



## Nocturnal Light Pulses Lower Carbon Dioxide Production Rate without Affecting Feed Intake in Geese

De-Jia Huang and Shyi-Kuen Yang\*

Department of Animal Science and Biotechnology, Tunghai University, Taichung 40704, Taiwan

**ABSTRACT:** This study was conducted to investigate the effect of nocturnal light pulses (NLPs) on the feed intake and metabolic rate in geese. Fourteen adult Chinese geese were penned individually, and randomly assigned to either the C (control) or NLP group. The C group was exposed to a 12L:12D photoperiod (12 h light and 12 h darkness per day), whereas the NLP group was exposed to a 12L:12D photoperiod inserted by 15-min lighting at 2-h intervals in the scotophase. The weight of the feed was automatically recorded at 1-min intervals for 1 wk. The fasting carbon dioxide production rate (CO<sub>2</sub> PR) was recorded at 1-min intervals for 1 d. The results revealed that neither the daily feed intake nor the feed intakes during both the daytime and nighttime were affected by photoperiodic regimen, and the feed intake during the daytime did not differ from that during the nighttime. The photoperiodic treatment did not affect the time distribution of feed intake. However, NLPs lowered ( $p < 0.05$ ) the mean and minimal CO<sub>2</sub> PR during both the daytime and nighttime. Both the mean and minimal CO<sub>2</sub> PR during the daytime were significantly higher ( $p < 0.05$ ) than those during the nighttime. We concluded that NLPs lowered metabolic rate of the geese, but did not affect the feed intake; both the mean and minimal CO<sub>2</sub> PR were higher during the daytime than during the nighttime. (**Key Words:** Feed Intake, Goose, Intermittent Lighting, Metabolic Rate, Photoperiod)

### INTRODUCTION

Geese have much lower feed efficiency than broilers, especially in the fattening period (Chen et al., 2003). Thus it is desirable to increase the feed efficiencies of geese during both growing and fattening periods. Within a reasonable range, a high feed intake results in a high weight gain and feed efficiency, because tissue accretion occurs only when the ingested nutrients exceed the requirements for maintenance. Therefore, increasing feed intake is a potential method for increasing both weight gain and feed efficiency in geese. To maximize feed intake and growth rate broiler chickens are usually kept on a continuous or nearly continuous lighting schedule. However, intermittent lighting has been shown to result in some benefits, including increased feed efficiency (Weaver et al., 1982; Ketelaars et al., 1986; Apeldoorn et al., 1999) and increased weight gain

(Ohtani and Leeson, 2000). Geese ingest more feed per hour during the daytime than during the nighttime (Chu, 2012). The geese which were subjected to a 1-h light pulse inserted in the scotophase (i.e. skeletal long photoperiod) concentrated their nighttime feed intake at the particular hour (Chu, 2012). In the present study, we aimed to increase feed intake in geese by using several short-time light pulses during the scotophase.

Although birds are quiet during the dark period, we assumed that short light pulses only shortly increase their activity, and do not substantially raise their heat production during the night. Historically, indirect calorimetry has mainly relied upon measurement of oxygen consumption. However, in recent years, increased attention has been placed on measuring carbon dioxide (CO<sub>2</sub>) production, because the current CO<sub>2</sub> analyzers have higher resolution than the typical O<sub>2</sub> analyzers for detecting the changes in air composition. In birds, the thermal equivalents of carbohydrates, fats, and proteins for CO<sub>2</sub> production are 5.047, 6.694, and 6.597 kcal/L, respectively (Robbins, 1993). When little is known about the catabolized substrates,

\* Corresponding Author: Shyi-Kuen Yang. Tel: +886-4-23590121 (37116), Fax: +886-4-23590385, E-mail: skyang@thu.edu.tw  
Submitted Mar. 19, 2015; Revised Jun. 8, 2015; Accepted Jun. 22, 2015

large errors can occur when estimating energy expenditure based on CO<sub>2</sub> production; however, errors are <1.5% when the catabolized substrates are limited to fats and proteins (i.e. in the fasting status). Therefore, the carbon dioxide production rate (CO<sub>2</sub> PR) theoretically is an acceptable index of energy expenditure rate for birds in fasting status. In this study, we also determined the fasting CO<sub>2</sub> PR to evaluate the effect of the photoperiod regimen on the energy expenditure rate. Briefly, the purpose of this study was to determine the effect of nocturnal light pulses on the feed intake and carbon dioxide production rate in geese.

## MATERIALS AND METHODS

Fourteen female adult Chinese geese (a breed of domesticated geese) before laying period were used in this study. The ages of the geese were >2 yr, and the body weights of geese ranged from 4.0 to 4.5 kg. The experimental protocols used in this study were approved by the Experimental Animal Care and Use Committee of Tunghai University. Before the experiment, the geese were raised in a 230-m<sup>2</sup> enclosed paddock with other geese, mallards, Muscovy ducks, and peacocks. The paddock contained a 50-m<sup>2</sup> shelter and a 40-m<sup>2</sup> pond. The birds were exposed to the natural photoperiod, and were fed a commercial feed (fattening diet for duck; Fuso, Taichung, Taiwan) twice per day. Just before the beginning of the experiment, the natural day length was about 12 h (from civil dawn to civil dusk) and was increasing. The geese used in this study were transferred to a light-tight barn, and were randomly assigned to either the control (C) or the nocturnal light pulse (NLP) group. Each group was kept at a separated room, which was divided into individual pens (1.5×1.0 m). During the experimental period, all geese were penned individually, and allowed free access to feed and water. The control group was exposed to a 12L:12D photoperiod (12 h light and 12 h darkness per day; light on at 06:15 h and off at 18:15 h). The NLP group was exposed to a 12L:12D photoperiod inserted by 15-min lighting at 2-h intervals in the scotophase. The light was offered with fluorescent tubes. The light intensity on floor during the lighting period ranged from 60 to 120 lx. A small red bulb, which generated a light intensity <1.0 lx at night, was lighted all day for each group.

This study included a 2-wk adaptation period, a 1-wk feed intake recording period, and a 1-d CO<sub>2</sub> PR recording period. During the experimental period, geese did not enter their laying period. After the 2-wk adaptation period, the geese were weighed. The mean body weights for C and NLP groups were 4.28±0.21 (mean±standard deviation) and 4.30±0.14 kg, respectively. When the feed intake was recorded, the weight of feed was automatically recorded at 1-min intervals for 1 wk. The feed was placed on a digital

platform balance (ML4001, Mettler Toledo, Columbus, OH, USA) connected to a PC for recording the weight data. Both readability and repeatability of the balance were 0.1 g. After the 1-wk feed intake recording, all geese were kept in the experimental room, and were sequentially (2 geese once) transferred into metabolic chambers within 10 d. Before transferring to the metabolic chamber the geese were weighed after a 24-h fasting. The mean body weights of geese in C and NLP groups were 4.11±0.14 and 4.20±0.16 kg, respectively. The CO<sub>2</sub> PR values were recorded at 1-min intervals for 1 d. The room of metabolic chamber was light-tight, and the lighting schedule was adjusted to the experimental photoperiod for each group. Within the metabolic chamber, water was supplied in a sink, but feed was deprived.

The air-tight metabolic chamber was made of clear acrylic plastic (72×72×82 cm), and had a removable lid to allow the addition and removal of a stainless cage. Ambient air was supplied from the outdoors by an exhaust fan through an adjustable valve. The air in the chamber was mixed well by 2 small fans. The CO<sub>2</sub> concentration, temperature, and linear velocity of air flow were detected at the outlet of the chamber. The CO<sub>2</sub> was detected using a non-dispersive infrared dual wavelength type CO<sub>2</sub> sensor (KCD-HP100x, Korea Digital Co., Seoul, Korea), with an accuracy of ±3% full scale +2% reading. The temperature was detected using a thermocouple sensor (Type K, Jetec, Taichung, Taiwan), with a detection error of ±0.2°C at room temperature. The linear velocity of the air flow was detected using a transmitter based on a hot-film anemometer (EE576, E+E Elektronik, Engerwitzdorf, Austria), with an accuracy of ±0.05 m/s +2% reading. The CO<sub>2</sub> concentration, temperature, and air flow velocity data were transmitted to and recorded on a multiple-channel recorder (TRM2006A000T, Toho Electronics Inc., Kanagawa, Japan) at 1-min intervals. The goose was placed into a stainless cage (50×54×70 cm) fitted with a sink to supply water. During the experimental period, the air flow was maintained at approximately 60 L/min. The room temperature were maintained at 23°C to 25°C, and the actual temperature of the chamber outlet was maintained at 22°C to 25°C. An empty identical metabolic chamber without goose was used as a blank for calculating the CO<sub>2</sub> PR.

The data of individual goose was considered as an experimental unit for statistical analysis. The CO<sub>2</sub> PR data of one goose in NLP group were discarded due to the fault of facility. The CO<sub>2</sub> PR was expressed on the basis of metabolic size (kg<sup>0.75</sup>). The feed intake of each goose used for drawing and statistical analysis was the mean calculated from the 7-d records. The mean and the minimal CO<sub>2</sub> PR of each goose during daytime or nighttime for statistical analysis were the mean and the minimal values during the

time phase, respectively. Data were analyzed by repeated measures analysis of variance (ANOVA) using the general linear model (PROC GLM) of SAS statistical software (SAS Inst. Inc., Cary, NC, USA). The statistical model was:

$$y_{ij} = \mu + \text{Trt}_i + \text{Tm}_j + \text{Trt}_i \times \text{Tm}_j + e_{ij}$$

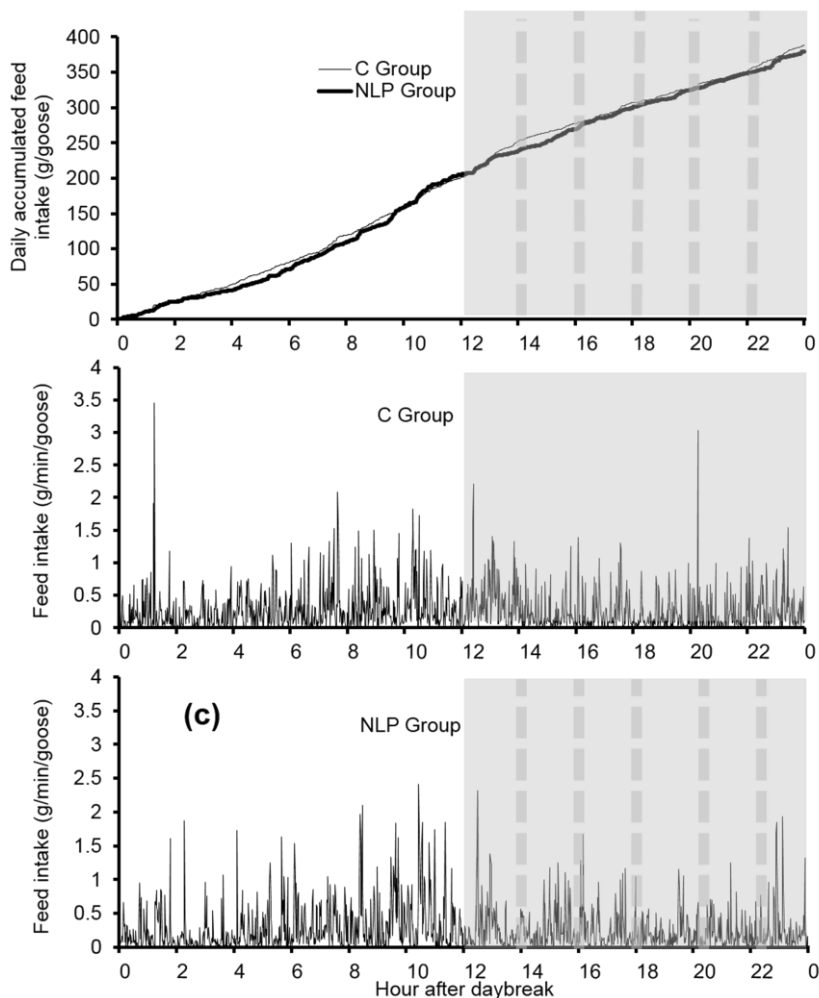
where  $y_{ij}$  is the observation,  $\mu$  is the overall population mean,  $\text{Trt}_i$  is the fixed effect of treatment ( $i = 1, 2$ ),  $\text{Tm}_j$  is the fixed effect of measuring time ( $j = 1, 2$ ),  $\text{Trt}_i \times \text{Tm}_j$  is the interaction between treatment and time, and  $e_{ij}$  is the residual term associated with the measure.

The statistical significances of differences between means were determined by the least squares means procedure with the significance set at  $p < 0.05$ . Because the carbon dioxide production rates rhythmically fluctuated with an approximately 3.5-h period, the curves were also smoothed by the simple moving averages to find the diurnal

trends. In smoothing, the value for a given time point was the mean which was calculated by using Microsoft Excel from the 105-min consecutive records both before and after the given time point. For example, the value at 10:00 was the mean of the records from 08:15 to 11:45.

## RESULTS

The feeding patterns varied among geese. Some geese frequently nibbled, whereas others fed infrequently but ingested a great amount of feed per bout (data not shown). The ingestion bouts were neither synchronized among geese, nor synchronized among dates for a given goose (data not shown). The mean accumulative feed intakes during a day in both groups are shown in Figure 1a. The accumulative feed intake curves of both groups almost overlap, and resemble a straight line. The feeding rate (g/min) in both groups fluctuated throughout a day (Figure 1b and 1c). The



**Figure 1.** The effects of nocturnal light pulses (NLP) on the daily accumulated feed intake (a) and feeding rate (b and c) during a day in Chinese geese. C group was exposed to a 12L:12D photoperiod (12 h light and 12 h darkness per day); NLP group was exposed to a 12L:12D photoperiod inserted by 15-min lighting at 2-h intervals in scotophase. The shaded areas indicate the scotophase, and the vertical broken lines indicate the 15-min nocturnal light pulses in NLP group. Both the daily accumulated feed intake and feeding rate were the means of 7-day records.  $n = 7$  for both groups.

**Table 1.** The effects of nocturnal light pulses<sup>1</sup> and time phase on the feed intake and carbon dioxide (CO<sub>2</sub>) production rate in geese

Trait <sup>2</sup>	C group		NLP group		RMSE	p-value		
	Day	Night	Day	Night		Trt	Tm	Trt×Tm
Feed intake <sup>2,3</sup> (g/phase/goose)	194.3	185.5	206.4	176.9	40.9	0.911	0.239	0.519
Mean CO <sub>2</sub> production rate (mL/min/kg <sup>0.75</sup> ) <sup>3</sup>	19.2 <sup>a</sup>	16.1 <sup>b</sup>	16.3 <sup>b</sup>	12.8 <sup>c</sup>	1.9	0.002	0.001	0.825
Minimal CO <sub>2</sub> production rate (mL/min/kg <sup>0.75</sup> ) <sup>3</sup>	13.9 <sup>a</sup>	12.8 <sup>ab</sup>	11.6 <sup>bc</sup>	10.1 <sup>c</sup>	1.3	<0.001	0.022	0.716

NLP, nocturnal light pulse; RMSE, root mean square error; Trt, photoperiodic treatment; Tm, time phase (day vs night).

<sup>1</sup> C group was exposed to a 12L:12D photoperiod (12 h light and 12 h darkness per day); NLP group was exposed to a 12L:12D photoperiod inserted by 15-min lighting at 2-h intervals in scotophase. This study included a 2-wk adaptation period, a 1-wk feed intake recording, and a 1-d CO<sub>2</sub> production rate recording.

<sup>2</sup> The feed intake for each goose was the average of 7-day records, and was separated into two phase (day and night).

<sup>3</sup> n = 7 for each mean except for the mean and minimal CO<sub>2</sub> production rates of NLP group, where n = 6.

<sup>a,b,c</sup> Means in a same row without a common superscript letters differ significantly (p<0.05).

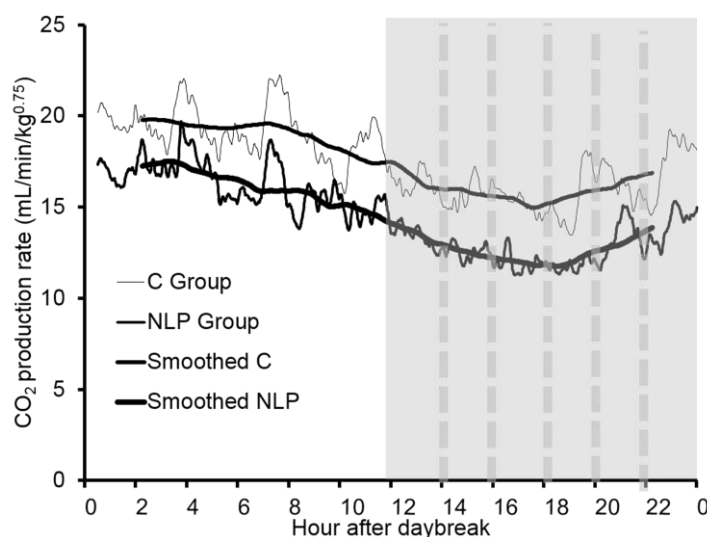
feed intake did not exhibit obvious relationship with nocturnal light pulses. Summarized data showed that feed intake did not differ between photoperiod regimens or between day and night, and there was no significant interaction between treatment and time phase (Table 1).

The CO<sub>2</sub> PR of each goose exhibited several fluctuations per day (data not shown). The curve of group mean of CO<sub>2</sub> PR for C group exhibited ultradian rhythmicity which period was about 3.5 h (Figure 2). The amplitudes of fluctuations were high in the daytime, and dampened in the nighttime. When the curve was smoothed by the moving averages, it exhibited an obvious circadian rhythm with a nadir at the middle night and acrophase at the middle day. The curve for NLP group almost parallels and is always below that for C group (Figure 2). The smoothed curves for C and NLP group clearly exhibit the parallelism

and the same phase shift. In NLP group, the CO<sub>2</sub> PR did not increase during the nocturnal intermittent lighting periods. Summarized data showed that both the mean and minimal CO<sub>2</sub> PRs during the daytime were significantly higher (p<0.05) than those during the nighttime (Table 1). Both the mean and minimal CO<sub>2</sub> PR were significantly lowered (p<0.05) by NLPs during both the daytime and the nighttime, compared with C group (Table 1).

## DISCUSSION

In the present study, the feeding behavior of geese in both groups was evenly distributed throughout a day, and the feed intake during the day was not different from that during the night. The result did not prove the circadian rhythm in ingestion. Originally we hypothesized that NLPs



**Figure 2.** The effect of nocturnal light pulses (NLP) on the carbon dioxide production rate during a day in Chinese geese. C group was exposed to a 12L:12D photoperiod (12 h light and 12 h darkness per day); NLP group was exposed to a 12L:12D photoperiod inserted by 15-min lighting at 2-h intervals in scotophase. The shaded areas indicate the scotophase, and the vertical broken lines indicate the 15-min nocturnal light pulses in NLP group. The smoothed curves are drawn on the basis of the simple moving averages, which are the means of 105-min consecutive records before and after the given time points. The numbers of observations for the C and NLP groups are 7 and 6, respectively.

stimulate geese to feed during the lighting periods. However, the results in the present study did not agree with this hypothesis. Feeding was neither entrained nor stimulated by the NLPs. In a previous study, the White Roman geese subjected to a skeletal photoperiod, in which 1-h lighting was inserted at the 8th hour of 16-h darkness, had a feed intake per hour during the continuous lighting hours similar to that of the short day controls (exposed to 8L:16D); however, their feed intake during the inserted lighting hour was substantially higher than those during the dark hours and the continuous lighting hours (Chu, 2012). The inconsistency between studies may be attributable to the differences in the length of the continuous lighting and the time, number, and length of light pulses.

Unexpectedly, the mean CO<sub>2</sub> PR did not increase during the intermittent lighting periods. In addition, the NLPs lowered the mean CO<sub>2</sub> PR. These results imply that the NLPs do not disturb the resting of geese, at least after a 2-wk adaptation period. The reasons for the decrease in heat production caused by NLPs are not clear. However, a similar phenomenon was found in voles. The mean energy expenditure levels of the voles experienced NLPs were lower than those of the voles exposed to a short day photoperiod (Zubidat et al., 2007). In addition, although the heat production during the light phase is higher than that during the dark phase in chickens (Apeldoorn et al., 1999; Ohtani and Leeson, 2000), the differences in total daily heat production between groups subjected to intermittent lighting and continuous lighting varied among studies. Ohtani and Leeson (2000) reported that intermittent lighting increased heat production, in contrast with Ketelaars et al. (1986); Apeldoorn et al. (1999) observed no difference between groups subjected to intermittent lighting and continuous lighting. In the present study, the equal feed intake and the reduced heat production rate during the night suggested that the net energy accretion rate during the night might be higher than that during the day in geese.

The fasting minimal CO<sub>2</sub> PR reflects the basal metabolic rate. In this study, the fasting minimal CO<sub>2</sub> PR in the lighting hours was faster than that in the dark hours. This result differed from that of a previous study, in which the minimal CO<sub>2</sub> PR of White Roman geese did not differ between day and night (Chu, 2012). It is also surprising that NLPs significantly lowered the minimal CO<sub>2</sub> PR. The differences between treatments regarding the mean CO<sub>2</sub> PR (2.9 and 3.3 mL/min/kg<sup>0.75</sup> for the day and the night, respectively) and the minimal CO<sub>2</sub> PR (2.3 and 2.7 mL/min/kg<sup>0.75</sup> for the day and the night, respectively) suggested that the decrease in heat production caused by the NLPs mainly resulted from a lowered basal metabolism. The differences between day and night regarding the mean CO<sub>2</sub> PR (3.1 and 3.5 mL/min/kg<sup>0.75</sup> for the control and the

treated groups, respectively) and the minimal CO<sub>2</sub> PR (1.1 and 1.5 mL/min/kg<sup>0.75</sup> for the control and the treated groups, respectively) suggested that the lowered basal metabolism contributed to only small portion of the difference in the mean CO<sub>2</sub> PR between day and night.

In conclusion, under a 12L:12D photoperiod, the feed intakes did not differ between day and night, but both the mean and minimal carbon dioxide production rates during the daytime were higher than those during the nighttime. Under a 12L:12D photoperiod, nocturnal light pulses affect neither the amount of feed ingested nor the time distribution of feed intake, but lowered both the mean and minimal fasting carbon dioxide production rates.

## IMPLICATIONS

Ingestion behavior and activity in broilers are controlled by lighting; they ingest and are active in the light, and rest in the dark. In this study, we found that geese ingest equal amount of feed during the day and night, but their heat production rates in the daytime are higher than those in the nighttime. The nocturnal light pulses lower the fasting metabolic rate of geese during both day and night without affecting feed intake. The lowered fasting metabolic rate implies that the nocturnal light pulses may lower the energy requirement for maintenance and improve the efficiency of energy accumulation.

## CONFLICT OF INTEREST

We certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

## ACKNOWLEDGMENTS

We thank Miss Pei-Wen Chen for her assistance in the data processing.

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