JAST (Journal of Animal Science and Technology) TITLE PAGE

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ARTICLE INFORMATION	Fill in information in each box below
Article Type	Research article
Article Title (within 20 words without abbreviations)	Development of a foaling alarm system using an accelerometer
Running Title (within 10 words)	A foaling alarm system
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Competing interests	No potential conflict of interest relevant to this article was reported.
Funding sources State funding sources (grants, funding sources, equipment, and supplies). Include name and number of grant if available.	This research was supported by the Korea Institute of Planning and Evaluation for Technology in Food, Agriculture, and Forestry (320017021HD020) and Korea Racing Authority.
Acknowledgements	The authors are grateful to Heejun Jung (Ajou University, Republic of Korea); Junyoung Kim, Yeonju Choi, Seongmin Kim, Yubin Song, and Shakeel Hafiz Muhammad (Kyungpook National University, Republic of Korea). The authors also thank the Korea Racing Authority for their assistance.
Availability of data and material	Upon reasonable request, the datasets of this study can be available from the corresponding author.

Authors' contributions Please specify the authors' role using this form.	Conceptualization: Jung YW, Yoon MJ. Data curation: Jang HH, Yoon MJ. Formal analysis: Jung YW, Jang HH. Methodology: Jung YW, Jang HH. Software: Jung YW. Validation: Jang HH, Yoon MJ. Investigation: Jung YW. Writing - original draft: Jung YW. Writing - review & editing: Jung YW, Jang HH, Yoon MJ.
Ethics approval and consent to participate	The study protocols were reviewed and approved by the Animal Experimentation Ethics Committee of Kyungpook National University (2020-0140 and 2022-0027-1).

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Abstract

Horse breeders suffer massive economic losses due to dystocia, abortion, and stillbirths. In Thoroughbred mares, breeders often miss the foaling process because approximately 86% of the foaling events occur from 19:00 to 7:00; consequently, breeders cannot assist mares experiencing dystocia. To solve this problem, various foaling alarm systems have been developed. However, there is a need to develop a new system to overcome the shortcomings of the existing devices and improve their accuracy. To this end, the present study aimed to (1) develop a novel foaling alarm system and (2) compare its accuracy with that of the existing Foalert™ system. Specifically, eighteen Thoroughbred mares (11.9 ± 4.0 years old) were included. An accelerometer was used to analyze specific foaling behaviors. Behavioral data were transmitted to a data server every second. Depending on the acceleration value, behaviors were automatically classified by the server as categorized behaviors 1 (behaviors without change in body rotation), 2 (behaviors with sudden change in body rotation, such as rolling over), and 3 (behaviors with long-term change in body rotation, such as lying down laterally). The system was designed to alarm when the duration of categorized behaviors 2 and 3 was 12.9% and that of categorized behavior 3 was 1% during 10 min. The system measured the duration of each categorized behavior every 10 min and transmitted an alarm to the breeders when foaling was detected. To confirm its accuracy, the foaling detection time of the novel system was compared with that of Foalert™. The novel foaling alarm system and Foalert™ alarmed foaling onset respectively 32.6 ± 17.9 and 8.6 ± 1.0 min prior to foal discharge, and the foaling detection rate of both systems was 94.4%. Therefore, the novel foaling alarm system equipped with an accelerometer can precisely detect and alert foaling onset.

Keywords: Accelerometer, behavior, foaling, horse

Introduction

Predicting foaling onset is beneficial to assist mares experiencing dystocia. In Thoroughbred mares, breeders often fail to assist the foaling process because 86% of the foaling events occur between 19:00 and 7:00 [1]. To prevent dystocia, several foaling detection systems have been developed and applied for precisely predicting foaling time. However, these systems are not without shortcomings. One of the most popular systems, Foalert™, detects the discharge of amniotic fluid at the end of the first trimester; however, a shortcoming of this system is that the device must be surgically attached to the vulva, and if the attachment site is infected, the sensor must be detached to prevent its further spread. Smart Foal™ is another popular foaling detection system, which senses sitting down and standing up behaviors; however, the shortcoming of this system is that the sitting down and standing up behaviors are not specific to the pre-foaling period and are also observed when horses have colic or when they are scratching and resting. In addition, horses typically sit down and roll when new bedding is provided in the stall. Therefore, this system often erroneously detects foaling under normal conditions. To prepare for foaling, a foaling alarm system that operates at a precise time and with high accuracy is essential. Specifically, at the onset of the first trimester, the system should notify foaling signs, such that assistance can be provided without delay. In addition, the system should be easily applicable, such that it can be operated by breeders without the assistance of a professional veterinarian. Therefore, an innovative highly accurate and easy-to-use foaling alarm system must be developed.

Before foaling, the frequency of walking and lateral and sternal recumbency behaviors significantly increases, whereas the frequency of eating and standing behaviors significantly decreases [2]. Furthermore, during the pre-foaling period, mares tend to exhibit behaviors, such as standing, weaving, defecation, lowering the head, sitting down and standing up, and pawing, more frequently. Conversely, eating time is significantly reduced on the day of foaling compared with that two days before foaling [3]. Auclair-Ronzaud et al. [4] investigated behavioral changes in pregnant mares using an accelerometer attached to the tail and recorded increased frequency but shortened duration of tail movement before foaling. Collectively, these reports indicate that the time of foaling onset can be predicted by observing behavioral changes prior to foaling. In this context, monitoring pre-foaling behaviors using an accelerometer can be useful to develop a foaling alarm system. To this end, the present study aimed to (1) develop a novel foaling alarm system with an accelerometer sensor and (2) compare its accuracy with that of the existing foaling alarm system Foalert™.

Materials and Methods

Experiment 1: Classification of horse behavior

Animals

To collect behavioral data, six horses (8.8 ± 3.2 years old) of the Thoroughbred, Haflinger, and pony breeds were included. The horses were housed in 3.5 × 3.5 m^2 stalls. Timothy hay (1.6% of body weight) and concentrate (0.4% of body weight) were supplied three times and once a day, respectively. Water was provided *ad libitum*.

The present study was conducted at the Domestic Animal Research Facility of Kyungpook National University, Sangju, Republic of Korea. The study protocol was reviewed and approved by the Animal Experimentation Ethics Committee of Kyungpook National University (permit number: 2020-0140).

Behavioral data

In the present study, a 3D accelerometer sensor (iBS03; INGICS TECHNOLOGY, New Taipei City, Taiwan; 43 × 43 × 14.8 mm^3) was used to measure behavioral data. The sensor attached to each horse collected triaxial acceleration data on behavior and transmitted these to a database server (WUYANG Corporation, Jeonju, Republic of Korea) through a gateway (IGS1S; INGICS TECHNOLOGY). Horse behavior was recorded for 2 h using a camera. The behaviors were classified into state (lateral recumbency, sternal recumbency, standing, walking, and eating) and frequent (defecation, urination, pawing, and rolling) behaviors. Numerical data were collected for each behavior.

Statistical analysis

Statistical analyses were performed using SPSS version 25 (IBM, Armonk, NY, USA). Discriminant analysis was performed to classify the acceleration values of horse behaviors.

Table 1. Classification of horse behavior using discriminant analysis

Categorized behavior	Description	Behavior
1	The body is upright without rotation, and the sensor is directed forward.	Standing, eating, defecation, urination, and pawing
2	The body is rotated or slanting in both directions.	Rolling and sternal recumbency
3	The flank on one side is touching the floor, and the sensor is tilted to the side.	Lateral recumbency

Experiment 2: Measurement of the accuracy of the novel foaling alarm system

Animals

Eighteen Thoroughbred mares (11.9 ± 4.0 years old) were included to measure the acceleration values of pre-foaling behaviors. The mares were grazed during the daytime and housed in 3.5 × 3.5 m^2 stalls during the nighttime. Water and hay were provided *ad libitum*, and concentrate was supplied twice a day. The mares were managed at three racing horse breeding farms on the Jeju Island, Republic of Korea. The study protocol was reviewed and approved by the Animal Experimentation Ethics Committee of Kyungpook National University (permit number: 2022-0027-1).

Behavioral data

Behavioral data of the pregnant mares were collected using an accelerometer (Figure 1). The gateways that transmitted behavioral data from the sensor to the database server were installed near the stall. The triaxial acceleration data were transmitted every second, collated in the database server, and classified into categorized behaviors every 10 min. The duration of each categorized behavior was measured by the foaling alarm system every 10 min. The alarm was transmitted to the breeders when foaling was detected. To identify differences in the duration of each categorized behavior, behaviors monitored on the day of foaling were compared with data on the one day before foaling. The mean frequency of each categorized behavior observed for 10 min was obtained from 40 min before foal discharge; data were obtained from 40 to 30 min (period 1), from 30 to 20 min (period 2), from 20 to 10 min (period 3), and the last 10 min (period 4). To confirm the accuracy of the foaling alarm system, its foaling detection time was compared with that of Foalert™ (Acworth, GA, USA). Pregnant mares close to the foaling date were equipped with a wearable foaling alarm device starting at 19:00. The wearable device was removed when the mares were in the pasture during the daytime.

Statistical analysis

Statistical analyses were performed using SPSS version 26 (IBM). Changes in the behavior of mares before foaling were assessed using repeated-measures analysis of variance (ANOVA). Post-hoc test with least significant difference was applied to compare the durations of categorized behaviors during the same period between the day of foaling and the one day before foaling. Differences in the durations of categorized behaviors among the four periods were assessed. In addition, Mann–Whitney *U*-test was applied to compare the foaling alarm time between the novel foaling alarm system and Foalert™. A $p < 0.05$ was considered statistically significant.

Results

Classification of horse behavior

Horse behaviors were classified into three categories according to the degree of body rotation (Table 1). The X-, Y-, and Z-acceleration data were substituted into functional equations and classified into three categorized behaviors. The functional equations for the three categorized behaviors were as follows: categorized behavior 1 = $-167.335 + 0.579 \times X + 0.306 \times Y + 1.199 \times Z$; categorized behavior 2 = $-155.403 + 0.499 \times X + 0.369 \times Y + 1.141 \times Z$; and categorized behavior 3 = $-102.379 + 0.609 \times X + 0.199 \times Y + 0.759 \times Z$. The classification accuracy for the three categorized behaviors was 99.98% (i.e., 1 out of 5,442 data points was misclassified).

Distribution of foaling time

All mares included in the present study foaled from 19:00 to 5:00. The highest percentage of foaling (33.3%) was recorded during 21:00–22:00, followed by 23:00–00:00 (22.2%) (Table 2).

Table 2. Distribution of foaling time

Hours	Number of foaling events	Percentage (%)
19:00–20:00	1	5.6
20:00–21:00	1	5.6
21:00–22:00	6	33.3
22:00–23:00	1	5.6
23:00–00:00	4	22.2
00:00–01:00	1	5.6
01:00–02:00	2	11.1
02:00–03:00	1	5.6
04:00–05:00	1	5.6

Duration of categorized behaviors before foaling

The duration of each categorized behavior was observed from 40 min before the time of foal discharge, and these data were compared with data collected on the one day before foaling (n = 6 mares). Moreover, the durations of categorized behaviors observed during different periods (1–4) on the same day were compared. The duration of categorized behavior 1 in periods 3 and 4 was significantly shorter on the day of foaling than on the one day before foaling. On the day of foaling, the duration of categorized behavior 1 was significantly shorter in periods 3 and 4 than in period 1. On the one day before foaling, however, there were no significant differences in the durations of categorized behaviors among the four periods (Figure 2). Furthermore, the duration of categorized behavior 2 in periods 3 and 4 was significantly longer on the day of foaling than on the one day before foaling. On the day of foaling, the duration of categorized behavior 2 was significantly longer in period 4 than in the other periods. On the one day before foaling, however, there were no significant differences in the durations of categorized behaviors among the four periods (Figure 3). Finally, the duration of categorized behavior 3 in period 4 was significantly longer on the day of foaling than on the one day before foaling. On the day of foaling, the duration of categorized behavior 3 was significantly longer in periods 3 and 4 than in periods 1 and 2. On the one day before foaling, however, there were no significant differences in the durations of categorized behaviors among the four periods (Figure 4).

Comparison of accuracy between the novel foaling alarm system and Foalert™

The novel foaling alarm system detected foaling 32.6 ± 17.9 min before foal discharge. Meanwhile, Foalert™ transmitted a foaling alarm 8.6 ± 1.0 min before foal discharge (Table 3). There was no significant difference in alarm time between the two systems. Notably, both systems failed to detect foaling in one of the eighteen mares (detection rate = 94.4%). In this case, the novel foaling alarm system missed foaling because the mare foaled while standing and Foalert™ missed foaling because it failed to monitor amniotic fluid discharge.

Table 3. Comparison of alarm time before foal discharge

	Foaling alarm system	Foalert™
Alarm time (min)	32.6 ± 17.9	8.56 ± 1.0

Discussion

In the present study, the pre-foaling behavior of mares was successfully detected using an accelerometer sensor. Recently, accelerometers have been frequently used to monitor and collect animal behavioral data. For instance, Waele et al. [5] developed an algorithm based on data collected using an accelerometer sensor attached to the halter; the system detected the onset of the second stage of foaling. In another study, Hartmann et al. [6] used an accelerometer sensor attached to the halter and measured acceleration data from 120 min before foal discharge; the authors noted that acceleration was significantly higher during 0-30 min than during 90–120 min before foal discharge. From these reports, accelerometers are useful tools to detect the pre-foaling behaviors of mares. Interestingly, in the present study, both systems applied failed to detected foaling in one of the eighteen mares (5.6%); this was because the concerned mare did not exhibit typical foaling behaviors, such as rolling and lateral recumbency. To prevent such misses, an additional sensor such as an altitude sensor can be introduced to the foaling alarm system.

Furthermore, we noted differences in the durations of categorized behaviors between the day before and the day of foaling. Specifically, the duration of abnormal behaviors significantly increased from the last 20 min until foal discharge. The duration of categorized behaviors 2 and 3 was significantly longer on the day of foaling than on the one day before foaling. Rolling behavior is a sign of abdominal pain due to colic and foaling [7]. In addition, lateral recumbency is considered a foaling-specific behavior. Typically, mares lie sideways such that their flanks contact the ground when amniotic fluid is discharged. Shaw et al. [2] observed that the frequency of lateral recumbency behavior significantly increased during the night of the foaling day, which is consistent with our observations. Therefore, the criterion of behavior categorization used in the present study can be applied to develop algorithms for foaling alarm systems.

Furthermore, to assess its accuracy, alarm time was compared between the novel foaling alarm system and Foalert™. Based on foaling behavioral data from the pilot experiment, the novel foaling alarm system was designed to transmit an alarm when the duration of both categorized behaviors 2 and 3 was over 12.9% and that of categorized behavior 3 was over 1% during 10 min. As a result, there was no significant difference in alarm time between the two systems, but the novel foaling alarm system tended to transmit the alarm earlier than that of Foalert™. Moreover, the detection rate of both systems was 94.4%. Therefore, the novel foaling alarm system exhibited comparable accuracy to Foalert™. Another advantage of the novel foaling alarm system is that the sensor can be attached without any surgical intervention. In addition, because the foaling alarm is transmitted via an Internet router, managers can receive the alarm regardless of the distance from the stall. In addition, the system detects the foaling behavior of mares every

10 min; thus, the managers can periodically receive alarms even when dystocia persists. Occasionally, Foalert™ can fail to detect the foaling process if the sensor is detached when mares rub their hindquarters against a wall. In contrast, the novel foaling alarm system cannot be easily detached. Overall, the novel foaling alarm system can serve as an alternative to Foalert™.

In conclusion, the novel foaling alarm system with an accelerometer sensor can assist breeders by detecting the onset of foaling. Furthermore, it may be used as a clinical device to monitor the status of health of horses.

Acknowledgments

The authors are grateful to Heejun Jung (Ajou University, Republic of Korea), Junyoung Kim, Yeonju Choi, Seongmin Kim, Yubin Song, and Shakeel Hafiz Muhammad (Kyungpook National University, Republic of Korea) for their support. The authors also thank the Korea Racing Authority for their assistance.

References

1. Rossdale PD, Short RV. The time of foaling of thoroughbred mares. J Reprod Fertil. 1967;13:341–3. https://doi.org/10.1530/jrf.0.0130341

2. Shaw EB, Houpt KA, Holmes DF. Body temperature and behaviour of mares during the last two weeks of pregnancy. Equine Vet J. 1988;20:199–202. https://doi.org/10.1111/j.2042-3306.1988.tb01499.x

3. Jung Y, Jung H, Jang Y, Yoon D, Yoon M. Classification of behavioral signs of the mares for prediction of the pre-foaling period. J Anim Reprod Biotechnol. 2021;36:99–105. https://doi.org/10.12750/JARB.36.2.99

4. Auclair-Ronzaud J, Jousset T, Dubois C, Wimel L, Jaffrézic F, Chavatte-Palmer P. No-contact microchip measurements of body temperature and behavioural changes prior to foaling. Theriogenology. 2020;157:399–406. https://doi.org/10.1016/j.theriogenology.2020.08.004

5. De Waele T, Fontaine J, Eerdekens A, Deruyck M, Govaere J, Joseph W, et al., editors. Internet of animals: Unsupervised foaling detection based on accelerometer data 7th World Forum on Internet of Things (WF-IoT). IEEE Publications; 2021. https://doi.org/10.1109/WF-IoT51360.2021.9595172

6. Hartmann C, Lidauer L, Aurich J, Aurich C, Nagel C. Detection of the time of foaling by accelerometer technique in horses (Equus caballus)-a pilot study. Reprod Domest Anim. 2018;53:1279–86. https://doi.org/10.1111/rda.13250

7. Taylor PM, Pascoe PJ, Mama KR. Diagnosing and treating pain in the horse: where are we today? Vet Clin North Am Equine Pract. 2002;18:1–19. https://doi.org/10.1016/S0749-0739(02)00009-3

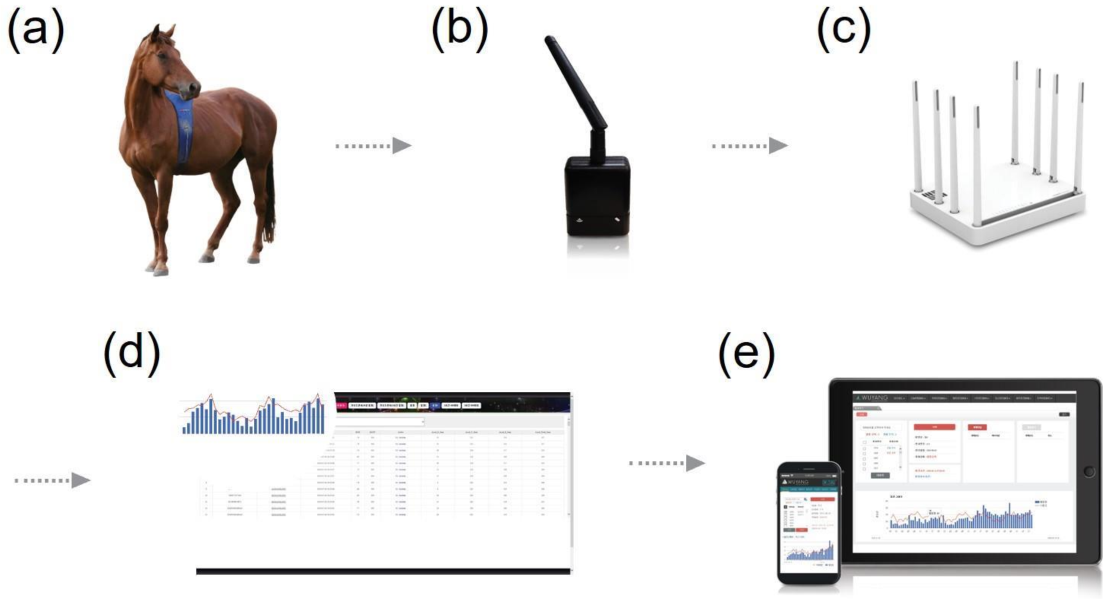

Figure 1. Architecture of the foaling alarm system. (a) Accelerometer sensor and wearable device; (b) Gateway; (c) Wireless router; (d) Database server; (e) Behavioral data decision tree algorithm program.

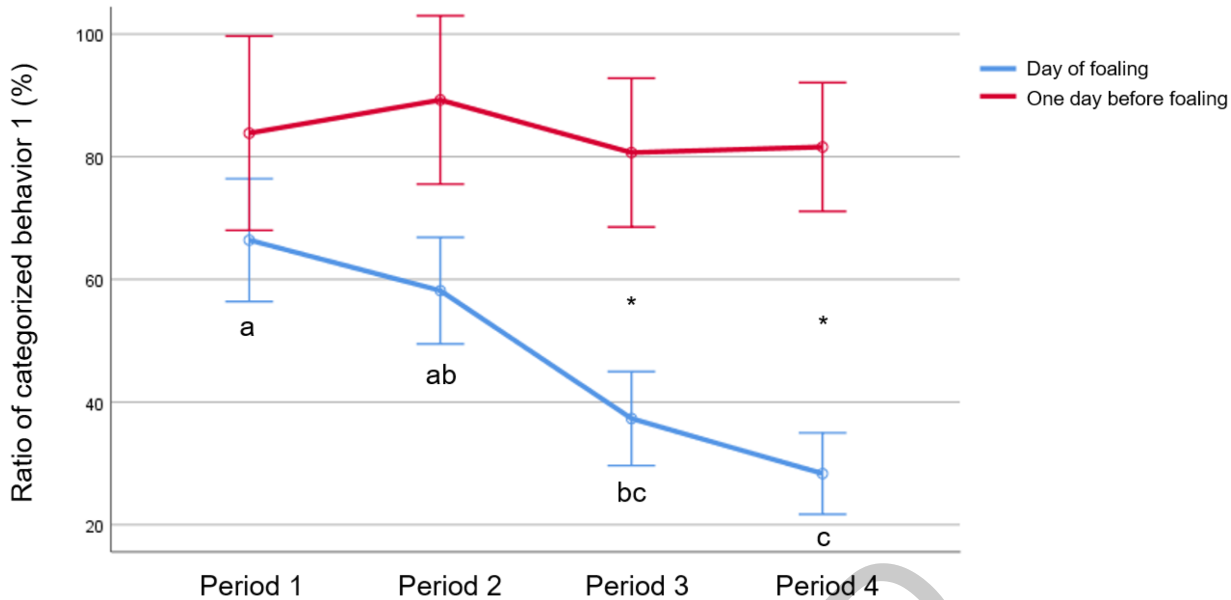

Figure 2. Curves of the ratio of categorized behavior 1 during periods 1, 2, 3, and 4. The mean duration of each categorized behavior observed for 10 min was obtained from 40 min before the discharge of the foal; the data were obtained from 40 to 30 min (period 1), from 30 to 20 min (period 2), from 20 to 10 min (period 3), and the last 10 min (period 4). Asterisks indicate significant differences between the day of foaling and the one day before foaling ($p < 0.05$). Different alphabets indicate significant differences among the four periods on the day of foaling ($p < 0.05$).

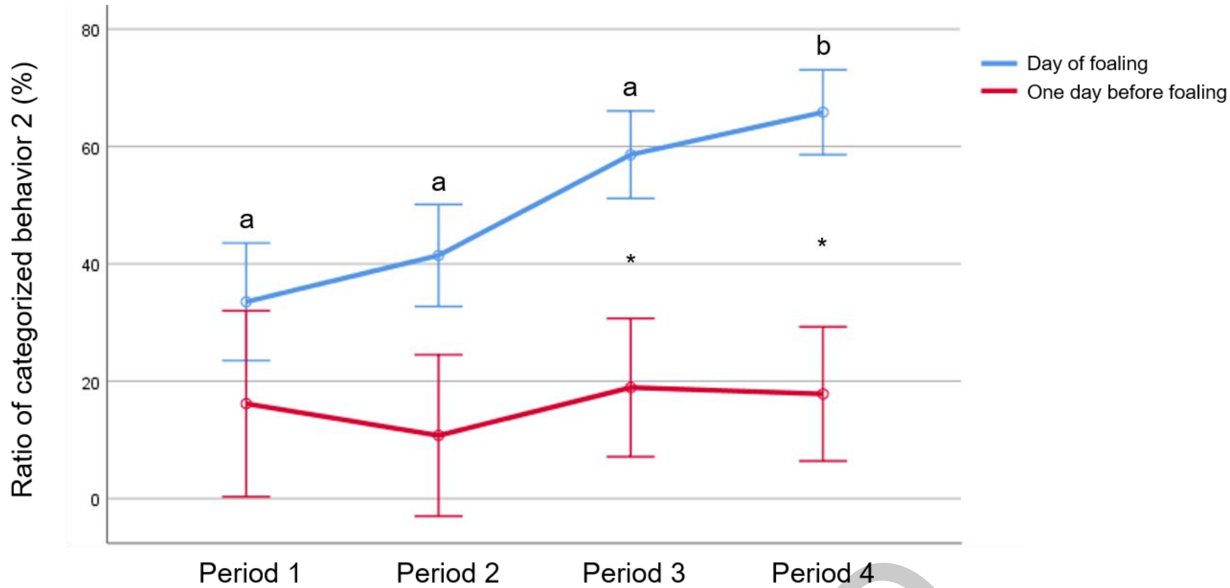

Figure 3. Curves of the ratio of categorized behavior 2 during periods 1, 2, 3, and 4. The mean duration of each categorized behavior observed for 10 min was obtained from 40 min before the discharge of the foal; the data were obtained from 40 to 30 min (period 1), from 30 to 20 min (period 2), from 20 to 10 min (period 3), and the last 10 min (period 4). Asterisks indicates significant differences between the day of foaling and the one day before foaling ($p < 0.05$). Different alphabets indicate significant differences among the four periods on the day of foaling ($p < 0.05$).

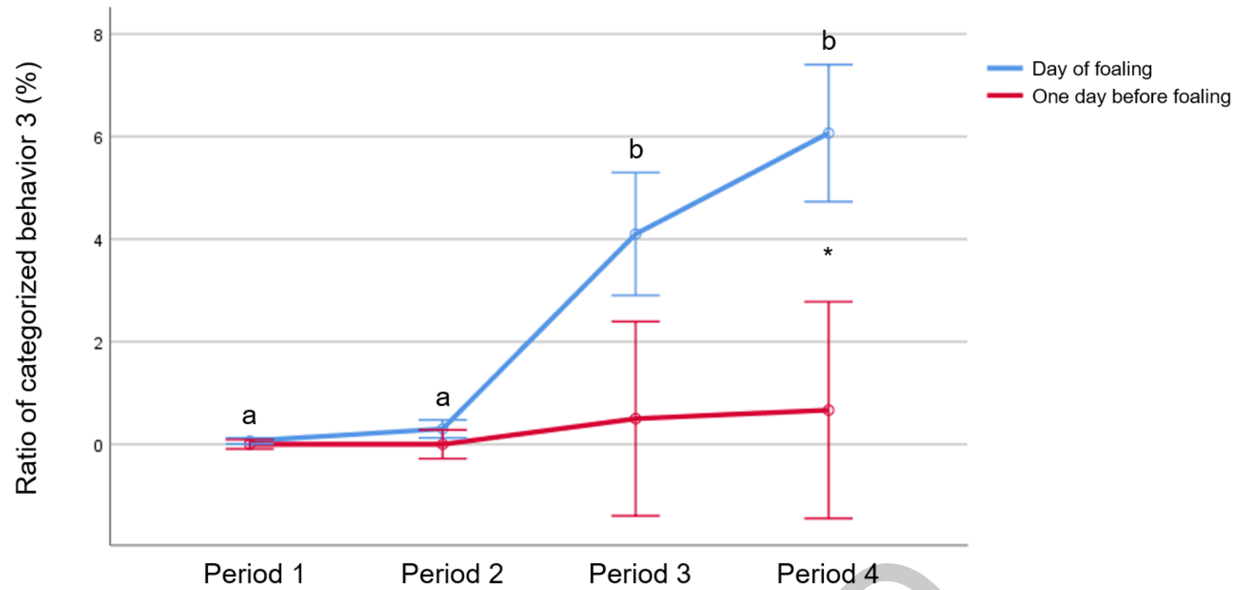

Figure 4. Curves of the ratio of categorized behavior 3 during periods 1, 2, 3, and 4. The mean duration of each categorized behavior observed for 10 min was obtained from 40 min before the discharge of the foal; the data were obtained from 40 to 30 min (period 1), from 30 to 20 min (period 2), from 20 to 10 min (period 3), and the last 10 min (period 4). Asterisks indicate significant differences between the day of foaling and the one day before foaling ($p < 0.05$). Different alphabets indicate significant differences among the four periods on the day of foaling ($p < 0.05$).