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# Avian malaria parasite infections do not affect personality in the chestnut thrush (*Turdus rubrocanus*) on the Qinghai-Tibet Plateau

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A R T I C L E I N F O

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A B S T R A C T

Personality traits, the consistent individual behavioral differences, are currently gaining much attention in studies of natural bird populations. However, associations between personality traits and parasite infections are not often investigated. Even less attention has been given to studies of birds in the high-elevation region such as the Tibetan plateau. This research aims to examine the relationship between avian malaria parasites and two personality traits in a population of the Chestnut Thrush (*Turdus rubrocanus*) breed in the Tibetan plateau.

Our results revealed no evidence of sex bias in malaria parasite prevalence. Furthermore, we found no effect of infection status on two personality scores: activity and boldness. Additionally, no effects on the activity level or boldness were observed for different parasite lineages of *Haemoproteus*, *Leucocytozoon*, the sex of the birds, or their interactions. Similarly, we did not find any relationship between activity level and boldness with nestling numbers, sex, or their interactions. Notably, individuals with a larger number of offspring tended to display greater boldness. Our findings indicate that blood parasite infections are common in this population but do not significantly impact the personality of the birds.

## 1. Introduction

Animal personality is defined as the consistency of behavior of the same individual across time and different environments. The study of animal behavior has seen extensive research on animal personality in recent years [1–3]. Different aspects of animal personality are associated with behavior variations and fitness outcomes [4–6]. It is hypothesized that body condition plays a key role in shaping the animal personality [7], and blood parasite infections may have an important influence on body condition and, and consequently affecting animal personality [8]. Additionally, parasites may modify host behaviors to enhance their transmission own efficiency, and these behavioral changes are often an important dimension of the personality research [9]. In general, individuals exhibiting bolder or more behavior patterns tend to have a higher likelihood of parasitization.

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Avian malaria can significantly impact the fitness of avian hosts, manifesting in adverse effects with the most direct being anemia and enlargement of organs such as the liver and spleen. Birds in the acute phase of infection may even succumb to the disease, with negative implications for the avian population as a whole [10,11]. Chronic infections can also exert long-term effects on the fitness of avian hosts and populations. A study on the Great Reed Warblers (*Acrocephalus arundinaceus*) demonstrated that the cost for long-term maintenance of chronic infection with blood parasites can accelerate telomere degradation in these birds, leading to reduced survival in nestlings [12]. Furthermore, numerous studies have shown that blood parasite infections can result in reduced reproductive success in avian hosts, ultimately impacting the overall fitness of offspring [13–15].

Parasites are commonly found in animal populations and play a significant role in impacting the health status of birds, including their physiology and behavior. This may lead to a reduction in the fitness of the host [16,17]. A study on house martin (*Delichon urbica*) has shown dramatic effects of malaria parasites on clutch size and other demographic variables, potentially influencing the evolution of its clutch size in this species [14]. Parasites rely on host resources to supply their own growth and reproduction, leading to increased energy demand and affecting the overall health of the host [9]. As the energy demand of infected individuals rises, they may exhibit a greater inclination to take risks or be more active to meet the heightened energy demand (Rands et al., 2008). This could explain why blood parasites may have a modulating effect on personality, making individuals more active and bolder. Studies conducted on Great Tits (*Parus major*) have demonstrated that parasite-infected individuals tend to display higher levels of exploratory behavior [8].

Bird reproduction requires large amounts of energy [12], and body condition can reflect the individual's ability to obtain energy and nutrients. As such, the body condition of parental birds may play an important role in the reproductive success of birds [18]. Infections caused by blood parasites generally reduces the body condition of birds, thereby affects their behavior and reproduction capabilities. A study on Northern House-martin (*Delichon urbica*) has confirmed that blood parasite infection can lead to a significant reduction in clutch size and hatching success rates [14].

The Qinghai-Tibet Plateau (QTP), situated in western China, is the largest high-altitude landmass on Earth and is characterized by cold and windy weather conditions [19]. A study suggests that the prevalence of blood parasite infections in bird populations decreases with increasing altitude [20]. However, global warming has led to an increase in parasite prevalence among forest bird populations in high-altitude regions [20]. Research on blood parasites in forest birds residing in the unique high-altitude environment of the QTP is scarce, highlighting the urgent need for more extensive studies. The QTP region has unique biodiversity due to its special geographical location and complex climate, and serves as habitat for several endangered bird species such as the Chinese Grouse (*Tetrastes sewerzowi*) and the Sichuan Jay (*Perisoreus internigrans*). Habitat fragmentation in this area has resulted in negative effects for bird populations [21,22].

The Chestnut Thrush (*Turdus rubrocanus*) is mainly distributed in Gansu, Ningxia, Tibet, eastern Qinghai, and western Yunnan regions of China [23]. It is one of the most abundant forest birds in the QTP. Currently, the prevalence and characteristics of blood parasite infection of the chestnut thrush remain unknown, although ectoparasite infections have been found on the head and throat (unpubl. data). This study aims to investigate the potential impact of blood parasite infection on individual fitness and behavioral plasticity in the chestnut thrush.

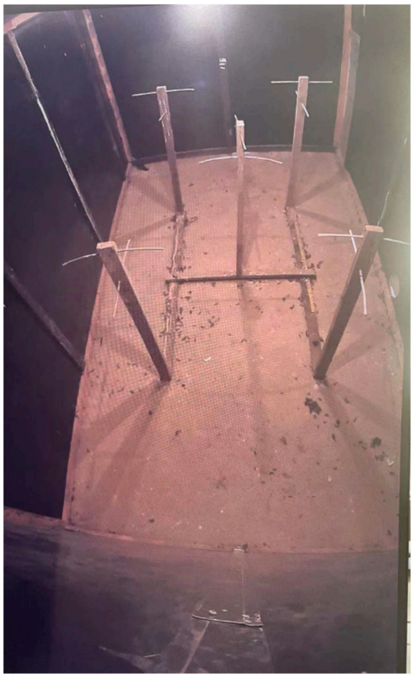

**Fig. 1.** Picture of the testing chamber used for the activity tests.

With the advancement of research on bird diseases, the study of avian blood parasites has emerged as one of the most active research areas. However, several key issues remain controversial. The chestnut thrush is suitable species for studying both life history traits and blood parasite traits. To gain comprehensive understanding of the infection characteristics of blood parasites and the ecological adaption mechanisms of the chestnut thrush, it is crucial to assess blood parasites, physiology, and life history traits together. Specifically, our study focuses on two aspects: (1) determining the prevalence and the avian malaria parasite lineages, and (2) evaluating the impact of these blood parasites on animal personality.

## 2. Material and methods

### 2.1. Study area and subjects

Chestnut Thrush individuals were captured in the Lianhuashan National Nature Reserve Gansu Province in China (34°400′ N, 103° 300′ E). Climate and environmental data at the study site are available from previous studies [21]. Fieldwork was conducted from April to August in the years 2019–2022. Chestnut thrush individuals were captured both during both mating season (April to May) and breeding season (June to August). Adult birds were captured using mist nets on the sixth day after the chicks had hatched. These captured individuals were fitted with a metal ring and color bands on each leg. Blood samples were collected through venipuncture of the brachial vein, and body condition indicators, including body length, tail length, wing length, and beak length, were measured. Birds were then transferred to a testing chamber for personality testing (see details below).

### 2.2. Personality experiments

Personality traits of each bird were assessed with two measures, activity and breathing rate using the methods described in Kluen et al. (2014), Lou et al. (2021) and Zhao et al. (2016) [24–26].

During testing days, between 9:00 and 16:00 h, each individual was placed in a testing chamber (Fig. 1) measuring 406*240*244 cm. Following a 10-min acclimatization period, the individual's activity level was recorded for 2 min using a video recorder. Subsequently, the video recordings were analyzed using the Potplayer software for playback (https://potplayer.daum.net/). The number of individuals' movements within the testing chamber was scored. Those who did not move at all were scored 0 points, those who took a step were scored 1 point, those who jumped were scored 2 points and those who flew were scored 3 points. The scores for each category were summed to obtain the activity score [25,26].

The handling test was scored based on a protocol similar to that of Kluen et al. (2014) and Zhao et al. (2016) [24,26]. During this test, the number of breast movements in 1 min (breathing rate) was recorded. Breathing rates were used as a proxy for boldness, with birds exhibiting lower breathing rates considered bolder than those with higher breathing rates.

### 2.3. Detection of parasitic infections

Total DNA was extracted from blood samples for blood parasite identification. We used a modified protocol based on a DNA extraction kit (Cat.#DP304-03, TIANGEN) followed by an ammonium acetate precipitation (Bensch et al., 2010; Richardson et al., 2001). The protocols used for detection of infections by *Haemoproteus* and *Leucocytozoon* spp. consisted of a nested PCR following Dunn et al. (2011) and Hellgren et al. (2004). We amplified partial *cyt b* sequences using two primer pairs for each type of blood parasite: HaemNF1 and HaemNR3 for *Haemoproteus* and the primers HaemFL and HaemR2L for *Leucocytozoon*. To determine the lineage and diversity of the blood parasites, we conducted parasite species identification using the BLAST module in the MalAvi database with the sequences from positive samples [16]. To calculate the prevalence of avian malaria parasites, we divided the number of infected individuals by the total number of individuals.

### 2.4. Statistics

Statistical analyses conducted using SPSS 21.0 and R v4.2.2 (R Core Development Team 2022). We used the independent samples *t*-test to test the parasite prevalence between males and females using SPSS. All other analyses were performed in R. The relationship between activity scores and boldness scores was assessed using a Pearson correlation test, while sex differences in activity scores and boldness scores were examined using a generalized linear model (GLM). We also used GLM to test the effect of infection status on activity and/or boldness. We used generalized linear mixed models (GLMM) when analyzing associations between parasite infection and each activity score, boldness score, and nestling number. The relationship between nestling number and boldness scores was analyzed using a Pearson correlation test.

## 3. Results

### 3.1. Parasite prevalence

The blood parasite infection prevalence was 82% in 2019, 80% in 2020, and 96% in 2021. On average during the three-year period, the total prevalence was 81%, with 77% prevalence of *Haemoproteus*, 57% prevalence of *Leucocytozoon,* and 48% prevalence with double infection.

The positive samples were sequenced and compared to the records in the Malvi database. All samples were successfully identified as either *Haemoproteus* or *Leucocytozoon*, resulting in a total of 16 lineages from 2 genera, including 4 *Haemoproteus* lineages and 12 *Leucocytozoon* lineages (Table 1).

No sex biases in prevalence were observed, with 92% of females and 91% of males being infected with at least one parasite. Trughout the three-year period, 77% of females and 77% of males were infected with *Haemoproteus* spp., while 72% of females and 58% of males were infected with *Leucocytozoon* spp. (Table 2).

### 3.2. Personality traits

There was no correlation between activity and boldness among individuals ($t = -0.013$, $DF = 102$, $P = 0.990$) (Fig. 2). No difference in activity was found between the sexes ($t = 1.047$, $DF = 120$, $P = 0.322$), and no difference in boldness score was found between the sexes ($t = -0.994$, $DF = 100$, $P = 0.323$) (Table 3).

### 3.3. Effects of parasite infection on activity

We did not observe any significant of infection status on activity and/or boldness (all $P > 0.05$). (Fig. 3 A, B). We did not observe any significant associations between parasite infection and each of activity score, boldness score, and nestling numbers (Table 4).

We observed that individuals with a larger number of offspring exhibited bolder behavior ($R = 0.31$, $P = 0.043$) (Fig. 4). However, when we excluded the two outliers on the left (log number $_{\text{of nestlings}} = 0$), the significance disappeared ($R = 0.19$, $P = 0.23$).

## 4. Discussion

### 4.1. Parasite prevalence

The chestnut thrush appears to exhibit a higher blood parasite prevalence compared to other passerine birds. The prevalence of 81% among adult chestnut thrush was higher than the average of 44% found in Australian passerines [27] and an average of 42% in Brazil [28]. Murata's long-term study of blood parasites in Passeriformes birds in Japan from 1988 to 2001 reported a prevalence of 11% [29]. In Beijing, China, the overall prevalence in *Parus* spp. Was 38%, which is lower than that observed in our study on the chestnut thrush [30]. Other thrush species have also been reported to be parasitized by numerous *Hemosporidian* parasites [31]. Rodríguez & Matta (2001) reported a prevalence of 21% for *Leucocytozoon* sp. In different bird species in the high mountains of Colombia. Some species, however, exhibit similar or higher prevalence compared to our study. For example, a study on *Turdus fuscater* showed a prevalence of 91% for *Leucocytozoon* [32].

Some studies had shown sex-biased in avian malaria parasite prevalence. Although females may face more reproductive pressures, which could weaken their immune abilities and lead to a higher prevalence of blood parasites, other studies have found that males have higher rates of blood parasite infection compared to females [33,34]. This difference may be attributed to sex-related hormones that directly influence the host's susceptibility to parasites. For example, testosterone is believed to have immunosuppressive effects in many species, making males more susceptible to parasite infections [35,36].

In our study, we found no difference in activity and boldness scores between sexes. This contradicts the findings of some previous studies. For example, Saino et al. (1995) found a correlation between higher parasite infection intensity and a higher plasma testosterone level [37], indicating that males were more affected by parasites compared to females [38]. In male yellow wagtails (*Motacilla flava*), higher parasite infection rates were found during the breeding season [39]. However, win out study on the chestnut thrush, we found no difference in prevalence between the sexes. This suggests that males and females of the chestnut thrush are

**Table 1**
The lineages (Malvi database) of blood parasites in infected chestnut thrush.

| Parasite | Lineage | Number of infected individuals |
|---|---|---|
| *Haemoproteus* | PERCAN07 | 1 |
| | PHYBOR04 | 7 |
| | TUCHR01 | 12 |
| | TURDUS2 | 78 |
| *Leucocytozoon* | HYBOR02 | 1 |
| | TUMER02 | 4 |
| | TUMER09 | 2 |
| | TUMER10 | 4 |
| | TUMIG19 | 5 |
| | TUMER013 | 2 |
| | TUOBS01 | 5 |
| | TURNAU01 | 9 |
| | TURNAU02 | 1 |
| | TURPEL02 | 40 |
| | TURSER01 | 1 |
| | TURSTR01 | 1 |

**Table 2**
Prevalence of blood parasites in the two sexes of chestnut thrush throughout the three–year period.

| Sex | Parasite prevalence | *Haemoproteus* | *Leucocytozoon* |
|---|---|---|---|
| Females (n = 66) | 92% | 77% | 72% |
| Males (n = 70) | 91% | 77% | 58% |

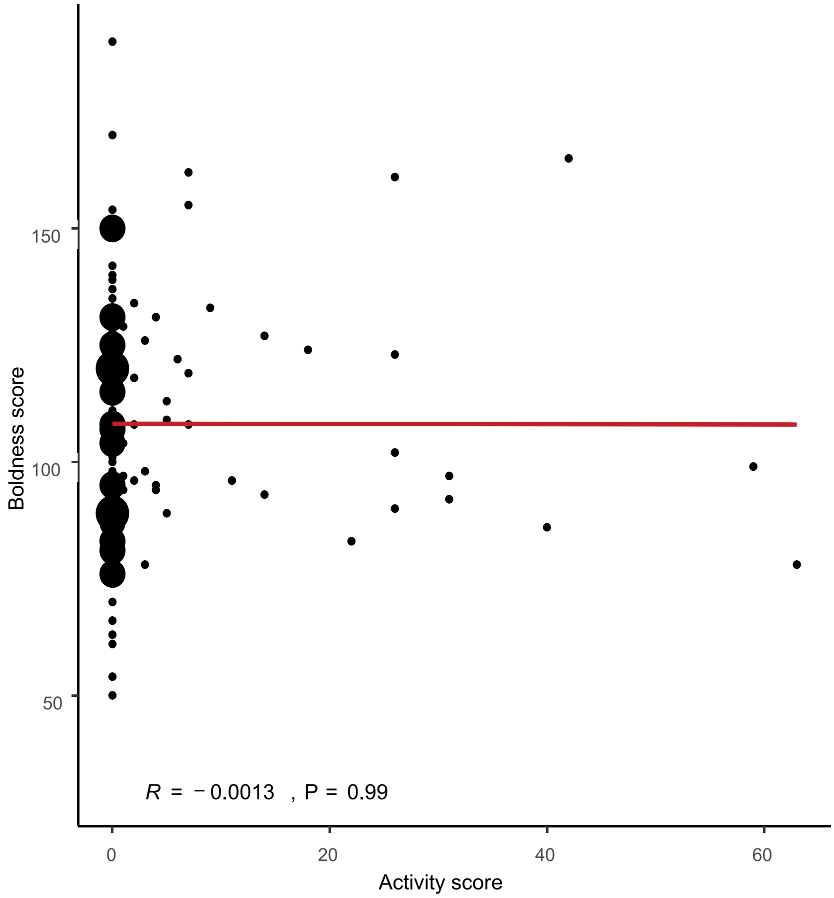


**Fig. 2.** Correlation between activity and boldness scores.

**Table 3**
Comparison of personality scores between sexes.

| Variable | Estimate Std | t value | DF | P |
|---|---|---|---|---|
| Activity | −3.521 | 1.047 | 120 | 0.322 |
| Boldness | 5.187 | −0.994 | 100 | 0.323 |

similarly susceptible to the physical constraints that influence infection rates. Therefore, we predict that males and females should exhibit similar body condition during the breeding season.

### 4.2. *Personality traits and blood parasites*

We conducted tests to examine the associations between two personality traits, namely activity and boldness, and infection by two avian malaria parasite genera, *Haemoproteus* and *Leucocytozoon*. These personality traits have previously established as repeatable or heritable in the chestnut thrush [25,26].

Associations between activity and parasitism, which include direct and vector-transmitted parasites, have been widely reported [40]. However, our findings do not demonstrate any significant impact of parasitic infections on host activity. In contrast to our results,

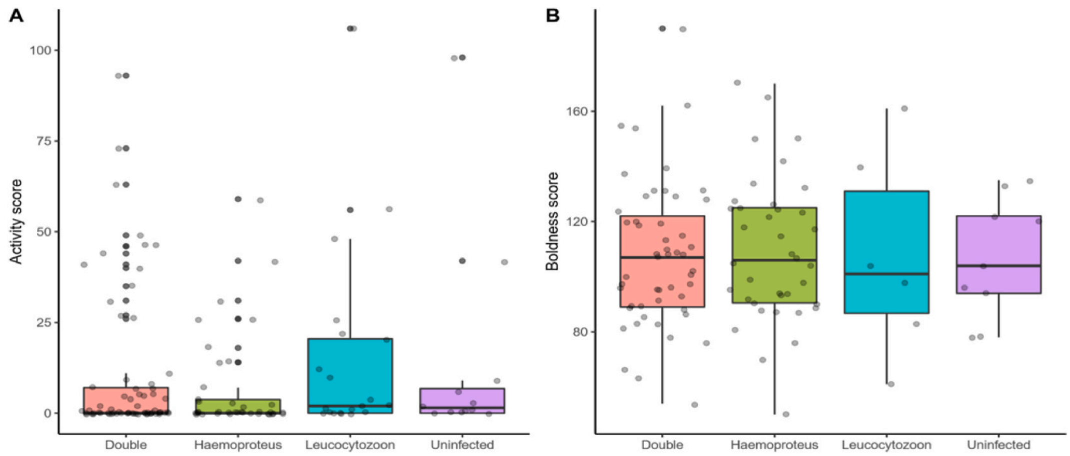


**Fig. 3.** Activity and boldness scores in uninfected, single-infected, and double-infected individuals.

**Table 4**
Full model results from generalized linear mixed models (GLMM) analyzing associations between parasite infection and each activity score, boldness score, and nestling numbers (n = 141).

| Dependent | Independent | DF | F | Std | t-value | P |
|---|---|---|---|---|---|---|
| Activity Score | *Haemoproteus* | 129 | −2.126 | 6.560 | −0.324 | 0.746 |
| | *Leucocytozoon* | 129 | −7.460 | 7.423 | −1.005 | 0.317 |
| | Sex | 129 | −4.459 | 3.274 | −1.362 | 0.176 |
| | *Haemoproteus*Leucocytozoon* | 129 | 7.029 | 8.060 | 0.872 | 0.385 |
| Boldness Score | *Haemoproteus* | 96 | 2.020 | 10.397 | 0.194 | 0.846 |
| | *Leucocytozoon* | 96 | −1.359 | 14.429 | −0.094 | 0.925 |
| | Sex | 96 | 5.655 | 5.370 | 1.053 | 0.295 |
| | *Haemoproteus*Leucocytozoon* | 96 | −1.644 | 15.503 | −0.106 | 0.916 |
| Nestling Numbers | *Haemoproteus* | 69 | −0.064 | 0.504 | −0.128 | 0.899 |
| | *Leucocytozoon* | 69 | 0.151 | 0.495 | 0.305 | 0.761 |
| | Sex | 69 | −0.127 | 0.088 | −0.677 | 0.501 |
| | *Haemoproteus*Leucocytozoon* | 69 | −0.563 | 0.556 | −0.101 | 0.920 |

some studies have found that parasitic infections can negatively impact personality. Blood parasites in birds play a crucial role in the health status of birds, and their prevalence serves as an important indicator of immune competence [31,41]. The negative impact of blood parasites on the health status of birds can be manifest in behavior traits and may result in reduced host fitness. This, in turn, can directly or indirectly contribute to a decline in host populations, posing a threat to their survival [12,16,42].

Blood parasites are known to have a significant impact on host fitness and health status [43]. By definition, parasites are associated with a decline in host fitness, due to their negative effect on host resources [44,45]. Consequently, it is expected that the health status of the host would positively influence their activity levels. Individuals with better body condition are likely to exhibit bolder and/or more active behavior [46]. Based on this reasoning, individuals with good physical condition are expected to display greater boldness and activity levels [47].

However, the interaction between host behavior and parasite infection can manifest in various ways [5,9]. Other studies have reported opposite results, indicating that infected individuals may exhibit higher boldness scores and greater levels of activity compared to uninfected individuals [9]. Similarly, several studies have documented a positive effect of parasitic infection on activity. For example, adult male *Anas platyrhynchos* displayed increased activity levels when affected by parasites during development [48], and *Vombatus ursinus* exhibited significantly higher activity levels when infected with *Sarcoptes scabiei* [49]. Webster (1994) observed increased activity in rats infected by *Toxoplasma gondii*. Furthermore, the behavioral characteristics of the host may also influence their susceptibility to infection [5]. Bolder *Peromyscus maniculatus* individuals, were found to be more susceptible to Sin Nombre virus, with bolder individuals facilitating further transmission of the virus [50]. Wilson found that differences in parasite transmission between bolder and shyer individuals were not attributed to parasitic infection, but rather to differences in their respective habitats [51]. Active birds often exhibit more diverse foraging habits, thereby increasing their exposure to parasites [52]. In line with our results, our previous studies on chestnut thrush did not reveal a correlation between the presence of a higher number of ectoparasites on the body and increased boldness or activity levels [26].

Furthermore, many studies have not found a relationship between parasites and personality traits. For example, in *Phoxinus phoxinus*, there was no significant change in activity and boldness after infection with *Diplostomum phoxini* [53]. Animal personality traits and individual immunity may co-evolve, as individuals exhibit higher activity or boldness are likely to have a higher immune function and more effective resistance to parasites [54]. Consequently, such individuals may have a lower likelihood of parasite

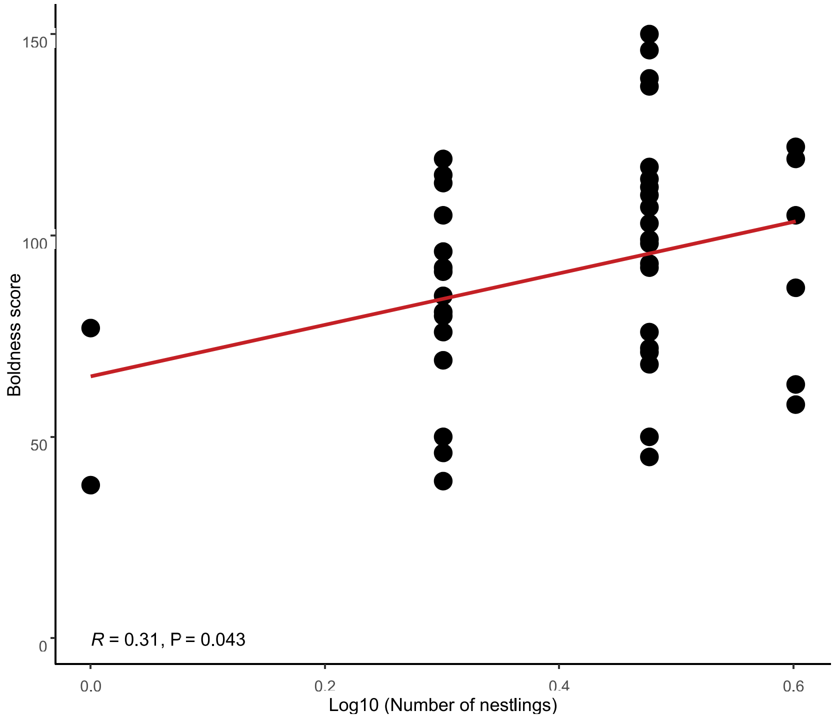


**Fig. 4.** Correlation between nestling number and boldness scores. Boldness score is defined as 200 – breathing rate in this figure.

infection [55].

It is also possible that the relationship between parasites and personality traits is multifaceted and may vary depending on species or context [8,55]. For example, in *Gobiomorphus cotidianus,* aggressiveness was only related to the number of parasites of the genus *Apatemon* spp., but not to other parasite species [56]. Additionally, other factors such as age may influence an individual's personality [57]. Our findings demonstrate that blood parasite infections are common in the chestnut thrush, but they do not appear to significantly impact the measured personality scores. Furthermore, if personality is associated with infection intensity, any significant effects on host behavior may only appear when the infections intensity is relatively high [58].

We found that individuals with a larger number of offspring exhibited bolder behavior. However, this relationship was weak, and the significance disappeared when we excluded two birds with one nestling (log = 0). Only a few studies have investigated the correlation between boldness and reproductive output. Assuming a link between boldness and energy status, bolder individuals may have more energy to invest during the breeding season [59]. Budaev et al. (1999) examined the association between boldness and paternal care in convict cichlids (*Amatitlania nigrofasciatum*) and found that bold and active males tended to provide more care to their offspring, thereby raising larger number of offspring [60].

It is important to note that our study was exclusively conducted during the spring season. In tropical regions, avian malaria parasites can infect bird hosts throughout the year [31], whereas in temperate regions, the prevalence of avian blood parasites peaks during spring and autumn seasons [61,62]. During spring, most hosts are actively involved in breeding activities, and the high reproductive investment during this period can result in a reduction in their immune capacity, which contributes to the elevated prevalence of blood parasites [13,63]. This is why we specifically chose to examine the impact avian malaria on thrush breeding success during the spring season.

However, the high prevalence of avian blood parasites in autumn can be attributed to several factors. Firstly, this period coincide with a large number of susceptible fledglings [64]. Secondly, many bird hosts migrate during this time, and the high energy expenditure with migration can decrease their resistance to blood parasite infection [39]. In future studies focusing on malaria population dynamics, it would be important to consider other seasons as well.

## 5. Conclusion

Our results did not provide evidence of any sex biases in prevalence or significant effects of infection status on activity and boldness. Previous studies have identified associations between parasite infection and various behavioral traits, such as problem-solving performance [65], exploration behavior [66], and startle latency [67]. However, in our study, the parasites studied are unlikely to be drivers of personality diversification.

## Ethics statement

The present study complies with the current laws of China and it was approved by the Animal Care and Use Committee of the Institute of Zoology, Chinese Academy of Sciences (Permission No. 2013/108). Birds were caught only during days without rain and with low wind speed. Birds were trapped and released into the wild near the trapping locations. No adults died during the experimental periods.

## Data availability statement

The data supporting the findings of this study are available upon request from the corresponding author Yue-Hua Sun, Email: sunyh@ioz.ac.cn. These data include raw experimental data, survey responses, code, etc.

We encourage researchers and interested parties to use these data for further analysis, validation, and collaboration. We believe that open access to research data promotes transparency and scientific progress.

## Contribution statement

Each author of this manuscript has made significant contributions to the research and preparation of this article, following the guidelines of Heliyon.

Chun-lei Jing

1) conceived and designed the experiments;
2) performed the experiments;
3) analyzed and interpreted the data;
4) contributed reagents, materials, analysis tools or data;
5) wrote the paper.

Yue-Hua Sun

1) conceived and designed the experiments;
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## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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