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Innovative sensors for the assessment of exercise stress in athlete horse

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ABSTRACT
Exercise tests are indicated for the evaluation of a horse's physical condition and for the analysis of poor athletic performance, often associated with discomfort during training or competition that creates excessive stress in the animal. In order to understand the different biological mechanisms of adaptation to exercise-induced stress, a large amount of data need to be collected in real time, to obtain what is called "deep phenotyping" (DEPH) that opens the way to the full exploitation of omic techniques. The aim of the study is the configuration of innovative low-cost sensors for real time detection of crucial stress parameters that will allow early identification of metabolic dysfunctions preserving the horse's welfare.

Section: RESEARCH PAPER

Keywords: Horse; exercise test; sensors; stress; DEPH

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1. INTRODUCTION

Competitive sports are known to be demanding and stressful for both human and animal athletes. Endurance (low-intensity long duration aerobic activity), in particular, and sprint races (high-intensity, short, anaerobic exercises) are among the most challenging equestrian disciplines [1], [2]. It is well accepted that exhaustive exercise will lead to immune deficiencies. During exercise, blood cell populations will change as during other stress responses – total white cells and neutrophils increase, and lymphocyte and other granulocyte populations generally decrease. These changes are usually associated with elevated plasma cortisol [3], [4]. To understand the comprehensive response to the stimuli, nevertheless, a large amount of data regarding stress and welfare indicators monitoring the subjects need to be collected in real-time, to obtain what is called "deep phenotyping" (DEPH) [5]. DEPH opens the way to the full exploitation of omics techniques for the genetic, epigenetic and metabolomic characterization of different individuals exposed to different stress conditions. A variety of biosensors have been recently developed to collect the amount of data necessary for these purposes, radically revolutionizing the outlook on contemporary healthcare monitoring systems, making it possible to get real-time, dynamic information on physiological functioning [6], [7]. In horses, training is essential to compete effectively and safely and to prepare them for the rigors of competition. Exercise testing is indicated for the evaluation of a horse's physical condition and welfare and represents a useful instrument to investigate cases of underperformance that may be correlated with high levels of stress associated with subclinical pathological conditions or with overtraining situations [8]. Those tests can be conducted in a treadmill laboratory or in the field, which has the advantage to have the same environment of the competition. In this context, wearable technologies are already used during exercise tests. Sensors developed for horses are based on Global Positioning System (GPS) and Inertial Measurement Unit (IMU) that allows to measure speeds and to analyse the gait. Other sensors work to evaluate the electrocardiogram (ECG) in order to assess cardiac rhythm and heart rate. However, these commercial sensors have several limits: they are not capable of communicating with each other, too costly for breeders, use proprietary standards, and sometimes do not communicate at a long distance to a central repository where Machine Learning (ML) and Artificial Intelligent (AI) analyses must be carried out. Nowadays ML and Big Data Analysis allow analysing and correlating large amounts of data, previously only analysed separately, thus highlighting connections and opening new scenarios for understanding biological relations. ML algorithms offer approaches for learning complex relationships and patterns from homogeneous and heterogeneous data. ML could pinpoint hidden or difficult to identify relationships, overcoming the limits of traditional linear models [9], [10]. Moreover, the application of omics techniques and phenotype collection by sensors are topics in line with the 2021-2027 PNR (“artificial intelligence applied to precision farming”).

2. OBJECTIVE

The aim of the study is to optimize innovative, low-cost, next-generation customized sensors for real-time detection of crucial physiological parameters to study exercise and response to stress, through the agreement with the company Nature 4.0 SB SRL.

Those sensors will have the following characteristics:

I. a unique orchestrating node with a powerful low-power chipset that gathers all the signals from the different sensors applied to the animal and transmit them to the High-Performance Cluster, where all the data will be elaborated;
II. the possibility to obtain a large amount of data per second (up to 600 data per second stored on a local SD card);
III. the possibility to include new sensors based on the particular application (for example, accelerometers to each leg for better control of the animal movements detecting stride length, stride frequencies, and stride symmetry);
IV. real-time data from each sensor to be related (e.g. GPS, heart rate, subcutaneous and superficial temperature, pulse blood oxygen saturation - sp02, respiratory rate);
V. full control of the raw data obtained by sensors to train AI algorithms;
VI. the possibility to execute the obtained AI models directly on the orchestrating node chipset for real-time analysis and feedback (edge computing), maximizing the amount of analysed data, while limiting the transmitted ones.

Thanks to these characteristics, these innovative sensors will be able to show more accurate results than other wearable technologies, in order to evaluate horses' welfare and maximize their athletic performance. Indeed, only this technology used in combination with the hematobiochemical profile allow to carry out the DEPH. DEPH together with omics analyses will enable to identify the genetic/metabolic pathways underlying resilience and adaptation to physical exercise stress. In this way, it will be possible to detect crucial stress parameters and early identify dysfunctions preserving the horse's welfare.

Figure 1.Movement sensor on the horse’s pastern.

3. EXPERIMENTAL

Given the preliminary nature of the study, the subjects chosen for investigation will be owned horses. At least ten animals will be selected. The horses will be evaluated at different gaits: during walk and trot in straight line and during trot and gallop in circle using the sensors here presented, which allow real-time collection of position (GPS), heart rate, blood oxygen parameters, temperature (cutaneous) and movements (Figure 1). The position is revealed using a Global navigation satellite system (GNSS) module, that mount an active or a passive antenna and supports four GNSS: GPS, GLONASS, Galileo and BeiDou). The pulse oximetry will register heart rate and blood oxygenation, using an optical sensor. The blood oxygenation can be obtained using the difference between the absorbed light of oxyhemoglobin and hemoglobin. The hearth rate is instead estimated through absorption, the pattern obtained can easily been converted into animal heartbeat. Also, the cutaneous temperature will be registered using an infra-red sensor. Finally, the movement is registered using a three-axis accelerometer. Inertial sensors will be applied in the pastoral region of the left forelimb during the first clinical trial, and in the thoracic region, at the level of the left cardiac area, tied to the surcingle, during the second clinical trial. In both clinical trials, the pulse oximeter and the sensor for skin temperature will be applied on the ventral face of the base of the tail. The GPS will be held by the person leading the horse. Biological samples (plasma blood, serum, and buffy coat) will be collected before the start and after the end of each trial. The results of the haematological profile will allow to detect the degree of dehydration (packed cell volume - PCV, total protein and albumin) and the severity of the stress leukogram. The results of the biochemical profile will allow, instead, to detect the muscular and metabolic adaptation to exercise (cortisol, creatine phosphokinase -CPK, glucose, urea, lactates) and the electrolyte concentration, essential to differentiate healthy from metabolically compromised animals. In this way, it will be possible to assess the effects of training on hematobiochemical parameters and how these are reflected in sports performance using data obtained from sensors. Validate a large amount of data derived from sensors collected in real-time, allow us to apply this technology to sport horses to obtain DEPH, opening the way to omics techniques for the genetic, epigenetic transcriptomic and metabolomic characterization of different individuals exposed to different stress conditions. These characterizations are crucial for understand mechanisms underlying adaptation and resilience to physical stress. A Machine Learning and "classical" statistic approaches will be applied to integrate sensor data and hematological parameters, also combined with other individual detections, in order to identify early markers capable of predicting particular physiological stress conditions. Indeed, the application of DEPH by using our innovative new generation low-cost custom sensors will allow real-time detection of crucial parameters to investigate exercise response in horses, providing the early identification of dysfunctions to better preserve the horse welfare during training and races [11]. In addition, in the case of poor performance, which represents a decline in the ability to perform certain athletic tasks [12], the sensors will allow to determine the real cause: orthopedic, thanks to the analysis of the symmetry and regularity of movements; respiratory and cardiovascular, thanks to the analysis of blood oxygenation, respiratory rate and heart rate. Data on the athlete's performance (average and maximum speed, stride regularity, frequency and amplitude, average and maximum heart rate, average and maximum respiratory rate and recovering time data) will let trainers set up appropriate training schedules in order to balance sports performance and animal welfare [13]. In conclusion, this integrated monitoring of assess and/or maintain the physical well-being of athletes as well as to optimize the athletic performance.

4. RESULTS

In the first trial, one animal was tested to demonstrate the ability of the three-axis accelerometer to distinguish walk (W), trot (T) and gallop (G). The sensor was collocated at the forelimb (AS) and at chest (TRX). On average, 600 point each second (~600 Hz) were collected. For AS, around 155, 43 and 78 thousand of points were collected for W, G and T, respectively.

For TRX, around 84, 83 and 80 thousand of points were collected for W, G and T, respectively (Figure 2). A ML algorithm, the K-Nearest Neighbours (KNN), was used to test the possibility to predict the horse gait and distinguish walk, trot and gallop. The KNN was tested using the entire dataset (~600 Hz) and subset of the same. In particular 210 Hz (~ one point each 4 millisecond), 126 Hz (~ one point each 7 millisecond) and 65 Hz (~ one point each 15 millisecond). The accuracy of the model was used as metric to evaluate the ability of KNN algorithm to distinguish the three gaits (W, T and G) (Figure 3). The accuracy for the model that use the complete dataset is, in both the cases, +0.02 than the reduced models. The accuracy values in the reduced model remain similar among them, around 0.7316 for AS and 0.7143 for TRX.

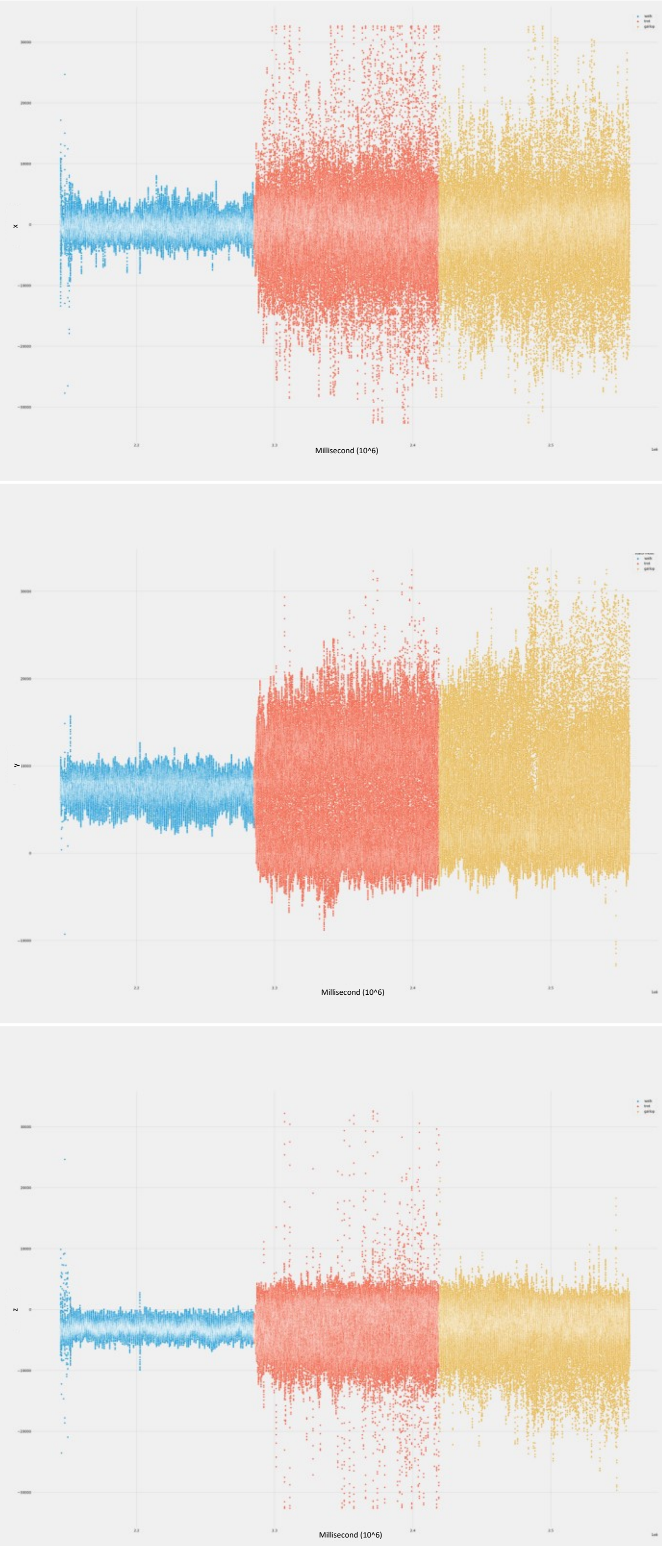

Figure 2. Three axis accelerometer data collected on the chest (TRX). From the first to the last plot, the X, Y and Z axes were reported. The three colours (blue, red and yellow) represent walk, trot and gallop. Even just seeing the walk behaviour in the three plots, it seems different from the others two gaits.

5. CONCLUSIONS

These first preliminary results obtained using the DEPH sensors here tested, showed the possibility to avoid storing a large amount of data to identify in an accurate way the horse gait.

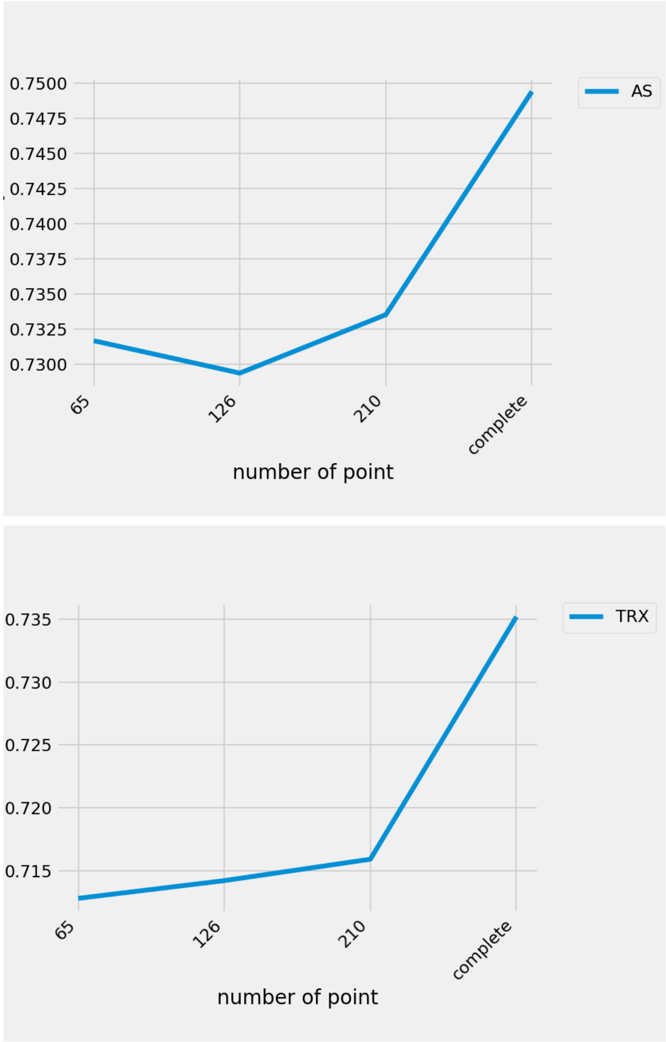

Figure 3. The accuracy (y-axes) reported for the 4 tested conditions (65 Hz, 126 Hz, 210 Hz and ~600 Hz – complete) for AS and TRX. The values range from 0.7294 (126 Hz) to 0.74xx (complete) for AS, and from 0.7128 (65 Hz) to 0.7391 (complete) from TRX.

Lower amount of data per second are sufficient to reach a good accuracy (greater than 0.71) also using the sensor on the forelimb or the chest. This will allow the possibility to send the data to the server in real-time, also allowing the analyses and warning sending. In this moment, using an SD card to store the collected information, the analyse are done only ex post facto. However, high frequency data could be interesting to detect, as already reported, “abnormal” situations, such as lameness. Additional analysis, combing the different sensors in different situation, need to be done to understand the DEPH potential.

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