental disability may accidentally hit an animal or make a loud sound. For the horse not to be afraid it must be specially trained to work with different patients. With the use of a mechanical simulator, such problems will not be associated. Also, utilizing a riding simulator allows to reduce costs associated with maintaining a horse and the treatment procedure can be performed nonstop, allowing more patients to be admitted.

VI. FUTURE WORK

The current experiment is a prototype of a larger project for a method for autism therapy. The present study limitation is employing a few numbers of participants and the number of trials in the horseback riding task, which is going to be extended in the next step. In the next experiment, three groups of professional, normal and autism patient horseback rider participants will attend. An automatic algorithm will be then designed for autism detection and monitoring the alterations of the participant's conditions for three times a week in two months.

VII. CONCLUSION

In this study, it was found that the professional rider's results exceeded the results of the non-professional rider on several occasions. Riding kinematics and neutral position of the pelvis with no rotation are very essential for the rider. Fixed pelvis and well-adjusted saddle allow the rider to avoid lordosis in the lower back, lumbar spine or anterior pelvic tilt, injuries and feel more conveniently, productively, and accurately [37]. When horse or horse simulator transmits movements to the rider, it is almost completely absorbed by lower body region – pelvis and hips. If the mobility in the lower body region is lost, the force will be transferred to the lumbo-pelvic region. Inexperience riders tend to make movements mistakes while riding a simulator, by keeping the pelvis either left or right and backwards. Riders with horseback riding experience try to adjust to horse's movements and depending on speed or gait tilt pelvis to the middle of the saddle and forward minimizing the movement of the body, especially lower region, and keeping it more fixed. Over time, inaccurate horseback riding may cause asymmetry shift in external hip and back regions, which are most vulnerable. Incorrect use of simulator by inexperience folks may lead to abnormalities in body symmetry described above even faster due to sharper movements of the simulator and a much tougher top corpus of simulator comparing to the real horse body.

The EEG of a horseback rider utilizing a horseback simulator was also performed in this research. Different correlations cause neuron activities at low and high-frequency ranges. In other words, low frequencies are responsible for any kinds of brain rest, for instance, relaxation and sleeping time. In turn, high frequencies refer to waking time and diverse activities, such as physical activities, chemistry and concentration of attention. It means that every brain lobe represents a different activity. The frontal lobe is active during riding with high frequency, in which related to the rider's intelligence, concentration and movement. The activated parietal and temporal lobes in Fig. 12, indicates that the sensor-motor cortex is active.

APPENDIX

See Figure 13.

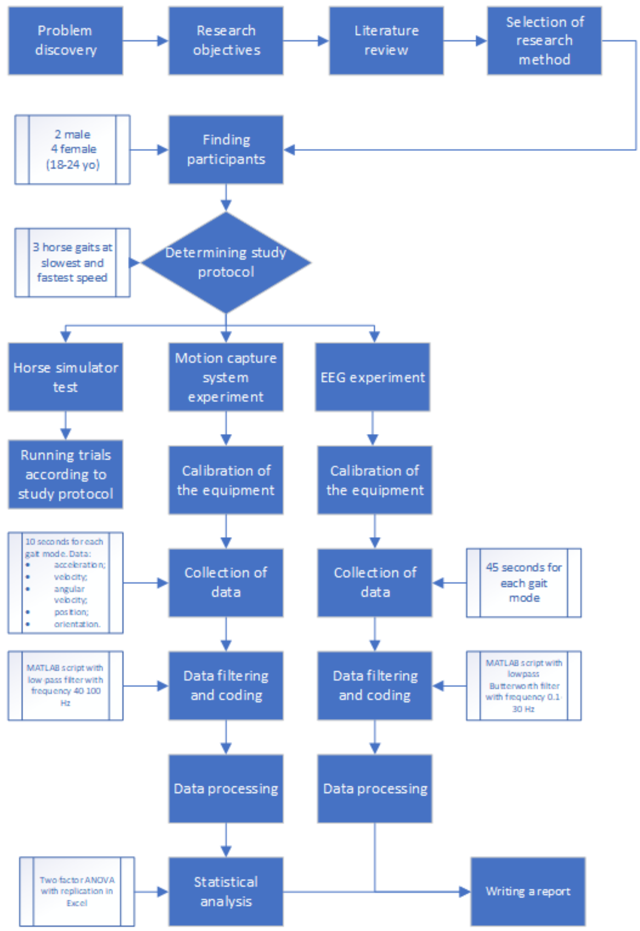

FIGURE 13. The flowchart diagram of the study.

ACKNOWLEDGMENT

The authors are grateful of all the participants, who have contributed the study devotedly. The authors acknowledge the help provided by Asko Kilpelainen with experiment and professional experience. The authors wish to thank Juha Koivisto with big help and technical support.

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