Thesis of the Ph.D. dissertation

THE DEVELOPMENT OF AN ACCELEROMETER-BASED MOTION ASSESSMENT DEVICE AND ITS USE TO DEMONSTRATE THE SUITABILITY TESTING OF DEFINITE HORSE POPULATIONS BASED ON MOTION PARAMETERS, FURTHERMORE THE EFFICACY OF HIPPOTHERAPY

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I dedicate this work to my four-legged friends.
To all of them who were happened, still happens to and will be my partners and masters.

'When certainty faces evidence, regularly certainty will prevail.
It seems that is the essence of human nature,
to ignore scientific evidence.'
(unknown author)

INTRODUCTION

I chose research on the efficacy of hippotherapy and the selection of horses according to the suitability for therapy as the topic of my doctoral thesis. This topic is both grateful and ungrateful at the same time. As there are only very few predecessors with similar scientific interest, therefore we could not start our work on a subfield of a well-established and developed topic with a solid scientific foundation, instead we took the challenge to explore a relatively uncharted area. However, when the scope of a research work aligns with the researcher field of interest it provides tremendous drive and motivation to elaborate the given topic thoroughly and precisely.

Relationships with animals and more specifically with horses are truly wonderful, which can only be understood while living within it. Dealing with horses and horse-riding is a partnership with no super- or subordination, but it is rather characterized by an almost irrational relationship based on ancient trust. The sole reason of the existence of this relationship is the humility of these fascinating animals towards humans. With the acceptance and use of this ancient trust, nowadays horses are not only instruments of work, partners, friends, sources of joyful experience, but they have already made their way into human medicine.

When it comes down to our health, we are often distrustful regarding the given active substance, procedure or therapeutic method. Nevertheless, the ancient loyalty of horses triggered a trust, which allowed us to fully rely on suitable horse specimens in the treatment of severely limited mobility using an carefully designed method. This circle of trust has always fascinated me as a hippotherapist, while feeling the responsibility that our 'colleague' is a sentient and instinctual being.

In case of any therapeutic method it is a fundamental expectation that the system of its effects is precisely understood. The demonstrated efficacy of horse riding therapy and in particular hippotherapy lags far behind compared to the level of scientific establishment of many physiotherapeutic treatments. The aim of this work is to provide a better scientific support of this treatment, which is accepted and used effectively worldwide.

'If a line of thinking is successful in science,
it is followed until it starts to clog.' Paul Davies

OBJECTIVES

The studies and assessments presented in this dissertation are the result of joint efforts and work with the research group of the Department of Solid State Physics of the University of Debrecen. The assembly, calibration, accuracy and precision checking of the instrument and the development of the analyzer software used during the studies are not my work. The statistical methods were compiled by mathematician. Below I detail the objectives of my own work, which were defined for our joint research.

The objectives of my dissertations:

- The picturesque spatial geometric presentation of the stride gait type of the horses and the explanation of its mechanism.
- Two dimensional image representation of the fine movements of the withers.
- The development of an accelerometer- and video-based segmenting real-time assessment method, which is suitable for the measurement of motion parameters of humans and horses.
- The correlation study of the movements of the withers of the horse and the human gait in healthy young volunteers.
- The assessment of the motion parameters of horses with longer trunk and higher withers (Gidran population) and shorter trunk and lower withers (Hucul population) with the objective to determine their motion suitability for hippotherapy using this newly developed system.
- The implementation of objective assessments with this system in order to explore the system of effects of hippotherapy in children with cerebral palsy.

'Share your knowledge with others: this is a way to become immortal.' Dalai Lama

LITERATURE OVERVIEW

Movements, which are accompanied by locomotion and generally forward moving are essentially fine-tuned, rhythmic process of shifting the centre of gravity. The general and most frequent basic type of forward movement is the stride in horses and walk in humans.

Stride is the slowest gait in horses, which has four phases with the following leg order: right hind, right front, left hind, left front. During stride one of the legs is always in the air, while the remaining three are on the ground, except for one moment, when the weight is transferred from one leg to the other. The step length of a horse with a general body-frame is between 1.30 and 1.80 m. The basic common feature is that hind legs providing the impulse for the movement overtake the corresponding, same side front limb by about a half step length. It is also typical that during the forward swinging of the front limb the rump ascends, then descends during the time of weight support. During stride the tail of the animals always swings toward the anterior limb providing support in that moment. GAMBARJAN (1972) created a picturesque illustration of step order and the corresponding supporting surfaces. He addressed normal, slow and fast step paces in his work.

Instrumental assessment methods provide the best way to objectivise the efficacy of hippotherapy. According to the reviewed corresponding literature there is a very limited number of researchers, who carried out investigations in this topic. Considering the methodology, basically they used two measuring systems: on one hand pressure-measuring platform and video analysis were used, while the other solution utilized accelerometers. The objectives of these investigations were also very variable: the possibility of instrument-aided horse selection (JÁMBOR et al, 2013), horse selection according to the horse's build (MATSUURA et al, 2008), classification of horse movements according to ground type during hippotherapy planning (FLORES et al, 2015), study of the horse-rider and the change in pressure points developing on the back of the horse (JANURA et al, 2009), study of the efficacy of hippotherapeutic treatment (MISAKO et al, 2013) and the comparison study of the human walk and horse stride (UCHIYAMA et al, 2011). The subjects of these studies were healthy individuals in several cases, thus just imitating the hippotherapeutic treatment. In three cases subjects with horse-riding knowledge

(MATSUURA et al, 2008, UCHIYAMA et al, 2011, FLORES et al, 2015) and in one case subjects without previous horse-riding experience participated in the trials (JANURA et al, 2009). In one case data was collected during the hippotherapy of children with cerebral palsy (MISAKO et al, 2013).

The results obtained during the study of horse's build, it is recommended using horses with lower height and thicker frame for hippotherapy, based on the acceleration values measured at the waist of the horse-rider (MATSUURA et al, 2008). The studies carried out on different grounds during horse-riding revealed that the pressure values developing on the horse-rider's sitting surface are the most ideal during the horse moving in stride on asphalt, followed by grassy, then sandy track, in which cases the excursion of the rider is greater (FLORES et al, 2015).

The study of developing pressure points on the sitting surface of healthy people as an effect of the movements during hippotherapy demonstrated an improvement in the core stability of the horse-rider (JANURA et al, 2009). The publication on the efficacy of hippotherapy involved children with spastic cerebral palsy and one session of hippotherapeutic treatment. The accelerometers were attached to the bodies of the children, one on the chest and one on the waist. According to the results in the publication, which were collected via the accelerometers, the autonomic balance of the trunk improved (MISAKO et al, 2013).

The gait-improving effect of hippotherapy was studied in a publication, in which the gait of 50 healthy individuals and 11 horses were detected with accelerometers. Both the humans and the horses were measured for 3 minutes on a straight line, during walking and in striding gait. Based on the acceleration parameters obtained the acceleration values in horses and humans are similar, so the potential gait-improving effect of hippotherapy was highlighted in their conclusions (UCHIYAMA et al, 2011).

Overall, it can be concluded that there are very few publications on the real-time instrumental assessment of hippotherapy. However, the objectivity of the results from such measurement are much more established.

MATERIALS AND METHODS

Assessment device

A measuring and data collection unit built by our team was used for the measurements. It consists of a microcontroller-based (Atmel ATMEGA-128) 3 sensor connected with USB cables and with data collection on an SD memory card. Sampling was carried out at 86 Hz with a 10-bit ADC. Each sensor consisted of a three-axis accelerometer (MMA 7260Q, Freescale Inc., USA, Austin, Texas). The microprocessor uses periodic sampling for recording the analogue signals via the AD converters. The collected data then is recorded onto an MMC memory card, which is connected to the microcontroller. The measurement can be started and stopped with the button on the surface of the data collector. Two LEDs indicate the operation of the instrument. Acoustic and visual feedbacks indicate when the measurement starts. The files created during the measurements have different, incremental numbers in their names and these files can be directly accessed and processed by the analyzer program on the computer. The data collection unit provides power for the sensor units, i.e. for the three accelerometers. The sensitivity of the accelerometers has four different levels for adjustment in two ranges. The range with threshold levels of 1.5 G and 2 G can be used for the assessment of small accelerations, while the range with threshold levels of 4 G and 6 G may be used for bigger accelerations. The threshold level was adjusted using the on-board jumper to 6 G. After the calibration and validation of the device an analyzing software was developed in the LabView programming environment. With the help of the synchronously recorded video files it became possible to divide the measurements to time segments.

Study subjects

Our study subjects consisted of healthy volunteers (37 persons), children with cerebral palsy (6 persons) and different groups of horses (8 Gidran, 5 Hucul, 1 non-breed therapeutic horse, 1 Kisber Felver, 1 Hungarian Sport Horse, 1 Pony).

Determining the points of interest and the recording mode of the sensors/data collection unit

According to our objectives we had to find those points of interest, which were the most suitable for the analysis of the data collected for the given purpose (Figure 1). We searched for points both on the horse and the persons participating in the study, which were close to the centre of gravity and were ideal candidates for securing the sensors. So the sensors were secured behind the withers and on the left front limb of the horse and in case of the human subjects they were secured at the level of the 1st sacral vertebra and on the left shin. The data collection unit was located on the therapeutic harness, while it was secured on the chest of the human subjects using an elastic strap.

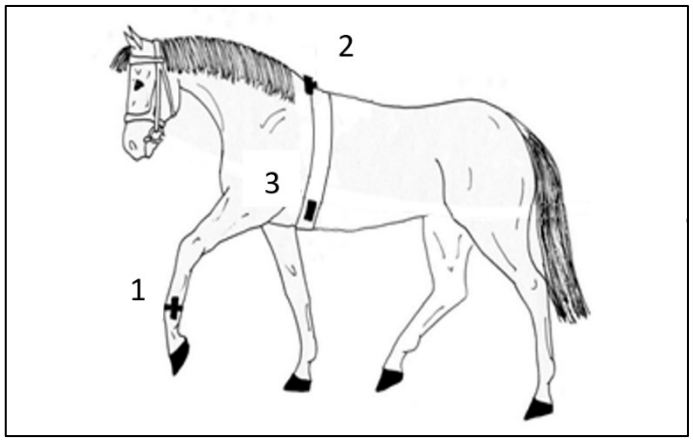


Figure 1: **Securing the device on the horses: Sensor 1 (left front extremity of the horse); Sensor 2 (behind the withers); 3. data collector (therapeutic harness)**

Measuring process

Three isolated measurements were carried out, which were compared while data evaluation. The fist type was person gait measuring, the second was the horse stride measuring and the third measuring while hippotherapy treatment. In the first two cases, we used two accelerometers for data collection and measurements were isolated in time and space. In the third case we used three accelerometer sensors while hippotheray treatment, collecting data at the same time both from horse and patient (Figure 2).

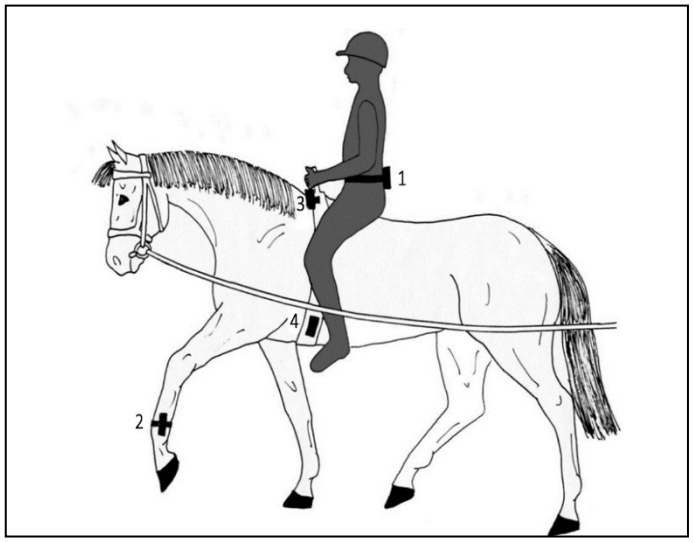


Figure 2. **Measure while hippotherapy; securing the device on the horse and patient; Sensor 1 (waist); Sensor 2 (left front extremity of horse); Sensor 3 (behind the withers); 4. Data collector (therapeutic harness)**

RESULTS

Visualization and phase identification

The key factor of hippotherapy is based on the movement of the stepping horse, which is transmitted through the pelvis of the rider and triggers a movement of the rider corresponding to walking. With this type of afferent input from the body to the central nervous system an intact walking pattern is reinforced instead of a pathological one.

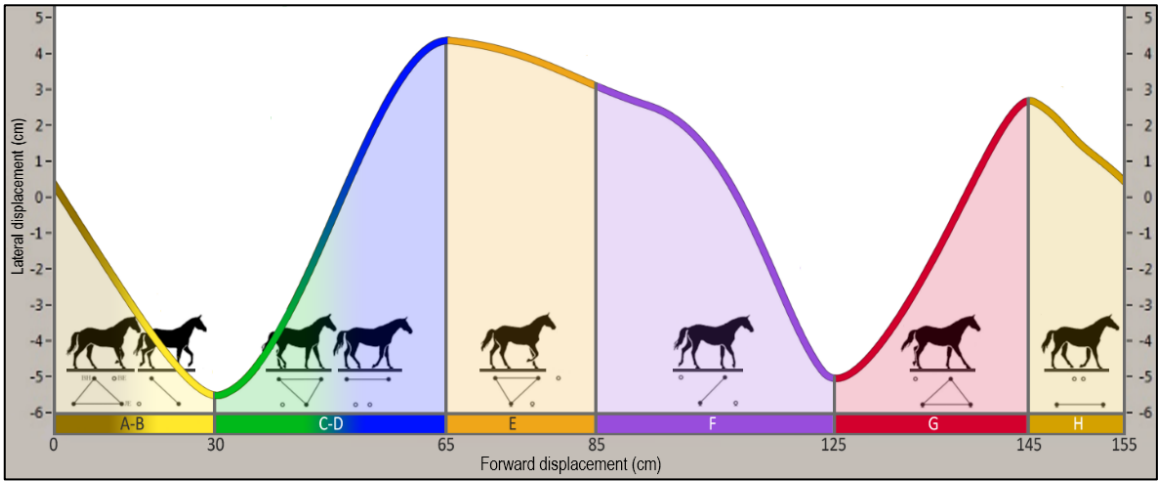


Figure 3: **The calculated displacement curve and the identification of phases according to GAMBARJAN (1972)**

In order to understand the key factor of the therapy, i.e. the movements of the back of the horses, we completed three dimensional visualization using the eight-phase step cycle according to GAMBARJAN (1972) with the momentary visualization of the supporting surfaces (Figure 3). We created a mean displacement curve using the data collected by the sensor on the back of the horse during guided rightward circles and identified all the eight phases. With the help of this the fine back movements appearing at the given moment of the step cycle of the horse become comprehensible analysable for the hippotherapist.

The demonstration of gait-specific core training – small sample study

Initially the analysis was performed based on three-directional acceleration date collected at the pelvises of 37 healthy young adults and the withers of 4 horses. The horses were classified based on their body sized, thus the pony and the large horses were assessed separately. Correlation analysis was performed per directions and with phase-shifts of different magnitude phase shifts determined by the maximum empiric correlation coefficients were used for all the

examined data pairs. Based on the phase-shifts adjusted averaged acceleration values of the horses and persons it may be concluded that there is significant equality in all three directions, which is clearly visible in both the sagittal and vertical planes.

Based on the empirical correlation coefficients calculated in each movement direction, accelerations in the sagittal plane show strong correlation in both cases, i.e. regarding the variable pairs obtained from the pony-persons sessions and the horses-person sessions (r=0.898; 0.804). Equality is somewhat weaker between the variable data pairs of acceleration in the vertical planes, although the correlation is tight (r=0.650; 0.634). The pony-persons variable pairs in the frontal plane are similar to the vertical plane variable pairs, but the horses-persons variable pairs showed the weakest correlation (r=0.430). It may be concluded that with the exception of the horses-persons lateral acceleration data-pairs the movements show strong correlation, which is the most remarkable in the anterior-posterior plane. The weaker correlation between the data pairs of horses and persons may be explained by the greater mass of the larger horses and the consequent higher lateral excursion of their movements. Based on the significance test of the correlation coefficients it may be concluded that all assess correlations are significant ($p<0.05$) i.e. the correlations are statistically confirmed.

The demonstration of gait-specific core training – large sample study

Based on the results obtained the small sample study was extended to the comparison analysis of the tri-directional acceleration data collected in the previously discussed group of 37 healthy university students and 8 Gidran, 5 Hucul and one therapeutic horses.

The data set of the study was provided by the average acceleration data of the individual subjects $\bar{a}(r_j)$, averaged at r_j time (in all three directions), while in horses the data was provided by the average acceleration data $\bar{a}(r_j)$ of the individual horses, which were generated in all three directions during two stride paces (slow and fast) and these parameters were also measured during right and left-handed lead.

The analysis of correlation between the acceleration data of humans and horses was carried out with the determination of correlation coefficients from the data sets and through significance testing. Phase shifts determined by the maximal empiric correlation coefficients were used for all analyzed data pairs per direction with phase shifts of different magnitudes. The comparison of correlation coefficients was carried out using the two-sided t-test for theoretical correlation coefficients.

Correlation between groups

Initially, we examined the correlation between the acceleration values of human subjects and the Gidran and Hucul specimens. The results show that in the case of the Gidran specimens (G1-G8) correlation was significant with more than half of them being above 0.75. In case of the specimens of the Hucul group (H1-H5) no all the correlation coefficients were significant. An empirical correlation coefficient larger than 0.75 was detected in only one case – in specimen H2, while leading the horse with right hand and measuring up-down acceleration parameters. From the above we may conclude that the back movements of the Gidran specimens resemble more to the human gait than that of the Hucul specimens. Altogether, a tendency may be observed in the Gidran horses, that the fast-paced stride showed higher correlation in all three directions. Forward-backward direction has very high correlation, which is followed by the up-down direction and the sideway correlations are the lowest during fast-paced stride. Altogether, a tendency may be observed in the Hucul horses, that the slow-paced stride showed higher correlation in all three directions. The up-down direction has the highest correlation, which is followed by the remaining direction with a similar value. We carried out the correlation study between the acceleration parameters of humans and therapeutic horse and all the correlation coefficients were proved to be significant, just as well in the case of Gidran specimens.

Intragroup correlation

Aftewards, the correlation parameters of Gidran and Hucul specimens and that of the therapeutic horse were depicted in all three major directions. This allowed for the analysis that the steps of which specimens are the most similar to that of the therapeutic horse, which served as a reference. In case of the forward direction the empirical correlation coefficients of the Gidran specimens were all higher, while only the 22% of the empirical correlation coefficients of the Hucul specimens were higher than the empirical correlation coefficients of the therapeutic horse. In case of the up-down direction the 91% of the empirical correlation coefficients of the Gidran specimens and 94% of the empirical correlation coefficients of the Hucul specimens were higher than the corresponding empirical correlation coefficients of the therapeutic horse. In case of the right-left direction the all the empirical correlation coefficients of the Gidran specimens while only 17% of the empirical correlation coefficients of the Hucul specimens were higher than the corresponding empirical correlation coefficients of the therapeutic horse.

Since in the case of the Gidran specimens the significant results are accompanied by negative test functions values, therefore we may conclude that the mean acceleration values measured during the walking of human subjects are more correlated with the acceleration values measured during the stride of Gidran specimens than with the corresponding acceleration values measured during the stride of the therapeutic horse. The non-significant results imply that the mean acceleration values of the given specimen and the human gait and the mean acceleration values of therapeutic horse and the human gait are identically closely related. Excluding one case (leading from the left, fast stride, right-left direction) all the correlation coefficients of the G1, 3, 5, 7 specimens were significantly higher than the corresponding correlation coefficients of the therapeutic horse. Significant results with positive test function values were also obtained for the Hucul specimens, therefore, we may conclude that the acceleration values of the given specimens and the average acceleration values of the human gait is less closely related than the acceleration values of the therapeutic horse and that of the human gait.

Assessment of Gidran horses according to pace and symmetry

Based on the correlation assessments it may be concluded that the motion qualities of the Gidran specimens resemble much more to that of the healthy adult walk than the motion parameters of the Hucul specimens. Further on, we assessed the homogeneity of the group. MVP (Motion Variability Parameter) was used for the comparison of the pace and symmetry, which shows the similarity of the individual steps within a full step cycle, i.e. the harmony of the steps. Wilcoxon signed rank sum test was used for the comparison of MVP parameters of the left and right side lead at different paces (with the generation of a $d_{left\text{-}right}$ difference variable). An increase in the pace does not significantly affects the MVP values of sagittal acceleration, thus the harmony of motion is preserved. The motion properties of each specimen is characteristic to the entire group. The same phenomenon may be observed for the MVP values in the frontal plane, however, the motion properties within the group show differences. The homogeneity of the motion properties of a group is characteristic at a slow pace, while increasing the pace leads to the differences in the individual MVP values in the horizontal plane.

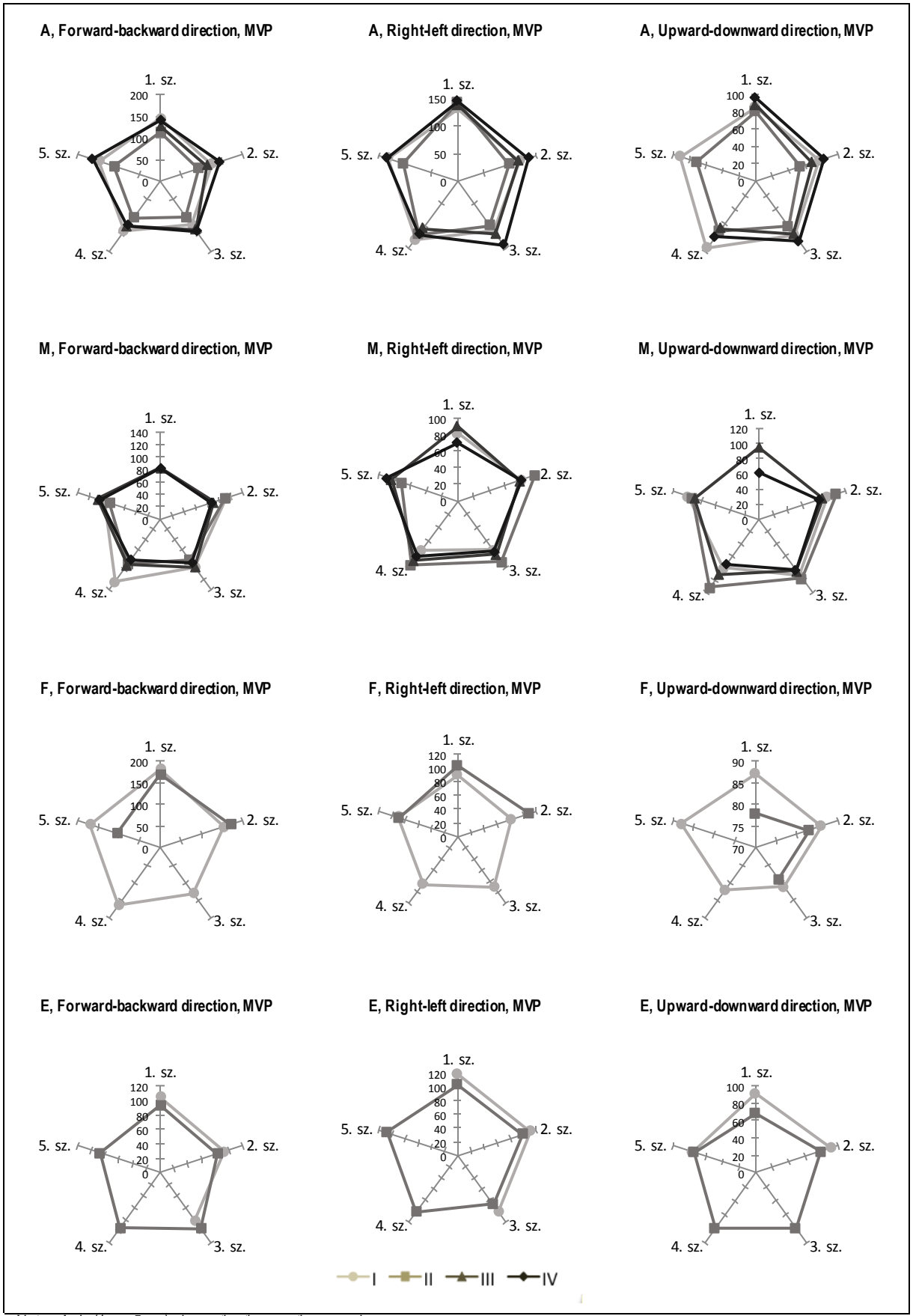
Regarding symmetry, the MVP values of left and right hand lead at slow pace do not differ significantly. However, during faster stride and left-handed lead the right-left and up-down MVP values are tending to be higher than the values obtained during right-handed lead. According to all these the individual motion characteristics show remarkable differences within the group during left- and right-handed lead, whose extent are basically the same in all three directions.

Demonstrating the system of effects of hippotherapy in children with cerebral palsy

The acceleration data of the movements of the pelvis of the child and the concomitant movements of the withers of the therapeutic horse were analyzed using the data obtained during hippotherapy. The therapeutic treatment was divided to five segments in each child. Significant results were obtained in four cases: in the first case, in right-left direction R_+ is larger than R_- between segment 1 and 2, i.e. the right-left direction MVP value of segment 2 is lower than the MVP value of segment 1. Thus, it may be concluded that examining the second segments of 12 children the lateral acceleration parameters – considering motion harmony calculated for each step - improved compared to the first round, which was confirmed statistically. In the second case, in right-left direction a similar correlation was observed between segments 1 and 3, i.e. the right-left direction MVP value of segment 3 is usually lower than the MVP value of segment 1. However, no statistically proven improvement was detected upon the analysis of segments 2 and 3. In addition, a worsening trend can be observed in segment 1., which is the most significant in case of segment 5 (p=0.153). This may be associated with fatigue occurring as an effect of treatment. However, the efficient phase of treatment was observed at the end of therapy in two instances. In the sagittal plane (forward-backward direction: segment 3 – segment 5) R_- is larger than R_+, i.e. the forward-backward direction MVP value of segment 5 is generally higher than the MVP value of segment 3. In the frontal plane (up-down direction: segment 3 – segment 5) a similar correlation can be detected, i.e. the up-down direction MVP value of segment 5 is generally higher than the MVP value of segment 3.

The MVP parameters of children estimated for the therapeutic segments was followed-up with multiple samples, when the comparisons were made between the therapeutic sessions. No further statistical tests were carried out, only the trend apparent from the figures were described. In case of child *A*, during the course of therapies no decreasing trends were observed in the MVP values in either directions, while in child *M* the MVP values of segments 2 of forward-backward direction and the MVP values of segment 5 of up-down direction can be characterized with a decreasing trend.

In children *E* and *F* a total of two therapeutic sessions were analyzed. In case of child *F* all the measured MVP (forward-backward direction, segment 3) values with one exception showed a decreasing trend.



Note: Axis (1.sz.-5.sz.) shown the therapeutic occasions

Figure 4. **MVP changes between therapeutic sessions in time**

'Scientific knowledge is a group of statements with different levels of confidence: some are very doubtful, others are roughly certain but none of them are absolutely certain.
Richard Feynman

CONCLUSIONS AND RECOMMENDATIONS

During my work I took up the motion analysis of horses and humans. Our system consists of three triaxial accelerometer sensor, data collection unit and the software engineered for the processing of the data obtained. I hereby summarize the four directions of my studies, along which I compare my work to the studies published in the international literature, highlighting the strengths and limits of my work, and in addition to my conclusion I describe my further direction of my studies.

- The visual representation of the stride gait of horses in eight phases, the visual representation and explanation of the mechanisms of the movements of the withers within the step cycle;
- The exploration of similarities between the pelvic movements triggered during the walking of humans and the movements of the withers of horses during stride gait;
- The selection of specimens within a horse breed based on their motion abilities for hippotherapy;
- Analysis of the system of effects of hippotherapy with the assessment of the acceleration data collected during therapy.

The utilization of accelerometer sensors is an established tool for the motion analysis of horses (KRUZE, 2012). They can be assembled easily, provide simple data collection opportunity and do not require laboratory conditions, thus the horses may be examined in their natural environment.

During the visualization of the horse stepping phases we built upon the work of GAMBARJAN (1972) and visualized the eight phases in space and after the calculation of the bidirectional travel of the back of the horse, the results were plotted on a curve. Our work helped us to better understand the fine movements of the withers. Our further objective is to measure the motions of the withers of horses performing figures used in hippotherapy and during transitions and pace changes to obtain information on their biomechanical consequences. By using this more precise methodological recommendations may be established in the individual clinical cases. Our more remote further objective is to complete these measurement using motion

synchronized video recording, more points of measurement, greater number of specimens and other horse breeds as well.

The acceleration measuring system developed by our team is suitable for the synchronous and separate measurement of the horses and riders as well, when used with synchronized video recording, the measurements may be segmented, the horses may be assessed alone, even in the case of specimens from the unhandled and young population. The targeted selection of young horses during their 'colt' age saves money and time for the professionals and pre-screening may further improve the quality of hippotherapy. We managed to find measuring points which can be well and easily secured on the subjects and lie close to the centre of gravity of the human and equine subjects.

The basic effect of hippotherapy i.e. the core training effect corresponding to walking was demonstrated with our measuring system (significant correlation based on the data from 37 human and 17 equine subjects). After eliminating the initial issues with the measuring system it can be stated that no measurement data had to be excluded from the analysis due to measurement errors, which reflects the reliability of the system. A limitation of our work is the individuals participating in the gait study were healthy adults and the intact and pathological gait patterns of children were not measured, as this scope of work would require a study on a much higher scale and this area is much more complicated as well. Therefore, upon selection of the human subjects we worked with a team, who had an already developed gait pattern, belonged in the same age group, had a developed body image and understood the instructions well and carried them out precisely.

There are only very few publications in the international literature with similar objectives. MATSUURA et al (2008) completed acceleration measurement with the aim to characterize the horse build most suitable for hippotherapy. They studied the motion of the horse with a horse-rider, therefore the potential effect of the rider was not ruled out, which I consider a limitation of their work, furthermore, the study of raw colts therefore is excluded a priori. UCHIYAMA et al (2011) also aimed to demonstrate the core training effect corresponding to walking with a similar limitations as they also studied horses with riders.

The selection of horses suitable for therapy is not an easy and not a sufficiently well-defined task. It is a recent pursuit to use an examination system for horses, which does not screen for the motion qualities of horses but only considers the horse's age, health status, training and obedience. The measuring system developed by our team provide means for pre-screening the

motion qualities of horses using independent and objective recommendations, either for the selection or determination of suitability for hippotherapy. Based on our results we may conclude that according to the data collected during the studies of the human gait and after the assessment of a given horse population, horses may be clearly classified by their motion qualities. It is a limitation of our work that the measurement bias was not completely eliminated during our measurements, as the Hucul and Gidran specimens were assessed at different sites and with different aiding staff. Based on our results it may be assumed that the Gidran specimens with larger motion amplitudes are more suitable for the improvement of gait in young adults. Our workgroup defined a further goal, namely to compare larger and more horse populations using the methodology described above.

There are numerous examples for the analysis of horses independently from the rider in the Hungarian scientific literature (JÓNÁS 2008, JÁMBOR 2012), which typically rely on the video-based motion analysis of horses. Our method is not a substitute for these systems but rather a complementary aid as the different inventory of tools may result that the selection procedure becomes more precise. Our accelerometer-based system only used the video recordings for the identification of the phases, while using the more detailed and more precise analysis methods of the aforementioned researches the combination of the two methods may complement each other.

The motion impulses originating from the back of the horse trigger an improvement, advancement and improvement of gait during hippotherapy. In order to evaluate the momentary effect a more precise measurement would be needed. The momentary effects of hippotherapy may be analyzed via the synchronous assessment of the horse and the rider by using our measuring system. Thus, the most effective point of therapy or the onset of fatigue can also be determined. After the analysis of these points the hippotherapist may compile a more precise therapeutic plan during his/her work. Based on our results, we may conclude that the sagittal motions measured during the initial phases of hippotherapy are less correlated to each other than those results, which are obtained during the advanced phase of the therapeutic session (therapeutic phase), while just before the end of the therapeutic session the correlations decrease yet again (fatigue). Regarding the other directions, the effective phase may be found during the second half of the therapy, which assumes that the treatment period may be extended beyond the time that was used in our studies. The analysis of measurement data gathered during several therapeutic sessions of a single patient is needed for the evaluation of the effects of hippotherapy. Regarding the two and four samples of the children in our studies showed the maintenance of

the condition or the improvement of motions which reflects the validity of the method. Nevertheless, in order to determine the level of improvement the sample size should be increased. Our workgroup defined a further goal of establishing a database with the assessment of horses of therapeutic riding-halls and thus the therapeutic horses may be classified by the gait-improving effect, moreover, based on the gait assessment results of the individuals arriving for hippotherapy the most suitable horse may be selected for each individual.

MISAKO et al (2013) studied the hippotherapy of children with cerebral palsy using accelerometers, but the sensors were only attached to the riders, thus the synchronous assessment of the horse did not take place. Their conclusions only included statements regarding the usability of the measuring system.

The most remarkable merit of our work that we can recommend and provide a ready-to-use method for the practice both in terms of horse selection and regarding the follow-up of the therapy. In light of these reassuring results there are several options to further enhance and develop our method. With the evolution of the sensors, certain phases of the validating process can be omitted, e.g. if the sensor contains a gyroscope. The reconstruction of the measuring system - the replacement of the difficult-to-handle cable system - would make it more easy to use and a more safe measurement process. Automatic measurement data processing would enable the widespread use of this system.

Our remote goal is to develop a professional conception that would validate the methodology of hippotherapy. In addition to seat design, which is independent from the grip, it may be used efficiently for the assessment of pace and hand switches, riding school figures, leading on straights and curves and the transitions, but their effects are currently unknown. Our method is suitable to explore the biomechanics of these and to designate damage-specific methodical directions according to the expected results. By using these the protocol of hippotherapy treatment may be specified, which may be added to the current training systems even internationally, as well.

NEW SCIENTIFIC RESULTS

I hereby summarize my new scientific results:

- Identifying the eight phases of the step-cycle via the analysis of the fine movements of the back of the horse in longitudinal and sagittal directions. The visualization of supporting surface developing concomitantly with movements of the back of the horse. The schematic three dimensional visualization of the step-cycle of the horse.
- The development of real-time system through the determination of the measurement points and using software processing, which provide very usable results even in practice. With the aid of the processable and comparable data both the selection of the therapeutic horse and the efficacy of therapy can be greatly improved.
- My measurement results numerically verified on of the basic theses of hippotherapy, the gait-specific core training, which therefore can be considered as scientifically proven.
- The development of suitability testing of specimens of different horse populations according to the quality and nature of back movements triggered during striding.
- Demonstrating the mechanism of action of hippotherapy in children with cerebral palsy. The uniform segmenting of the progress of therapy with the help of video-based motion recording, which allows the comparison of measurement results. Identification of the effective phases of hippotherapy and the definition of the onset of fatigue.
- The follow-up of hippotherapeutic treatment, the presentation of the duration of effects and the determination of motion quality improvement in children with cerebral palsy.

THE POTENTIAL PRACTICAL USEFULNESS OF OUR RESULTS

The system developed by us is suitable for its introduction to every-day practice and its usefulness consist of the following:

- The introduction of biomechanical models for the exploration of the mechanisms of action of hippotherapy - the visual representation of the fine movements of the withers.
- The instrumental support of the selection of the horse breed and specimen, the determination of motion characteristics of the horse specimens in terms of their suitability to improve human gait.
- Possibility of pre-screening based on the motion parameters of horses upon enrolling them into training for hippotherapy.
- The assessment of therapeutic horses according to the motion qualities – the screening of unsuitable specimens.
- Treatment adaptable to the individual patient - the comparison of individual motion characteristic in case of the therapeutic horse and the patient as well, thus the most suitable specimen may be selected for each patient.
- The comparability of the effects of hippotherapy within one given patient or patients with the same clinical presentation.
- The objective follow-up and 'dosing' of hippotherapy. Based on the motion responses the most efficient range of therapy may be determined during a course and therefore the treatment may be adapted and optimized to the individual's need.

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'Show me an ungrateful, yet happy man.'
Zig Ziglar

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List of publications related to the dissertation

Hungarian scientific articles in Hungarian journals (5)

1. **Pálinkás, J.**, Manó, S., Soha, R. F., Nagy, J. T.: A ló egy lépésciklusának nyolc periódusú képi megjelenítése és a marmozgások kétdimenziós gyorsulásaival való szinkronízálása. *Biomech. Hung. 9* (1), 31-40, 2016. ISSN: 2060-0305.
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