— Original article —

Measurement of frequency of sucking in rubber teat-fed dairy calves using an accelerometer attached on the neck-collar

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Summary

A wireless accelerometer is a useful device for developing an activity record of calves. The objective of this study was to test the wireless accelerometer for measuring the frequency of sucking in dairy calves. Four calves were reared in individual pens. The sucking duration and the number of sucking movements were determined from individual video data. The accelerometer was attached on the collar placed around the neck. A spectral analysis was used for estimating the frequency of sucking movement. Average duration of sucking was 219 seconds, the number of sucking movements was 473, and observed sucking frequency was 2.2 Hz. The average of estimated sucking frequency was 2.4 Hz. In 70% of cases, the difference between the observed and estimated was under 10%. The frequency of sucking movements correctly measured by an accelerometer. The duration of sucking and number of sucking movements decreased, and the frequency of sucking movement increased with days of age, but changes were very small in the frequency of sucking movement. The frequency of sucking milk of calves should be measured and characterized automatically by sensors with an accelerometer.

Keywords: Frequency of sucking movement, sucking behavior, Calves, Accelerometer

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Introduction

Sucking is one of the essential behaviors of calves to acquire the nutrients for their growth. Dairy calves are normally fed restricted amounts of milk twice a day, or fed individually at automatic milk-feeding stations in milk replacer feeding program. The manager can observe the sucking behavior in manual feeding, and check their behavioral changes for early detection of disease during routine work on a small farm. However, on a middle or large farm, the manager could not observe the behavioral changes of individual calves, because many calves were kept. On a farm using automatic milk-feeding stations, the manager could not be present at the time of sucking.

The automatic milk-feeding system is useful for labor saving of routine work for pre-weaned calves, and is good for recording the behavior of calves. Costa *et al.* (2021) pointed out that the changes in the behavior of milk-feeding measured by the automatic feeding system have been associated with diarrhea. The drinking speed of milk and the number of unrewarded visits to the station decreased, when the calves got an illness (Knauer *et al.* 2017). They did not discuss the reason why the ill calves drank slowly. The factors of change of milk-drinking speed are the frequency of sucking movement and the amount of milk per one sucking movement. The early detection of a change in suckling pattern of a calf should bring a warning of a possible disease, and might enable the reduction of adverse effects on

the health of calves. The behavioral indicator of calves should not variable much within the day and with the growth of calf for clear detection as a sign of disease.

The frequency of sucking movement might be the indicator that has these characters. There were some reports about the changes of frequency of sucking movement and the volume of sucking in calves. Morita and Nishino (1986) described that the milk-replacer intake speed did not differ between morning and afternoon feeding, but increased with days of age. Shuji and Ito (1996) reported that the drinking speed of milk and the volume of milk per 100 sucking movements increased, but the frequency of sucking movement almost did not change by days of over 20 days. Pre-weaned calves suck milk rhythmically, and a few reports said that the frequency of sucking movement of artificial nursing Holstein calves was 130 suckings (2.2 suckings per second (Hz), Shuji and Ito, 1996), and 74 suckings per minutes (1.2 Hz, Hafez and Bouissou, 1975) in Hereford calves suckling their mother.

A wireless accelerometer is a useful device for developing an activity record, locomotion (Swartz *et al.* 2016), rumination (Hill *et al.* 2017), eating (Roland *et al.* 2018), and lying (Bonk *et al.* 2013) behaviors of cattle. Some devices for real-time monitoring systems of cattle are pushing for precision dairy farming. Kuźnicka and Gburzyński (2017) and Kour *et al.* (2018) tried to develop an algorithm based on the acceleration data for measuring the daily time and daily frequency of milk intake behavior. Roland *et al.* (2018) also developed such an algorithm, and they concluded that the result for milk intake was not reliable and required further research. There was some research for measuring the daily time of sucking behavior, but there was no report that measured the frequency of sucking milk movement from the frequency-domain with an accelerometer.

The objective of this study was to test the wireless accelerometer for measuring the sucking behavior of individual calves, and to compare the estimated frequency with the actual frequency, and to discover the characteristics of the sucking behavior in rubber teat-fed dairy calves.

Material and Methods

Observation was had on an experimental dairy farm in Rakuno Gakuen University, Japan. Four Holstein calves (from 4 to 55 days, from 10 to 54 days, and 2 calves from 17 to 73 days of age) were reared in individual pens with straw bedding, and used for the following experiment. All calves were healthy and did not get diarrhea or pneumonia throughout their experimental period. Milk replacer was fed from a bucket with a rubber teat twice a day. The amount of milk replacer changed between 1.5 L to 3.0 L with the days of age of the calves. There was one increasing pattern (2.0 L in 14 days, and 3.0 L in 20 days and after), but two decreasing patterns (3.0 L feeding finished at 42 days, 2.0 L from 43 to 46 days, and 1.5 L from 47 to 55 days for 2 calves; 3.0 L feeding finished at 60 days, 2.0 L from 60 to 72 days, and 1.5 L on 73 days for 2 calves) in milk replacer feeding.

Calf sucking behavior was recorded by video camera (HERO9, GoPRO Inc., California, USA) from a short time before offering the milk to the completion of sucking. The start and end time of sucking (the sucking time) at rubber teats were determined, and the number of suckings were counted from individual video data. The number of observations was from 12 to 36 per calf. The observed frequency of sucking (per second) was calculated by the number of sucking movements by the time of sucking. The effect of the age of days and the offered amount of milk to the time of sucking, the numbers or the frequency of sucking movements were analyzed by multiple regression analysis. In all data analysis, we use the data without individual distinction.

The three-dimensional accelerometer (20 g, BWT61CL, WitMotion Co., Ltd., Shenzhen, China) was attached at the right of the collar placed around the neck of experimental calves as Y-axis was the up-down direction. A weight-ring (177 g) was used to prevent the collar from turning. The bucket was suspended on a fence. The accelerometer measured 150 samples per second (interval was 0.02 second and three-dimensional acceleration values). The acceleration data were collected and sent to a smartphone with a Bluetooth continuous connection, and recorded as a text-file (csv file) in the smartphone during the video recording period. This study was approved by the Animal Experiment Committee of Rakuno Gakuen University (DH20C5 and DH21C5).

The acceleration data of one axis from just after the start of sucking was used for the calculation of estimated sucking frequency. The acceleration of the up-down direction (Y-axis

in the present study) was the first choice for the estimation of the frequency, because calves exhibited head movement in an up-down direction while drinking milk from a rubber teat on the bucket. If the neck-collar rotated, the up-down movement was detected by Z-axis in the present study. Then, the second choice was Z-axis when sucking movement was not detected by the data of the Y-axis.

The duration of nursing was the time that elapsed from when the calf contacted the teat to when it remained away from the teat of the milk bucket. During the nursing period, the calf stopped the sucking movement in short time when the calf's muzzle was off the teat or the calf stroke with the muzzle toward the teat (upward movement with its head). The nursing period with continuous sucking movement should be used for the accurate estimation of sucking frequency. Therefore, the almost continuous sucking period was used (The minimum period was 20 seconds; The maximum period was 164 seconds) for estimation of sucking frequency.

Time series behavioral data should be analyzed not only by time-domain but also by frequency-domain (the periodic pattern of behavior). The spectral analysis is a useful technique for detecting the frequency distribution of the periodic pattern of waveforms (Omori *et al.* 1991. Sahara *et al.* 1996). The acceleration data of calves' sucking is shown by the waveforms. The spectral analysis by maximum entropy method (free software; special analyzer Spcana ver4.92) was used for estimating the frequency of sucking. The estimated frequency of sucking was determined as the peak of Maximum Entropy Method (MEM) power spectra under the range of three suckings per second (3 Hz).

Results and Discussion

Table 1 shows the average time, number and observed frequency of sucking, and the results of the multiple regression analysis with the age of days and the amount of milk. The average time of sucking was 219 seconds and standard deviation was 115 seconds, so the coefficient of variation of time was 53%. The time of sucking decreased with the age of days, and regression coefficient was -3.29, thus the time shortened by approximately 33 seconds per 10 days. The time of sucking was not related to the amount of offered milk.

Table 1 The average time, number and frequency of sucking movements, and the results of multipule regression analysis with age of days (x_1) and amount of milk (x_2)

	Age of days	Amount of milk
Time of sucking (seconds)	219 ± 115[1)]	
Significance for time	P<0.001	P=0.434
Regression coeffficient	-3.29	13.09
Coefficient of determination	0.196 (*P*<0.01)	
Number of sucking	473 ± 249	
Significance for number	P<0.001	P=0.193
Regression coeffficient	-6.79	48.02
Coefficient of determination	0.185 (*P*<0.01)	
Frecuency of sucking movement (Hz	2.22 ± 0.18	
Significance for frequency	P<0.001	P<0.05
Regression coeffficient	0.0041	0.068
Coefficient of determination	0.209 (*P*<0.01)	

1) Average ± Standard deviation

The average number of sucking was 473 suckings and standard deviation was 249 suckings, so coefficient of variation of the number was 53%. The number of sucking also decreased with the age of days, and regression coefficient was -6.79, thus the number decreased by approximately 68 suckings per 10 days. The number of sucking was not related to the amount of offered milk.

The average of observed frequency of sucking was 2.22 suckings/second (Hz) and standard deviation was 0.18 Hz, so coefficient of variation was 8.1%. The variation of the observed frequency was extremely lower than that of the time and the number of sucking.

The observed frequency of sucking increased with the age of days, and regression coefficient was 0.0041, thus the frequency increased only 0.04 times/second even after 10 days passed. The observed frequency was also significantly (P<0.05) related to the amount of milk, and the regression coefficient was 0.068. These values only exhibited a rise of approximately 0.1 Hz with increasing milk by 1.5 L. Costa *et al.* (2021) said that some changes in feeding behavior (drinking speed and milk intake) might depend on milk-feeding strategy (the amount of milk and age of calves). The frequency of sucking movement slightly changed with the age of calves and the amount of offered milk. The frequency of sucking movement changed with the proportion of sucking movement in sucking time. The sucking was paused when the calf released the teat or butt at bucket, even if only a short time. The average time or frequency

Fig.1. (Left) Milk replacer was fed from a bucket with a rubber teat. The bucket was suspended on a fence. (Right) The three-dimensional accelerometer was attached at right side on the collar with a weight-ring.

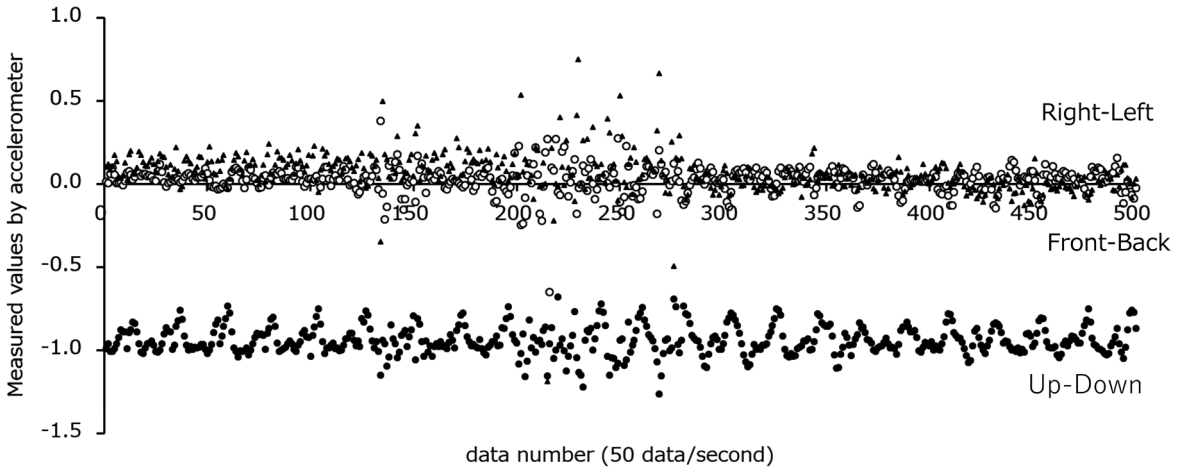

Fig.2. The typical waveforms of acceleration data (3 dimensions) with time (50 data per one second). ● :Up-Down, ▲ : Right-Left, ○ : Front-Back

of these behavior increased, and the proportion of the sucking time decreased during the following time of nursing (Lidfors *et al.* 2010). The observed frequency of sucking movement might change with time in the nursing period.

Figure 2 shows the typical waveforms of acceleration (3 dimensions) with time (50 data per one second). In this data, the acceleration of Y-axis (up-down direction) clearly exhibited the periodic pattern. The periodic patterns were presented in the acceleration data of the Y-axis in other cases. The acceleration of the Y-axis was the first choice for the estimation of the frequency of sucking in our experiment.

Figure 3 shows the acceleration direction that was used for the estimation of the sucking frequency of calves. In almost all of the cases (98%), the sucking frequency could be estimated by the Y-axis (up-down direction at start of experiment). The Z-axis (right-left direction) was used in only 2% cases for the estimation. The results of the analysis of the acceleration data matched with the movement of the calves' head by direct observation. We concluded that the frequency of sucking movement was able to be estimated by the one-direction acceleration (up-down direction), and the accelerometer had to be a 3-direction type for the support of the cases undetected by the Y-axis.

Table 2 shows the average of estimated frequency and the length of the period for the analysis. The average of estimated frequency was

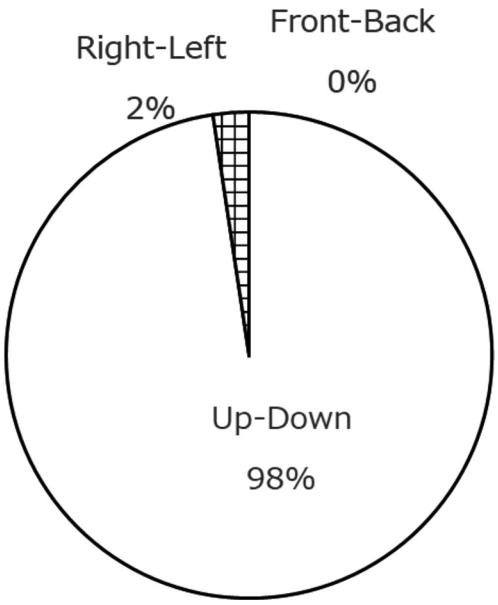

Fig.3. The acceleration direction that was used for the estimation of the sucking frequency of calves.

Table 2 The estimated frequency of sucking milk and the period for calculation of the sucking frequency

		Average	S.D.
Estimated	suckings / second	2.38	0.14
Data period	seconds	80.0	63.8
	% of observed sucking time	38.9	23.6

2.4 suckings. The differences between 4 calves in the present study was very small (from 2.3 to 2.5 suckings, individually). The data of acceleration for the estimation was 80 seconds on average. This time period was 38.9% of the observed sucking time of calves. Time series behavioral data contain the behavioral time (time-domain) and the periodic pattern of behavior (frequency-domain). Our results indicated that the sucking frequency could be estimated from the frequency-domain by the data of the part of sucking behavior of calves.

Figure 4 shows the distribution of the difference between the observed and the estimated sucking frequency. The difference was calculated by following formula: Difference (%) = | estimated - observed | / observed × 100

The average of the difference between observed and estimated sucking frequency was 9.0%. In 70% of cases, the difference between the observed and estimated was under 10%. We concluded that the frequency of sucking movement could be correctly measured by an accelerometer fitted on the neck-collar of calves.

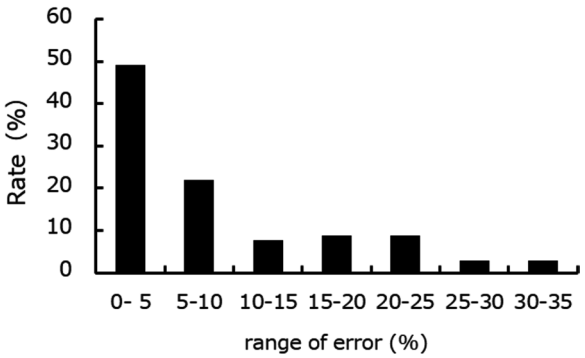

Fig.4. The distribution of the difference between the observed and estimated frequency of sucking movement.

Morita and Nishino (1986) described that the drinking speed of the milk replacer increased with days of age, and that it might be affected by increment of the frequency of sucking movement rather than the volume of one sucking of milk. On the other hand, Shuji and Ito (1996) measured the frequency of sucking movement in calves and concluded it did not change with the days of age over 20 days. Smith and Petersen (1945) showed that the negative pressure of sucking did not change with the growth of calves. This study supported the assertion that the growth of the tongue and the oral cavity space might cause a change in the increment and the amount of one sucking movement, resulting in a rise in the drinking speed with age in calves.

In our study, we measured the frequency of sucking movement, and it changed with age, but the increment of the frequency was very small with the growth of calf, and tendency of increasing was in the period under 20 days of age (regression coefficient 0.018, P=0.091). So, our results supported Shuji and Ito's conclusion (1996) that the raising of the drinking speed depended on the increase of the amount of milk by one sucking movement, and there was no change of sucking frequency with days of age over 20 days (regression coefficient 0.0011, P=0.478). The behavioral indicator of illness should not change with the growth of calf, for clear detection as a sign of disease. Thus, the frequency of sucking movement might be a better indicator for detecting the change of calves' condition rather than the time or the number of sucking. The drinking speed of milk decreased when the calves got an illness (Knauer *et al.* 2017). However, there is little information about the relationship between the frequency of sucking movement and calves' health condition, so further research is

needed to examine the factors for the changes of the frequency of sucking movement.

The changes in calves' behavior of milk-feeding are associated with diarrhea (Costa 2021). In the automatic milk feeding system, the information of drinking time and amount of milk was recorded. However, the frequency of sucking milk was not recorded. Sensors with an accelerometer for the management of calves would be installed on more dairy farms. We suggested that the frequency of suckings movement of milk should be monitored and characterized automatically by the sensor with accelerometer.

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加速度計を用いた人工哺乳子牛における吸乳行動の測定

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要　約

無線式加速度計が、子牛の動作を記録する機器の開発に利用されている。本研究では、無線式加速度計を用いて子牛の吸乳行動記録に利用し、子牛の吸乳行動の特徴を検討した。4 頭のホルスタイン種子牛を単飼した。子牛の吸乳時間と吸乳回数は、ビデオ記録から求めた。加速度計を首輪に装着し、得られたデータから、最大エントロピー法を用いて吸乳頻度を推定した。推定平均吸乳時間は 219 秒であり、平均回数は 473 回であった。観察された吸乳頻度は 2.2Hz（回 / 秒）であった。主に上下の動作を含む方向での加速度変化から、吸乳頻度が推定でき、推定された吸乳頻度は 2.4Hz であった。用いたデータ期間は、平均 80 秒で、これは全吸乳時間の 38.9％であった。全体の 70％で、実測値と推定値の差が 10％以内であり、加速度計で吸乳頻度が推定できることが示された。吸乳時間や吸乳回数は日齢とともに大きく変化するが、吸乳頻度の増加はわずかであった。

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