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Examining stance phases with the help of infrared optical sensors in horses

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Abstract: The purpose of the present study was to examine the walking phases in horses using the OptoGait system, which works with optical sensors. In this pilot study, 52 healthy horses were used. For each horse, an average of 45 steps were examined. The stance phase, swing phase, step distance, and walking speeds of the horses were recorded. The stance phase of each step was examined in a separate manner in 3 steps: contact phase, foot flat, and propulsive phase. The contact phase and the propulsive phase of the forelimb and hind limb were significantly different. The propulsive phase was significantly shorter in the forelimb compared to in the hind limb, and the contact phase was significantly shorter in the hind limb. The fact that the propulsive phase of the European warmblood horses used in our study was longer than that of the British and Arabian horses was significant. It is considered that this technique might be used in the diagnosis of lameness in horses in the future with the reference measurements that were created with these data obtained from healthy horses.

Key words: Biomechanics, horse walking analysis, stance phase, veterinary anatomy

1. Introduction

In medicine, gait analysis systems are used commonly, especially in the diagnosis and treatment of musculoskeletal diseases. In recent years, this method has been included in veterinary medicine as well. The use of gait analyses is becoming widespread in the diagnosis and treatment of gait disorders as well as in demonstrating the normal biomechanical characteristics of animals.

A step process consists of the stance phase and swing phase. For one of the feet, the stance phase starts with the first contact of the hoof on the ground and continues until the last contact with the ground ends. The stance phase is divided into 3 parts. The first part is the time that is spent between the first contact of the hoof with the ground and the contact of the sole of the hoof with the ground. The second part is the time of the full contact of the foot on the ground. The third and last part consists of the time spent between the moment when the foot leaves the ground and the moment when the contact with the ground ends completely. The swing phase, on the other hand, is the part when the foot is moving in the air. These two phases together form the step. When these phases' times differ from normal values, this indicates a pathological condition. This may enable one to comment on lameness by evaluating the delays in certain parts of these phases. Walking techniques can give all or some parts of these phase values (duration, step distance, step count, step speed, etc.) to the physician. Kinematic and kinetic data obtained could help the physician in diagnosis and treatment [1,2].

There are various gait analysis methods. The patient walks in front of 2 or more specialist physicians. Then the patient is evaluated, a common decision is made, and treatment is initiated. Although this method is the most common form of walking analysis, possible visual mistakes made by the examiners may affect the diagnosis and treatment in a negative manner [2].

3D quantitative gait analysis allows examination of the patient in terms of kinematics and kinetic and dynamic electromyography. The movements of the walking patient are recorded. For this purpose, retroreflective markers are used in general. In addition to this method, electromyographic analysis of the patient is also performed to allow a more specific interpretation. The results obtained are used for the diagnosis and treatment by combining them with additional data that have been obtained previously such as history, physical examination findings, and comments of the physicians obtained from the patient [3–5].

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Force plate and pressure plate methods are the other gait analysis techniques that help the physician to make a diagnosis. Obtained results are more objective and quantitative with these two techniques. They also allow static and kinematic measurements to be obtained. The vertical load distribution that is applied by the patient on the floor is obtained with the force plate [6–8]. The pressure plates [9,10] enable physicians to interpret the pressure that is applied to the ground in Newtons (N) and help them to evaluate the necessary orthopedic approaches by creating a pressure map on the floor.

In recent years, another method used in medicine has been the infrared optical sensor test. Two sticks parallel to each other are used in this test. There are LEDs used for communication at infrared frequency on each of these bars positioned facing each other. Any object entering between the bars interrupts the infrared communication. This information is sent to the computer and is processed. This test allows real-time motion analysis via specific software and cameras. All parts of the 2 basic phases of a step might be measured with this method and also basic gait analyses like the step length, step time, and walking speed of the patient [11].

There are studies conducted on walking analysis in horses. The sensor method is very common, especially in lameness diagnoses. Methods like kinematics and force plates are also employed in the literature [12–16]. In addition, the relation between walking parameters and muscle fiber components were also examined with gait analyses. The stance phase and swing phase of gait have been investigated separately or together in various studies in horses [17,18]. The functions of the muscles were examined in these phases. The muscular activity durations of the flexor and extensor muscles that corresponded to stance phase were determined [19].

The purpose of the present study was to introduce a new gait analysis method with infrared optical sensors for testing and recording lame-free horses in order to provide normal reference values that could be used for diagnostic purposes in horses with orthopedic problems.

2. Materials and methods

A total of 7 British horses, 12 Arabian horses, and 33 European warmblood horses (Austrian, Belgian) were used in the present study. Clinical examinations of the horses used were carried out. Horses with gait abnormalities and those that had been treated previously for lameness were not used in our study. In order to ensure that all animals were similar, shod horses were selected.

A gait analysis system, produced by OptoGait (Fullbalance, Ataşehir, İstanbul, Turkey), was used. This system consists of two rods that are placed parallel to each other with the same number of LEDs that establish communication with infrared frequency (Figure 1). The rods are laid on flat ground. The distance between both rods was set to be 1 m in the system to ensure that there was a comfortable movement area for a horse to walk in. The system is activated after the position of the LED rods becomes parallel. When the system is active, the infrared rays establish the communication between the two horizontal rods. The contact of the animal passing between these two rods with the ground causes interruption in the communication. The time and position of this interruption are processed by a computer connected to the system. The system measurement tools employed in the present study can measure 1 ms and have 1.041-cm surface resolution. In addition, walking is recorded in real time by the computer with the help of cameras. The results can be read with the OptoGait Software (Software OptoGait v. 1.12.1.0) that is installed on PCs.

Three of the 1-m rods were used and a 3-m platform was prepared. In preliminary trials, it was determined that this distance was appropriate for 6 steps in each round for an adult horse. The cameras were positioned outside the platform and were connected to the main computer together with the LED bars. Each horse was registered and the system was made ready for the study.

The horses were walked for 10 min prior to the analysis for warm-up to obtain natural results. The horses were walked on the platform at walking speed after warm-up without any interruptions. It was ensured that the speeds of the walking horses were close to each other.

The values were recorded for each foot separately. Forty-five steps on average were considered adequate for each horse.

With the test, 3 timing groups were examined separately for each step in the stance phase (Figure 2):

1. The time that is spent between the first contact of the hoof with the ground and the full contact of the sole with the surface (contact phase, CP),
2. The complete length of time of the sole touching the surface (foot flat, FF),
3. The time spent between the moment when the sole starts leaving the ground until the last moment when the hoof leaves the ground (propulsive phase, PP).

All of these times comprising the stance phase were recorded as percentages. An example from a preliminary measurement is as follows: stance phase 0.968 s; CP 0.019 (2%) s, FF 0.863 (89.2%) s, and PP 0.086 (8.8%) s.

The time measurements of the phases that were obtained in the present study were recorded in milliseconds (ms), the walking speeds were recorded in meters per second (m/s), and the step lengths were recorded in centimeters (cm). SPSS (Windows, version 21.0) was employed for statistical analyses. The average values were computed and are shown in the tables. The independent-samples t-test

Figure 1. Measuring walking phases in a horse by OptoGait analysis system.

was carried out for all data. The differences between the groups are given in the tables.

The present study was approved in terms of ethics by İstanbul University-Cerrahpaşa Faculty of Veterinary Medicine, Faculty of Medicine (No: 72796624 - 604.01.01).

3. Results

An average of 45 steps of 51 horses that passed through the walking platform were measured. The analysis data of the European warmblood horse with the number 32 were not sufficient and for this reason this horse was excluded from the study. The average walking speed was calculated as 1.42 m/s.

In the present study, the average stance phase time for the right forelimb was 951.38 ms. The average swing phase was 448.75 ms. The average times of the CP, FF, and PP were 22.53 ms, 836.01 ms, and 90.23 ms, respectively. A stance phase consisted of 2.34% CP, 88.44% FF, and 9.22% PP on average.

The average stance phase for the left forelimb was 955.21 ms and for the swing phase was 456.89 ms. The average of the CP was 22.41 ms, of the FF was 836.38 ms, and of the PP was 91.6 ms. A stance phase consisted of 2.36% CP, 87.95% FF, and 9.6% PP.

The average stance phase for the right hind limb was 915 ms and for the swing phase was 473.61 ms. The average of the CP was 17.89 ms, of the FF was 794.06 ms, and of the PP was 104.39 ms. A stance phase consisted of 1.91% CP, 87.27% FF, and 10.76% PP.

The average stance phase duration of the left hind limb was 923.32 ms and of the swing phase was 467.67 ms. The average of the CP was 15.69 ms, of the FF was 799.22 ms, and of the PP was 106.85 ms. A stance phase consisted of 1.66% CP, 87% FF, and 11.45% PP on average.

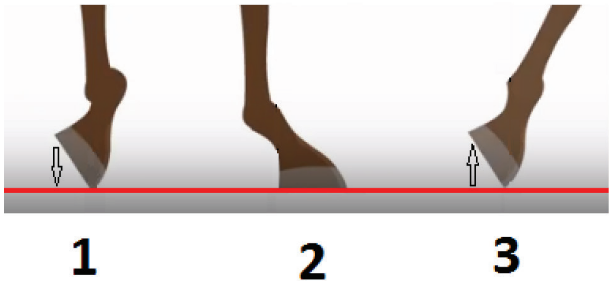

Figure 2. Parts of the stance phase; 1: Contact phase, 2: Foot flat, 3: Propulsive phase.

The average stance phase and swing phase durations of different horse breed groups, standard deviations with percentages, and statistically significant differences between the breed groups are summarized in Tables 1 and 2. Comparisons between legs of stance phase times including CP, FF, and PP are summarized in Table 3.

The difference between the stance phases between the fore and hind limb steps was statistically significant ($P < 0.01$). The difference between the FF phase percentages was not significant for all horses. However, the percentile difference between the CP and PP was statistically significant ($P < 0.01$) (Table 3).

4. Discussion

Veterinarians use physical examination as well as auxiliary devices like magnetic resonance imaging and ultrasound

Table 1. The stance phase values of the British, Arabian, and European warmblood horses. CP: contact phase, FF: foot flat, PP: propulsive phase, H: hind limb, F: forelimb, 1: British horse, 2: Arabian horse, 3: European warmblood horse.

Stance phases	Horse group	N	Mean (ms)	Standard deviation (ms)	Mean (%)	Standard deviation (%)
CP - F	1	7	29.23	7.94	3.30	0.98
	2	12	23.27	8.41	2.58	0.99
	3	32	21.70	6.02	2.21	0.58
	Total	51	23.10	7.22	2.45	0.83
CP - H	1	7	11.51	6.01	1.40	0.79
	2	12	11.09	7.00	1.32	0.80
	3	32	19.85	6.75	2.02	0.66
	Total	51	16.64	7.82	1.77	0.77
FF - F	1	7	802.04	51.34	89.39	2.96
	2	12	810.21	81.38	89.46	2.70
	3	32	855.58	75.93	87.32	2.21
	Total	51	837.56	76.89	88.11	2.60
FF - H	1	7	748.03	41.08	91.27	1.02
	2	12	755.40	60.83	89.88	2.22
	3	32	827.27	76.58	85.48	2.06
	Total	51	799.48	77.36	87.31	3.12
PP - F	1	7	61.97	14.88	6.95	1.51
	2	12	68.93	13.63	7.60	1.17
	3	32	104.75	25.08	10.58	1.94
	Total	51	90.45	28.51	9.38	2.33
PP - H	1	7	60.20	1.93	7.33	0.50
	2	12	75.27	23.12	8.82	2.01
	3	32	125.88	34.29	12.56	2.09
	Total	51	104.96	40.24	10.96	2.87

Table 2. The statistical significance of stance phase differences of the British, Arabian, and European warmblood horses. CP: contact phase, FF: foot flat, PP: propulsive phase, H: hind limb, F: forelimb, 1: British horse, 2: Arabian horse, 3: European warmblood horse (P < 0.05*, P < 0.01**, P < 0.001***, NS: not significant).

	1 - 2	1 - 3	2 - 3	1 - 2 (%)	1 - 3 (%)	2 - 3 (%)
CP - F	NS	**	NS	NS	***	NS
CP - H	NS	*	***	NS	*	**
FF - F	NS	NS	NS	NS	*	*
FF - H	NS	*	**	NS	*	***
PP - F	NS	***	***	NS	***	***
PP - H	NS	***	***	NS	***	***

to diagnose lameness [20]. Especially in large animal medicine, auxiliary methods are expensive, and therefore their use is limited in clinical practice. Data on walking and stepping on the ground were obtained in dogs by making use of orthopedic tools like force plates and pressure plates [7,10]. There are several studies in the literature about the use of force plates in horses [15,16]. Analyses were also conducted in horses by using markers [19]. Pressure plates were also used in horses and the static values applied to the ground by horses were examined in normal stance [21]. In addition, since there is horn tissue on the solar surface of horses instead of soft tissue, the results obtained will vary according to the trimming method of the hooves, and, for this reason, such results will not reflect accurate data in scientific terms. We planned to develop a new field by using the OptoGait gait analysis system, which is used in

Table 3. Average values and standard errors of the stance phase values of the forelimb and hind limb steps of all horses.

	CP			FF			PP		
	n	Mean (ms)	SE	n	Mean (ms)	SE	n	Mean (ms)	SE
Forelimb	817	22.37[a]	0.473	817	837.94[a]	3.75	817	91.03[a]	1.24
Hind limb	817	16.80[b]	0.520	817	798.51[b]	3.38	817	105.9[b]	2.35
% Forelimb	817	2.36[a]	0.05	817	89.06	0.99	817	9.45[a]	0.11
% Hind limb	817	1.78[b]	0.05	817	87.14	0.15	817	11.03[b]	0.14

[a, b] different letters differ significantly ($P < 0.01$).

human orthopedic practice, for horses. With this device, we succeeded in obtaining reference values by studying horses. The values were recorded in milliseconds. With these values, which are so sensitive that it is impossible for the human eye to catch them, the step durations for each foot will be transferred to the computer medium and help veterinarians in interpreting examination results.

In the present study, the FF phase constituted a large part of a stance phase in all steps. The difference between the CP and the PP was statistically significant in the fore and hind limbs. The fact that the CP in hind limb steps was shorter (22.37 ms in the forelimb on average and 16.65 ms in the hind limb on average) was particularly interesting. It suggests that this difference occurs due to the anatomical difference between the fore and hind limbs.

In the present study, the statistical differences between the breeds were also investigated. Although there were no significant differences between Arabian horses and British horses, the values of European warmblood horses were significantly different from those of the other horses. It was especially interesting that the PP was longer in European warmbloods in the fore and hind limbs, which means that the European warmbloods lift their feet more slowly compared to the other two breeds during normal walking. The CP, however, was shorter in European warmbloods. The FF time constitutes a large part of a stance phase in all breeds.

In a previous study [19], the stance phase of the forelimb of a horse galloping was examined according to muscle activity values. Although the stance phase of the forelimb in a galloping horse was 75 ms, the average stance phase was recorded as 953 ms for the forelimb. It was reported that the average stance phase of the muscle activity peaked between 4.9% and 41% in the superficial digital flexor muscle and between 8.5% and 42% in the suspensory ligament. It may also be foreseen in anatomical terms that the flexor muscles will work more since the leg will try to pull the body to the front after the first contact during a step. Based on that study, which reported that the flexor muscles peak in the first percentiles of the total step, it is foreseen that the work of the extensor muscles will peak during the last stages of the step. With the device that was employed in our study, we think that interpretations may be made about the muscles that cause lameness by interpreting the times in the first and last stages of the step.

OptoGait was used in athletes in a previous study [22]. The purpose of using it in athletes was that physicians could make faster decisions about the presence of walking disorders, which might be overlooked by the physician, prior to competitions. With this device, real-time data can be provided for the referees before horse races for soundness examinations. However, future studies and more reference data are needed to improve the usage of OptoGait Analysis System in horses.

In conclusion, it is considered that this novel technique is applicable in horses. Following this pilot study, this field may be improved by adding more reference data. With this device, real-time data can be obtained for lameness diagnosis by developing technical data (software) for animals (stance phase, swing phase, step length, walking speed, etc.).

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