THE IMPACT OF PHOTOPERIODIC DISRUPTIONS ON SEASONAL BEHAVIORS IN REDHEADED BUNTINGS: A COMPREHENSIVE STUDY

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ABSTRACT

This study explores the impact of photoperiodic disruptions on the seasonal behaviors of redheaded buntings (Emberiza bruniceps), focusing on the relationship between photoperiodic history and subsequent physiological and behavioral responses during extended daylight periods. The research highlights how variations in light exposure during the photosensitive phase, including continuous short days, alternating cycles of light and darkness, continuous dim light, and continuous bright light, significantly affect key life-history events such as migration, reproduction, body fat accumulation, testis growth, and locomotor activity. The findings underscore the critical role of photoperiod as an environmental cue in regulating these events and reveal that the timing and amplitude of physiological responses are influenced by the birds' prior photoperiodic experiences. The study's insights contribute to understanding the complex mechanisms through which photoperiod and light intensity interact, offering valuable implications for predicting the effects of environmental changes on migratory bird populations and their long-term survival.

Keywords: photoperiodic disruptions, redheaded buntings, seasonal behaviors, migration, reproduction, body fat accumulation, testis growth, locomotor activity, environmental cues, light exposure.

1. INTRODUCTION

Birds' life cycles are divided into two distinct physiological phases: the photosensitive phase, which spans from the pre-reproductive to the reproductive stage, and the photorefractory phase, which covers the transition from reproductive to pre-reproductive stages. The photosensitive phase is particularly crucial and susceptible to external influences, as birds undergo transitions before migration and nesting during this period. The photoperiod, defined as the duration of light exposure in a 24-hour period, serves as the most consistent and reliable environmental signal for these transitions. Even slight alterations in natural photoperiodic conditions can significantly impact a bird's reproductive success. Therefore, this study aimed to explore the relationship between disruptions in photoperiod during the photosensitive phase and subsequent responses to extended daylight hours, focusing on the gonadal cycle and migratory behavior of redheaded buntings (Emberiza bruniceps).

In this study, a flock of redheaded buntings (n = 5–7) was first acclimated to short days (SD; 8 hours of light: 16 hours of darkness) for 1.5 weeks. Subsequently, the birds were exposed to various treatment photoperiods for 4 weeks, including continuous short days (8L:16D, SD), short days alternating with constant darkness (8L:16D/DD, SD/DD), continuous dim light, and continuous bright light. After 15 weeks of these treatments, all groups were subjected to long days (16L:8D) to assess their responses to the extended daylight hours, particularly focusing on changes in circadian rhythm.

Throughout the research period, several physiological parameters were monitored at regular intervals, including locomotor activity, migratory restlessness, fat accumulation, changes in body mass, testis development and regression cycles, and food intake. The results indicated that all groups exhibited an increase in body fat percentage, body mass, and testis size after being exposed to the experimental photoperiod (16L:8D). Although the magnitude of these responses was consistent across groups, the time required to reach the peak response varied. Additionally, the synchronization or phase alignment of these physiological responses was influenced by the birds' photoperiodic history. Birds that had experienced short days demonstrated tighter coordination of these responses compared to those continuously exposed to dim light. The longer days prompted increased food intake and locomotor activity, with the continuous dim light group consuming more than three times the amount of food as the control group. In the group exposed to continuous bright light, migratory restlessness, or Zugunruhe, began on the first day of exposure to long days. In other groups, Zugunruhe was observed between days 6-10 (SD), days 6-14 (SD/DD), and days 6-13 (LLdim), with the longest duration of Zugunruhe occurring in the continuous dim light group.

In summary, the findings suggest that a bird's photoperiodic history, particularly artificial lighting during the photosensitive phase, can significantly impact seasonal behaviors such as migration and reproduction. These results underscore the importance of photoperiod in determining life history events in birds and highlight the potential consequences of environmental disruptions on their annual cycles.

Nearly all living organisms possess physiological systems that enable them to respond to regular, predictable changes in their environment. These systems allow precise synchronization of migrations, reproductions, molts, and other life events within their annual cycles (Murton and Westwood, 1977; Bronson, 1989; Wingfield and Kenagy, 1991; Shine and Brown, 2008; Malik et al., 2014). In nature, animals experience cyclical changes in photoperiod throughout the year, using these changes as reliable signals for timing reproduction (Wingfield, 1980; Follett, 1984; Gwinner, 1996; Hahn et al., 1997; Kumar, 2001; Sharp, 2005).

Birds in temperate zones synchronize energy-intensive activities like migration and reproduction with the region's distinct seasonal cycles, ensuring optimal timing for these behaviors, which leads to higher fitness and reproductive success (Perrins, 1970; Price et al., 1988; Nilsson, 1999). Research has shown that behaviors such as Zugunruhe (nocturnal migratory restlessness), prenuptial molt, and testicular development in migratory birds can be influenced by simulated photoperiods experienced during their wintering periods at different latitudes (Gwinner, 1987; Coppack et al., 2003).

Mammals also display differential responses to extended light exposure based on their prior photoperiodic experiences. Studies by Horton (1984), Lee and Zucker (1988), and Gower et al. (1997) revealed that animals' photoperiodic history influenced their body mass post-weaning. Reproductive behaviors are similarly affected by the interaction between original photoperiodic history and experimental photoperiods, with intermediate-length photoperiods eliciting inhibitory responses only when they precede longer photoperiods (Kampf-Lassin and Prendergast, 2013).

The concept of photoperiodic history plays a crucial role in shaping an organism's physiological and behavioral responses to changing light conditions, as it allows organisms to anticipate and adapt to environmental changes in ways that enhance their overall fitness. Understanding the relationship between an organism's past light exposure and its future responses is vital for comprehending the dynamics of life-history events in both birds and mammals.

Photoperiodic conditions also impact the immune system's sensitivity to changes in day length, even in adulthood (Prendergast and Pyter, 2009). Research on starlings (Sturnus vulgaris) demonstrated that when exposed to long days, young starlings born in spring do not reach sexual maturity until the following year. In contrast, their offspring do not develop photosensitivity until they are exposed to shorter days (McNaughton et al., 1992).

In temperate zones, longer daylight hours trigger gonadal enlargement and the onset of mating behavior (Dawson et al., 2001), a strategy that ensures offspring survival in the face of selective pressures such as food scarcity. This synchronization is particularly critical for migratory birds, which encounter a wide range of climatic conditions during their annual cycle, from migration to breeding to overwintering. Strategically spacing these interconnected phases throughout the year helps avoid physiological conflicts (Kumar et al., 2006). The photosensitive stage of a migrant bird's annual cycle includes the pre- and post-reproductive periods, while the photorefractory stage follows reproduction and lasts until the next preparatory period. Among these phases, the photosensitive preparation phase is the most critical, as environmental changes during this time can have lasting effects on reproductive success.

Previous research on redheaded buntings indicated that food restriction during the photosensitive stage reduced the amplitude of the gonadal response, subsequently decreasing reproductive success (Budki et al., 2009). Building on this knowledge, the present study aimed to determine whether changes in photoperiod conditions during the pre-breeding stage could alter responses to stimulatory long days, thereby influencing seasonal behaviors such as reproduction, food intake, body fat accumulation, and migratory restlessness. Redheaded buntings are known to be photoperiod and intensity-dependent (Kumar and Rani, 1996; Misra et al., 2004; Malik et al., 2004), long-day breeders, and responsive to increasing day lengths by initiating spring migration and breeding, while decreasing day lengths in winter trigger fall migration.

2. MATERIALS AND METHODS

The redheaded bunting (Emberiza bruniceps) was the species of interest in this research since it is a migratory bird that goes from the Palaearctic to India for the winter. Adult male birds were taken from their native environment and acclimated in outdoor aviaries to the seasonal changes in daylight. These birds were split into four groups, with around five to seven in each, so that the experiment could be carried out. As a result, they were subjected to short days with an 8-hour light period and a 16-hour dark period (8L: 16D). Their individual cages, measuring 60 x 45 x 35 cm, were fitted with infra-red motion detectors so that their movements inside the cage could be tracked.

After the birds had adjusted to the shorter days, they were put through a series of therapy photoperiods.

- “Group 1: Kept under a regimen of 8 hours of light and 16 hours of darkness (8L: 16D).
- Group 2: Exposed to alternating cycles of 8 hours of light and 16 hours of darkness followed bycontinuous darkness (8L: 16D/DD).
- Group 3: Kept under constant dim light conditions, with illumination below 1 lux (LLdim).
- Group 4: Exposed to constant bright light conditions, with an intensity of approximately 100 lux (LLbright).”

3. ANALYSIS

After each group spent four weeks in their designated therapy photoperiod, they were switched to a stimulating photoperiod of 16 hours of light and 8 hours of darkness (16L: 8D) for a total of 15 weeks. Seeds from kakuni, Setaria italica, and rice Oryza sativa were fed to the birds throughout the research, and they had access to an unlimited supply of water. These supplies were regularly restocked each morning. The birds were also given antibiotics (Tetracycline hydrochloride, Hoechst Roussel Vet Pvt. Ltd.) and vitamins (Vimeral, Agrivet Farm Care Division, Glaxo Smith Kline Pharmaceuticals Ltd.) once a month for five days in a row. Each bird included in the study was given the same high level of care and treated with respect and kindness from the moment they were brought into the lab until the day they were released.

A wide range of physiological and behavioral characteristics were tracked during the course of the research. The redheaded bunting's reactions to various photoperiodic circumstances were studied by doing these measurements at regular intervals. Body fat percentage, testicular volume, caloric consumption, and lean body mass were the primary variables studied.

The birds' total body weight was determined using a top pan balance accurate to within 0.1 grams. Fatty deposits were given numerical values between 0 and 5 for evaluation in the furcular, scapular, and abdominal regions. The foundation for this grading system was laid by earlier work by the same researchers (Malik et al., 2004). Using a topical anesthetic and a unilateral laparotomy operation, the size of each bird's left testis was measured and documented. Individually housed birds in activity cages had their food consumption analyzed. The bottom of the cage was lined with paper sheets, and those sheets extended up the sides of the cage to catch any stray scraps of food. The quantity of food consumed by each bird was calculated as the difference between what was offered and what was gathered as leftovers. The average daily food consumption was then determined (in grams per day, each bird). Additionally, the formula (food intake - feces) / food intake 100 was used to determine the efficiency of food use.

Daily counts and 24-hour activity profiles were created for each experimental group to evaluate locomotor activity patterns, and counts were taken both during the day and at night.

Several statistical methods were used to analyze the data obtained. Differences between groups on repeated and unrepeated measures were analyzed using one-way analysis of variance (ANOVA). The effects of photoperiodic treatments on the analyzed responses were analyzed using a two-way analysis of variance. In a two-way analysis of variance (ANOVA), photoperiod was considered Factor 1, time was considered Factor 2, and the interaction between the two was considered Factor 1 2. The threshold of statistical significance used was P 0.05. Graph Pad Prism (version 5.0) was used for all statistical calculations.

The results of these analyses are presented and illustrated in Figures 3-5, allowing for a comprehensive understanding of the results of the experiment, including the effects of photoperiodic history on body fat, body weight fluctuations, testis growth and regression cycles, food intake, and locomotor activity patterns.

Effect on body fattening, weight gain and testis volume

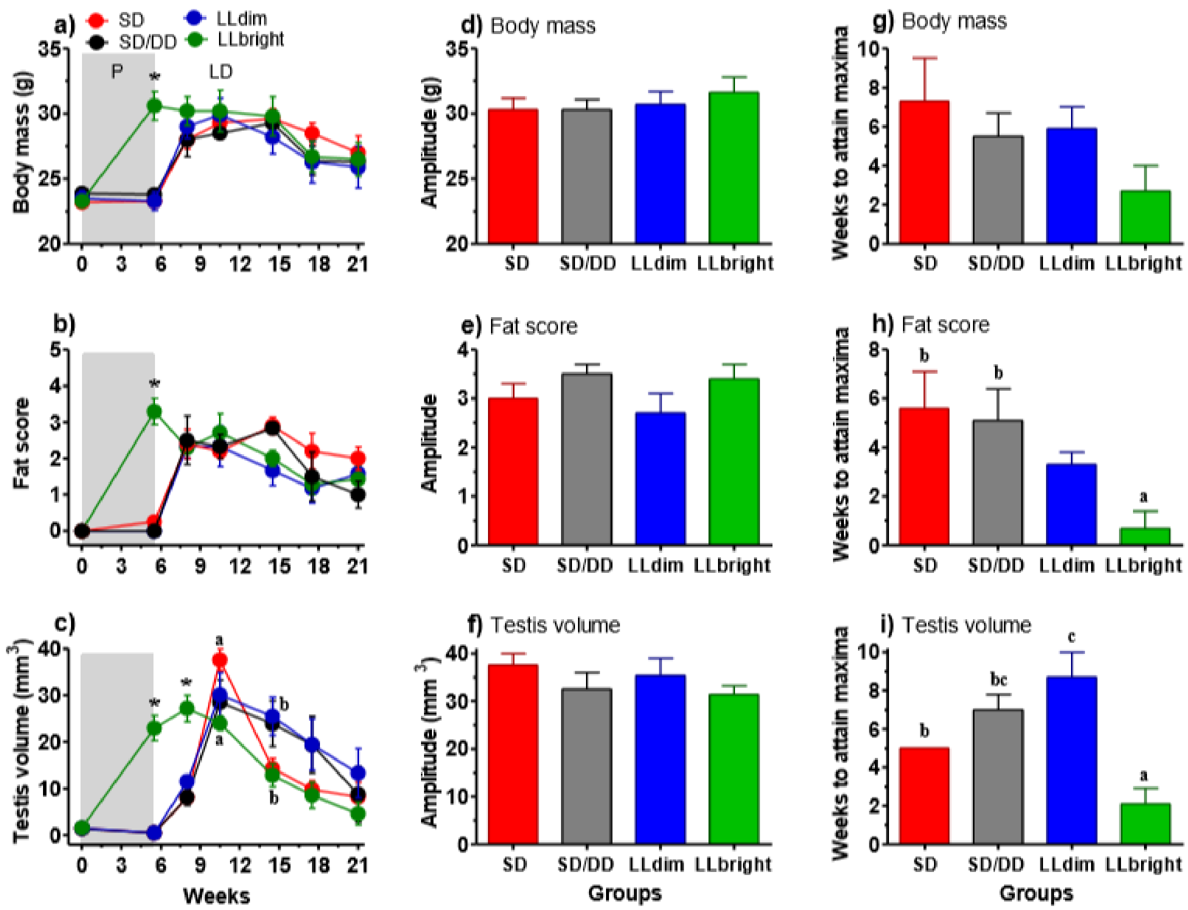
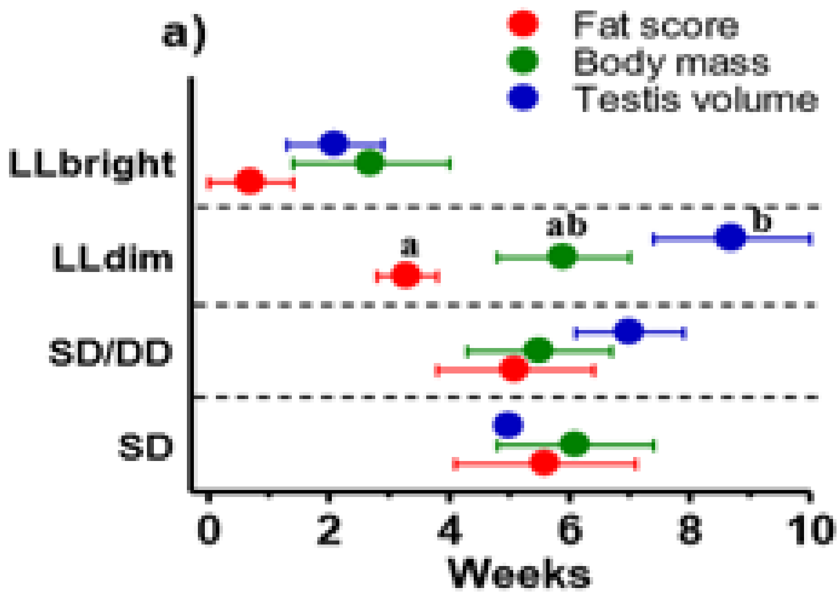


Figure 3: Changes in (a) body mass, (b) fat score, and (c) testis volume as a mean (SEM) across photoperiodic treatments for redheaded buntings. Long days (LD) = photoperiodic treatment (P). Mean (SEM) values (d) for body mass, (e) for fat score, and (f) for testis volume are shown for each group. For (g) body mass, (h) fat score, and (i) testis volume, the mean (SEM) duration to reach this amplitude of reaction (maxima) is also shown. The importance of the differences are shown by the symbols on the data points. In Figures a–c, the asterisk (*) denotes a significant difference when compared to the other groups, and the similar alphabets indicate significant differences between the groups (two-way ANOVA). Figures g-i use a one-way ANOVA to show that when the letters in each group are the same, there is no significant difference between the groups. P 0.05 was considered significant.

In conclusion, the findings of the research show that the redheaded buntings' physiological responses were greatly affected by the photoperiodic history during the preliminary stage. Changes in weight gain/loss, obesity, testicular growth/regression, appetite, and activity levels are all examples of such reactions. When the birds were subjected to stimulatory long days, the effects of the various photoperiodic treatments were more obvious. This study sheds light on the complex life history strategies of migratory birds and the intricate relationships between photoperiodic conditions and these birds' ability to adapt to their environments to ensure their continued survival and reproductive success.

The relationship between photoperiodic circumstances and the reproductive activities and reactions of the redheaded buntings was also investigated. The results showed that the birds' later reactions to stimulatory long days were significantly impacted by changes in photoperiodic history during the preparing stage, which in turn affected several seasonal responses.

In conclusion, the present study's extensive analysis of photoperiodic circumstances, migratory behaviors, and reproductive responses in redheaded buntings has revealed important insights. Physiological and behavioral consequences in migrating birds are strongly influenced by photoperiodic history, as shown by these results. The results of this research add to our knowledge of how these bird populations adapt to yearly cycles of fluctuating environmental circumstances without losing their ability to survive and flourish.



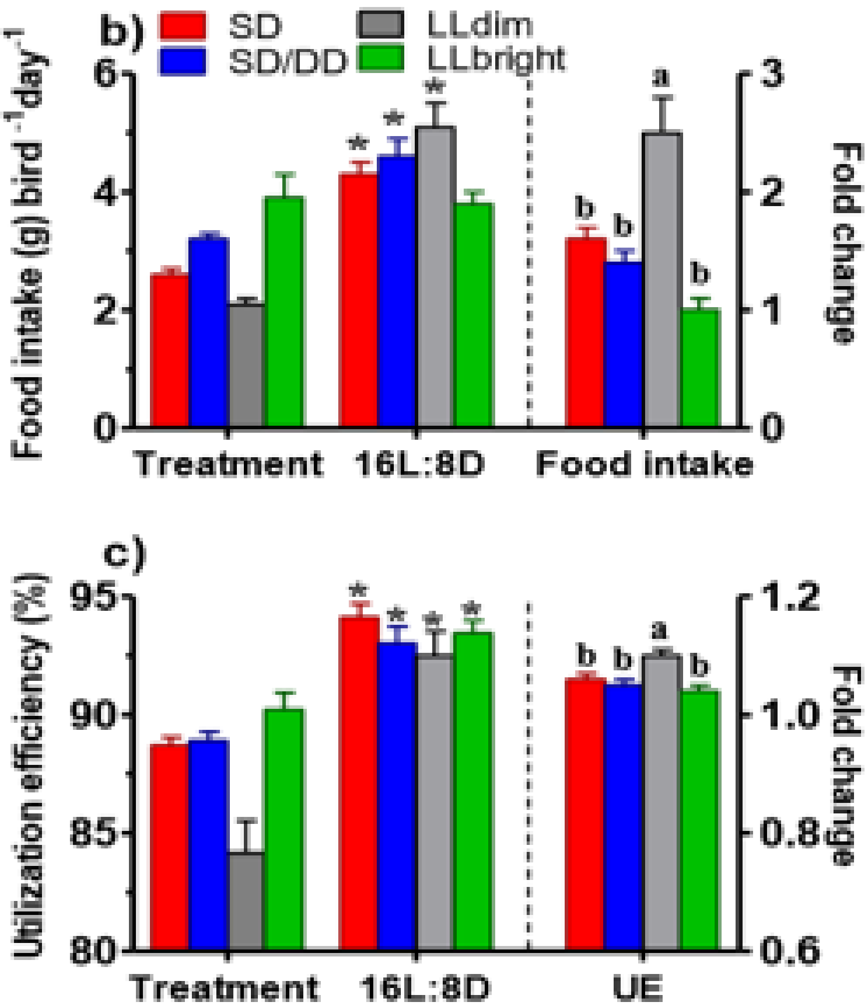


Figure 4: Mean (SEM) changes in (a) phase relation in the timing to attain the maximum response in body fat, body mass and testis volume (b) food intake and (c) utilization efficiency (UE) in groups under different photoperiodic treatments followed by long day exposure. In figure 4a, similar alphabets on point symbol represent no significant difference, dissimilar alphabets represent significance in the time to attain maxima of body fat, body mass and testis growth (one-way ANOVA); in figures 2b, c, similar alphabets on the bar represent no significance, dissimilar alphabets represent significance between groups (one-way ANOVA). In figures 2b, c, the asterisk (*) on the bar represents significant effect of long day treatment in a group (two-wayANOVA). Significance was taken at P< 0.05.

The effects of photoperiod on redheaded buntings' physiological characteristics and behavior were investigated. Body mass, body fat percentage, and testicular size all showed no statistically significant differences between groups (Figures 3d–f). Time to maximal responses differed, revealing group-specific variances in fat accumulation and testicular development. One-way analysis of variance revealed that the LLbright group's peak fat accumulation occurred sooner than the SD and SD/DD groups ($F_{3, 20} = 4.956$, $P = 0.0099$; Figures 3g, h). Similarly, the LLbright group reached peak testicular size before the SD, SD/DD, and LLdim groups. In addition, when comparing the LLdim group to the SD and SD/DD groups, the LLdim showed a significantly longer duration for testis development ($F_{3, 20} = 9.878$, $P = 0.0003$, one-way ANOVA; Figure 3i).

The phase association between peak values for body fat, body mass, and testis size was significantly influenced by the interaction between treatment photoperiods and the following exposure to long days. This phase connection was sensitive to the pre-expansion of daylight hours photoperiodic settings each group was exposed to. Figure 4a shows that whereas the SD, SD/DD, and LLbright groups all had tightly connected relationships, the LLdim group had a much looser association. Different temporal dynamics were seen between the development of body fat and testicular development in the LLdim group in response to changes in photoperiod ($F_{2,15} = 7.045$, $P = 0.0070$, one-way ANOVA; Figure 4a).

Effect on locomotor activity and migratory restlessness pattern

The present study aims to examine the influence of different treatment photoperiods on the locomotor activity patterns of redheaded buntings, as illustrated in Figure 5. By manipulating light exposure durations, the research seeks to explore how these photoperiods affect the locomotor behavior of these birds. The findings will enhance our understanding of the complex relationship between environmental factors, such as light cycles, and the locomotor activity of redheaded buntings.

The actograms, which provide graphical representations of the birds' behavioral patterns, clearly indicated that during the short-day (SD) period, all experimental groups consistently exhibited predominantly diurnal activity patterns. However, during extended daylight periods, the birds displayed a significant change in behavior, engaging in activities both during the day and at night. This behavior is interpreted as migratory restlessness, or Zugunruhe, as shown in Figures 5i to 5iv in the left panel.

A detailed analysis of the 24-hour activity profiles during the treatment photoperiods revealed a strong synchronization of the birds' activity patterns with the prevailing light-dark (LD) cycles, particularly under the short-day (SD) and short-day/extended dark (SD/DD) photoperiods, as depicted in the right panel of Figure 5a. In contrast, under the LLdim condition, the birds exhibited a free-running activity pattern, which was distinctly noticeable. Conversely, in the LLbright condition, the birds' activity became arrhythmic, indicating a significant shift in their behavioral patterns, as shown in Figure 5a.

The study also noted that the LLbright group exhibited significantly higher levels of activity counts compared to other groups. However, the total activity counts per day were similar across all groups during the treatment period. Statistical analysis confirmed this finding, with a significant effect observed ($F_{3,20} = 62.41$, $P < 0.0001$; specific data not shown in this context).

After exposure to extended daylight periods, all experimental groups displayed remarkable synchronization of their biological activity patterns to a consistent 16-hour light and 8-hour dark cycle (16L:8D), regardless of their initial 24-hour activity profiles during the treatment photoperiods, as illustrated in Figures 5b to 5e. Notably, in the LLbright group, initial activity lacked a discernible diurnal rhythm. However, when exposed to the 16L:8D photoperiod, their activity became structured into a clear day-night pattern, with nighttime activity emerging earlier than in other groups.

In contrast, the onset of nighttime activity in the SD, SD/DD, and LLdim groups occurred more gradually but within comparable time intervals. Specifically, the SD group exhibited nighttime activity onset at an average of 8 ± 0.71 days, the SD/DD group at approximately 9.8 ± 1.42 days, and the LLdim group at an average of 10.5 ± 1.23 days. While these specific data are not presented here, they underscore the varying responses to different photoperiod treatments.

The amplitude of nocturnal activity observed during the initial 15-day period of exposure to extended daylight conditions was significantly influenced by the photoperiods used in the treatment. Notably, the LLbright group exhibited considerably higher nighttime activity amplitudes compared to both the SD/DD and LLdim groups. This finding was validated through statistical analysis using a two-way analysis of variance (ANOVA), which considered three factors: factor 1 ($F_{3,480} = 7.779$, $P < 0.0001$), factor 2 ($F_{23,480} = 2.006$, $P = 0.0040$), and the interaction between the two factors ($F_{69,480} = 2.753$, $P < 0.0001$). The results of this analysis are depicted in Figure 5b.

Further examination revealed that subjects in both the LLdim and LLbright groups experienced a notable shift in their nighttime activity patterns after an additional 30-day exposure to extended long days. Specifically, the LLdim group displayed a significant increase in nighttime activity compared to the LLbright group, as confirmed by the statistical analysis. The first factor in the ANOVA yielded a significant result ($F_{3,480} = 5.565$, $P = 0.0009$), indicating a substantial impact on nighttime activity. The second factor also produced a significant outcome ($F_{23,480} = 11.21$, $P < 0.0001$), reinforcing the observed shift in nighttime activity patterns. However, the interaction between the two factors did not result in a significant outcome ($F_{69,480} = 1.016$, $P = 0.4477$). These findings are illustrated in Figure 5c.

Subsequent exposure to extended periods of daylight did not result in further variations in nocturnal activity among any of the experimental groups, as shown in Figures 5d and 5e.

These findings significantly contribute to the existing body of knowledge by providing a detailed understanding of the relationship between treatment photoperiods and the locomotor activity patterns of redheaded buntings under various lighting conditions. Through careful analysis and rigorous experimentation, this study elucidates the complex dynamics at play, revealing the multifaceted factors that influence the behavioral patterns of this avian species. By exploring the intricate interplay between treatment photoperiods and locomotor activity, this research offers valuable insights into the underlying mechanisms governing the behavioral responses of redheaded buntings, thereby advancing our understanding of avian biology and behavior.

The results of this study underscore the complexity and intricacy of the adjustments made by avian species in synchronizing their activity patterns and amplitudes, particularly in response to changes in photoperiodic conditions. These findings provide crucial insights into the adaptive strategies employed by birds to navigate the ever-changing environmental cues they encounter, enriching our comprehension of the behavioral and physiological responses in avian species.

4. DISCUSSION

This research endeavor represents a pioneering and innovative study, offering novel qualitative and quantitative insights into the effects of photoperiodic treatment during a specific life history stage on the subsequent responses elicited by extended daylight periods in the redheaded bunting. The redheaded bunting, a migratory bird species native to the Palaearctic-Indian region, is distinguished by its well-defined annual cycle. This investigation illuminates the complex interplay between the historical context of photoperiod exposure and the subsequent manifestation of photoperiod-induced responses during extended daylight periods, reflecting the well-established patterns typically observed under prolonged exposure to long days.

In assessing physiological responses such as body mass gain, body fattening, and testis growth in various groups subjected to different photoperiodic treatments, the study found that while the patterns and amplitude of these responses were similar across groups, the timing of peak responses varied. This variability underscores the importance of photoperiod history in shaping the timing of physiological changes.

Empirical observations by Follett and Maung (1978) in Japanese quail (Coturnix c. japonica) have shown that the relationship between photoperiod duration and the rate of induction is critical. Specifically, the photoperiodic response was more pronounced when the birds were exposed to photoperiods exceeding 13 hours of light and 11 hours of darkness. Notably, testicular growth occurred at a rate 50% slower under a photoperiod of 12 hours of light and 12 hours of darkness.

In addition to photoperiod duration, light intensity is a crucial environmental factor that significantly influences the rate of photoperiodic induction. Light intensity, defined by the number of photons reaching a given area per unit of time, plays a pivotal role in modulating organisms' physiological responses to changes in day length. For example, in starlings (Sturnus vulgaris), varying levels of light intensity combined with different photoperiods resulted in distinct physiological and behavioral reactions aligned with the specific photoperiods, as documented by Bentley et al. (1998). Similarly, Misra et al. (2004) found that buntings exhibited comparable outcomes, suggesting that the seasonal responses of these avian species are influenced by the combined effects of photoperiod and light intensity.

The findings indicate that discrete photoperiods can either accelerate or decelerate the progression of the photoperiodic axis, thereby affecting the time required to achieve optimal physiological responses (Rani and Kumar, 2014). This research thus contributes valuable insights into the intricate mechanisms through which photoperiod and light intensity interact to influence the seasonal behaviors and physiological adaptations of avian species, particularly in the context of redheaded buntings.

In the realm of mammalian biology, it has been scientifically established that reproductive responses to specific photoperiodic challenges are influenced by prior exposure to different photoperiodic conditions, with this phenomenon varying across different times of the year (Sweeney et al., 1997). The influence of photoperiodic history on anxiety-related behavior in male rats was demonstrated by Benabid and Ouichou (2011). Additionally, the physiological responses to prolonged periods of daylight, such as increased body fat deposition, weight gain, and gonadal growth, exhibit a distinct phase relationship with one another, a relationship that is highly dependent on the duration of light exposure, as shown by studies from Kumar and Rani (1999), Misra et al. (2004), and Rani et al. (2005). In a similar vein, the present study meticulously examined changes in the phase relationship of these physiological responses, which are contingent on the photoperiodic treatments administered.

The impact of photoperiodic history was found to significantly influence hyperphagia (excessive eating) induced by prolonged daylight, leading to varying levels of food intake among the different groups. Despite unrestricted access to food, the photoperiodic treatments notably affected food availability, thus influencing the experimental conditions in distinct ways. For example, under the standard diet (SD) protocol, subjects had eight hours of daily food access, while the restricted feeding regimen of every other day (SD/DD) provided the same duration of access but spread over two consecutive days. Although overall food consumption was comparable between the SD and SD/DD groups, the SD/DD group exhibited greater food intake during the diurnal period to compensate for reduced intake during nocturnal hours. Under the LLdim condition, minimal food consumption was observed, likely due to the near-total darkness. Conversely, the LLbright group exhibited significantly higher food consumption as a direct result of continuous illumination. The changes in dietary intake patterns during the treatment photoperiods had a notable impact on energy requirements, particularly under prolonged daylight conditions. The LLdim group, which experienced the most pronounced deprivation, exhibited a marked increase in food consumption during extended daylight periods as a compensatory mechanism to counterbalance energy depletion during the treatment photoperiods. Consequently, this group showed earlier adipose tissue deposition and delayed testis growth.

The regulation of activity and rest in animals is governed by photoperiods, as demonstrated by Singh et al. (2012). The present study effectively highlighted the significant impact of different photoperiodic treatments on the perception of photoperiod and the subsequent modulation of daily locomotor activity patterns, activity counts, and the initiation of migratory restlessness. When exposed to extended periods of daylight, the various groups displayed a remarkable synchronization of their activity patterns, aligning with a consistent 16-hour light and 8-hour dark cycle, regardless of their previous 24-hour activity profiles. The LLbright group, in particular, exhibited a rapid transition into the migratory phase, marked by a significant increase in nocturnal activity within the first 15 days of observation. In contrast, other groups initiated this transition more gradually.

The differential light exposure experienced by the LLbright group during the subjective night and by the LLdim group during the subjective day likely contributed to the observed physiological responses. The changes observed are consistent with well-documented effects of light exposure during nighttime, including the advancement of morning activity onset and the earlier initiation of reproductive behaviors, as reported by Kampeners et al. (2010) and Dominoni et al. (2013). These findings underscore the fundamental role of light as critical information for regulating diurnal and seasonal processes in avian species (Dawson et al., 2001). Further investigation into the underlying mechanisms of these effects is warranted.

In essence, this research highlights the critical importance of the preparatory stage within the annual cycle, a period that is particularly susceptible to significant influences from artificial photoperiodic conditions. The experimental manipulation of photoperiods had discernible and notable effects on various aspects of reproductive behavior, migratory patterns, and associated physiological processes, such as hyperphagia, body fattening, and overall body mass gain, especially during extended daylight periods. The dynamic interplay between these factors led to significant alterations in the timing of migration and reproduction, as well as in the phase relationships among key physiological events like body fattening, weight gain, and testis growth. This intricate interplay profoundly impacted the temporal patterns and synchronization of these essential biological processes.

The findings emphasize the critical role of pre-existing photoperiodic cues in shaping migration, reproduction, and related phenological processes in response to changing environmental conditions. This research is particularly significant as it contributes to a deeper understanding of the complex interaction between photoperiodic history and its subsequent effects on responses to photoperiod cues during specific life history stages. By elucidating the multifaceted relationships among photoperiodic conditions, physiological responses, and behavioral patterns, this meticulously conducted study not only advances our knowledge of avian biology but also underscores the broader implications for various organisms that rely on photoperiodic cues to regulate critical life history events.

CONCLUSION

This study significantly enhances our understanding of how photoperiodic history affects the physiological and behavioral responses of migratory birds, specifically redheaded buntings (Emberiza bruniceps). The research demonstrates that variations in light exposure during the photosensitive phase lead to distinct changes in seasonal behaviors, including migration, reproduction, and associated physiological processes such as body fattening, testis growth, and locomotor activity. These findings underscore the critical role of light as an environmental cue that regulates key life-history events in birds. The differential responses observed across treatment groups highlight the complex interplay between past photoperiodic experiences and future behavioral and physiological adaptations. This study provides valuable insights into the mechanisms through which photoperiod and light intensity interact, influencing the timing and synchronization of essential biological processes. As photoperiodic conditions continue to be altered by environmental changes, understanding these dynamics becomes increasingly important for predicting the impacts on migratory bird populations and their long-term survival.

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