Jump distance of *Monistria concinna* in relation to metabolic rate and femur length:mass ratio

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Abstract

Monistria concinna is an abundant grasshopper species from Kosciuszko National Park (KNP). *Monistria concinna*'s performance levels can be influenced by both morphology and physiology, which can in turn influence KNP's ecosystem. We studied the effects of femur length:mass ratio (morphology) and metabolic rate (physiology) of *M. concinna* on jump distances. Jump distance was used as a proxy for performance levels, and there were two treatments used to compare temperatures – ambient temperature and cold temperature. Femur length:mass ratio was not correlated with jump performance, irrespective of temperature. However, the difference in the metabolic rate of the grasshoppers in these treatments approached statistical significance, and grasshoppers in the ambient temperature treatment jumped further than in the cold treatment. Sexual dimorphism was observed. Males had greater femur length:mass ratios and higher mass-specific jumping abilities, but males and females had equivalent jumping abilities. At the time of the experiment, there had been no previous studies on the factors which affect jump distance in *M. concinna*, though our results indicate that *M. concinna* may perform better in warming climates.

Key Words

Monistria concinna, sexual dimorphism, temperature

Introduction

Alpine spotted grasshoppers (*Monistria concinna*) are endemic to south-eastern Australia (Key 1985). They are particularly prominent in alpine regions (Tatarnic et al. 2013) and can be found throughout Kosciuszko National Park (hereafter KNP). This suggests that KNP's ecosystem is highly influenced by this species. Research into *M. concinna* and the factors which influence their performance levels is thus important in understanding Kosciuszko's ecosystem as a whole. However, little research has been done on Australian alpine invertebrates, including *M. concinna* (Tatarnic et al. 2013).

Jump distance can be used as an indication of performance levels of grasshoppers (Queathem 1991). Jumping is of major importance both for movement and in the escape of predators (Queathem 1991), and as *M. concinna* are flightless (Bland 1991), this importance is heightened. Jump distance is affected by both morphological and physiological characteristics. In this paper, we examine the jump distance of *M. concinna* in relation to their femur length:mass ratio (morphology) and their metabolic rate (physiology).

The femur length:mass ratio can account for some of the variability in jump performances of grasshoppers (Gabriel 1985). Other factors include muscle mass and absolute size (Gabriel 1985). The femur length:mass ratio is a measure of the length of the hind leg in relation to the overall mass of the grasshopper. Intuitively, longer legs for a given mass should allow a grasshopper to be able to jump further because of greater leverage, and this has been supported by literature (Gabriel 1985). Thus, our first hypothesis is that the greater the femur length:mass ratio of *M. concinna*, the further they will be able to jump.

However, the femur length:mass ratio may vary between the sexes of *M. concinna*. Many grasshopper species display sexual dimorphism – females are typically larger with longer femurs (Belovsky et al. 1990). To the best of our awareness, there have not been any studies specifically comparing the femur length:mass ratio of the sexes in grasshoppers, though jumping abilities have been compared (Queathem

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1991). For the American grasshopper *Schistocerca americana*, male and females have equivalent jumping abilities (at ~30°C) despite their differences in size (Queathem 1991). Males have greater mass-specific jumping abilities (Queathem 1991), which suggests differing anatomies. For example, males could have a greater femur length:mass ratio. Thus, our second hypothesis for *M. concinna* is that males and females will have equivalent jumping abilities, but males will have a greater femur length:mass ratio. We predict that this will correspond to males having higher mass-specific jumping abilities.

Metabolic rate could also affect the jump distance of *M. concinna*. Metabolic rate refers to the amount of energy required per unit time to sustain life (Hulbert and Else 2000). This is known to affect jump performance of grasshoppers, with an increased metabolic rate resulting in an increased performance (Kirkton et al. 2005). However, temperature also affects metabolic rate of ectotherms (Hulbert and Else 2000). For the desert American grasshopper *Taeniopoda eques*, a decrease in temperature comes with a decreased metabolic rate, and in turn a decreased jump distance (Whitman 1988). Our third hypothesis predicts the same trend in *M. concinna*.

Methods

Study site

Monistria concinna were collected by hand from Mt Stillwell (36°24’S, 148°19’E), in Kosciuszko National Park, New South Wales, Australia. They were collected on 5 December 2016, at temperatures between 18 and 22°C, with winds ranging from 15 to 25 km/hr. Both males (n = 4) and females (n = 4) were collected (total n = 8).

Initial conditions and treatments

On the morning of 6 December, the grasshoppers spent approximately five hours in a refrigerated room (0°C). All grasshoppers were then exposed to two sequential treatments: cold temperature followed by ambient temperature. Oxygen consumption and jump distance were measured in both treatments. The grasshoppers were weighed prior to any treatment.

Oxygen consumption was measured with a closed system respirometer. Grasshoppers were placed into 20 mL glass vials, which had pyro-science contactless fibre-optic oxygen sensor spots. Oxygen content was recorded every second for each vial, by Pyro Oxygen Logger software v3.2 and a FireSting fibre optic oxygen probe. Grasshoppers remained in their vials for approximately 15 minutes and the respirometry data were analysed over 15-minute intervals. The temperature of each grasshopper was recorded with an infrared thermometer (DIGITECH QM7215) before and after being placed into each vial. Grasshopper mass was taken into account by converting mass to volume and subtracting this from the vial space. This relied on the assumption that the grasshopper mass:volume ratio was 1:1 – that is, that each grasshopper consisted purely of water. Whilst this assumption was not correct, it allowed an approximate volume to be calculated, and as such, allowed size variation in the grasshoppers to be factored into the equations.

Femur length was measured with calipers to the nearest 0.01 mm, and jump distance was measured with a tape to the nearest centimetre. The initial and final positions of the grasshoppers were noted with a finger. Grasshoppers were prompted to jump by poking at them or, if they would not move, stroking them with a paintbrush. The jump distance was recorded for three jumps per grasshopper, which were then averaged. Jumps which were obviously not intended for distance (e.g. jumping high and landing on the same spot) were not recorded. The temperature of each grasshopper was recorded before their first jump and after their third.

For the cold treatment, the grasshoppers were taken from the cool room and placed into a cold, insulated box. They remained in the box until just before the experiment, after which they were placed into vials at ambient temperature. For the ambient temperature treatment, the grasshoppers were kept at ambient temperature, as were the vials. The temperature of the vials was recorded as an indication of ambient temperature. The grasshoppers were then placed in the vials.

Statistical analysis

The data were analysed in Microsoft Excel. The average jump distance in comparison to femur length:mass ratio was analysed with linear regression. Paired *t*-tests were used to compare the oxygen consumption of the grasshoppers in relation to the temperature treatments, alongside the jump distance in relation to the temperature treatments. Two-sample *t*-tests were used to compare the femur length:mass ratio, jump distance and mass-specific jump distance of the sexes. A *p*-value of < 0.05 represented a significant value for all *t*-tests.

Results

The temperatures of the *M. concinna* in the cold treatment ranged from ~10 to 15°C before being placed in the vials, and warmed to ~17–19°C after their three jumps. For the ambient temperature treatment, the grasshoppers' temperatures ranged from ~19 to 21°C before being placed in the vials, and their temperatures remained approximately constant after their third jump.

Femur length:mass ratio

The jump distance of *M. concinna* demonstrated little correlation with femur length:mass ratio (Figure 1). This was irrespective of temperature. The R^2 value for the average distance jumped in relation to femur length:mass ratio was 0.131 for the cold treatment (~10–19°C), and 0.001 for the ambient temperature treatment (~19–21°C). The relationship between femur length:mass and jump distance was very weak.

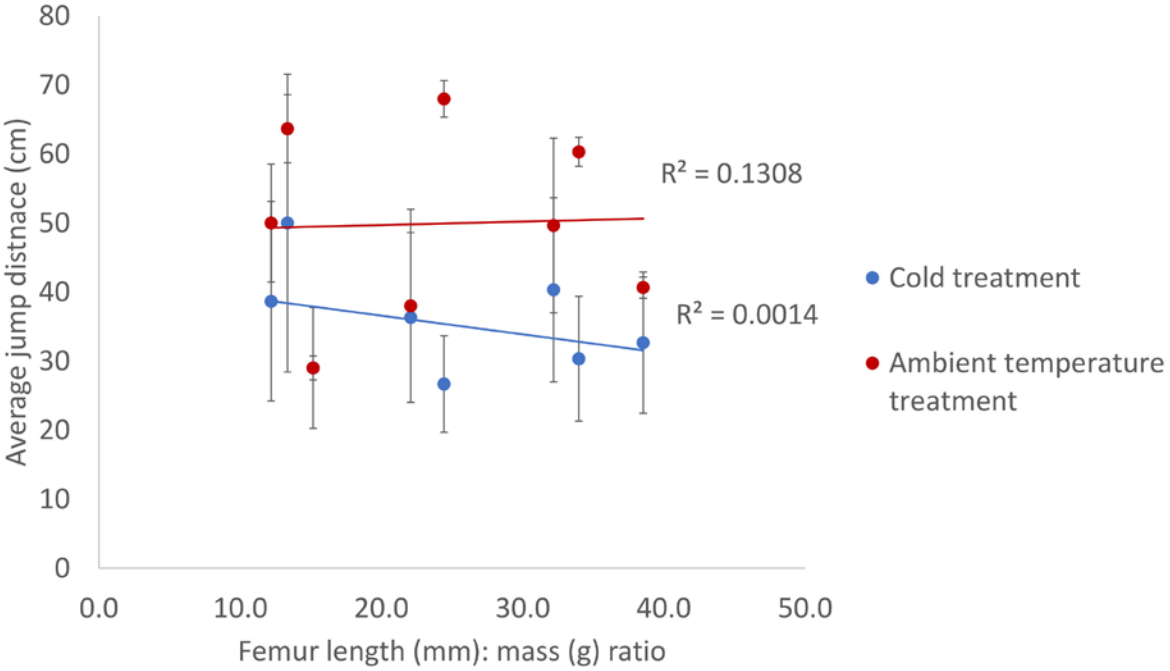

Figure 1: Average distance jumped by *M. concinna* in relation to their femur length:mass ratio for the cold treatment (~10–19°C) and ambient temperature treatment (~19–21°C). Error bars represent ±1 SD.

Temperature

There was a significant difference in the jump distance of *M. concinna* in the two temperature treatments. The grasshoppers jumped further in the ambient temperature treatment (mean = 49.92 ± 13.57 cm) than in the cold treatment (mean = 35.50 ± 7.55 cm) (paired *t*-test, $n_1 = 8$, $n_2 = 8$, $p = 0.024$) (Figure 2).

The oxygen consumption of *M. concinna* in the ambient temperature treatment was higher than those of the cold treatment (Figure 3). However, whilst the p-value was close to significance (paired *t*-test, $n_1 = 8$, $n_2 = 8$, $p = 0.060$), it was not below 0.05.

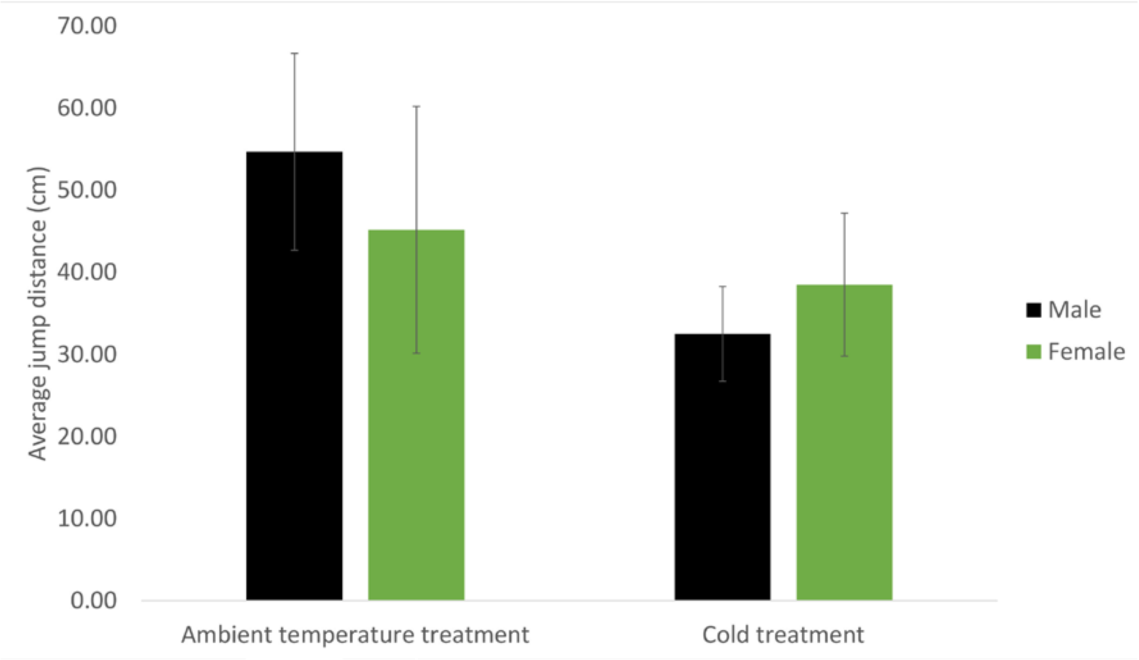

Figure 2: Comparison of jump distance of female and male *M. concinna* in the cold treatment (~10–19°C) and ambient temperature treatment (~19–21°C). Error bars represent ±1 SD.

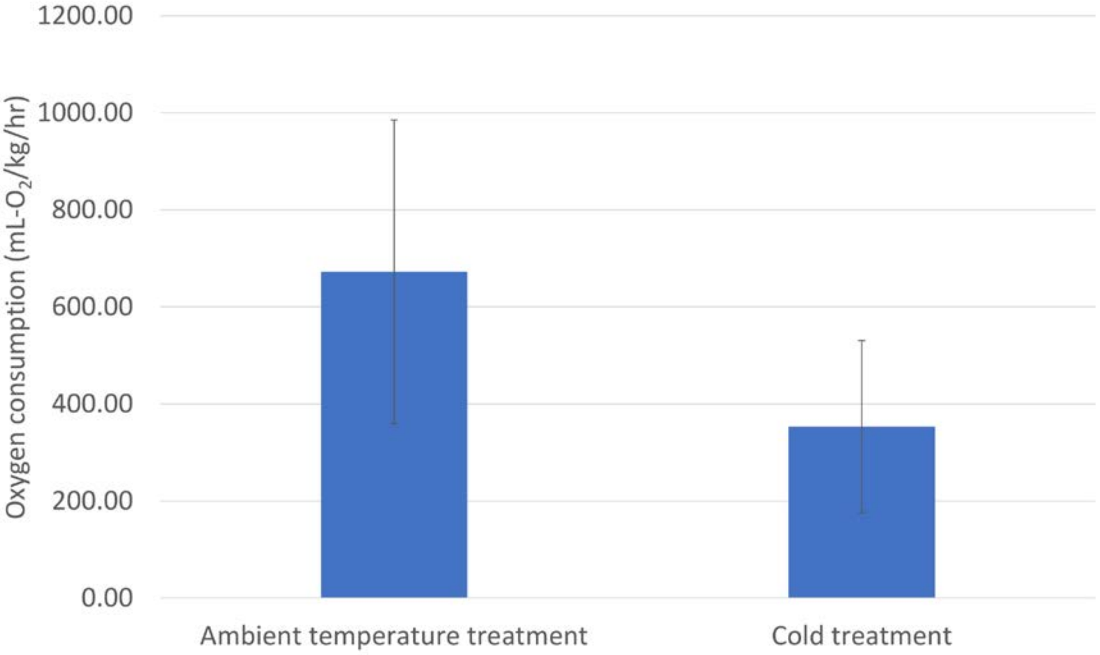

Figure 3: Comparison of oxygen consumption of *M. concinna* in the cold treatment (~10–19°C) and ambient temperature treatment (~19–21°C). Error bars represent ±1 SD.

Sexual dimorphism

The sexes of *M. concinna* demonstrated differences in their femur length:mass ratio. The femur length:mass ratio was significantly smaller for females than males (2 sample *t*-test, $n_1 = 4$, $n_2 = 4$, $p = 0.004$) (Figure 4).

Males and females demonstrated no significant difference in their jump distance for the cold treatment (2 sample *t*-test, $n_1 = 4$, $n_2 = 4$, $p = 0.294$) or the ambient temperature treatment (2 sample *t*-test, $n_1 = 4$, $n_2 = 4$, $p = 0.361$) (Figure 2). However, male grasshoppers demonstrated significantly greater mass-specific jump distances. This was for both the cold treatment (2 sample *t*-test, $n_1 = 4$, $n_2 = 4$, $p = 0.034$) and the ambient temperature treatment (2 sample *t*-test, $n_1 = 4$, $n_2 = 4$, $p = 0.000$) (Figure 5).

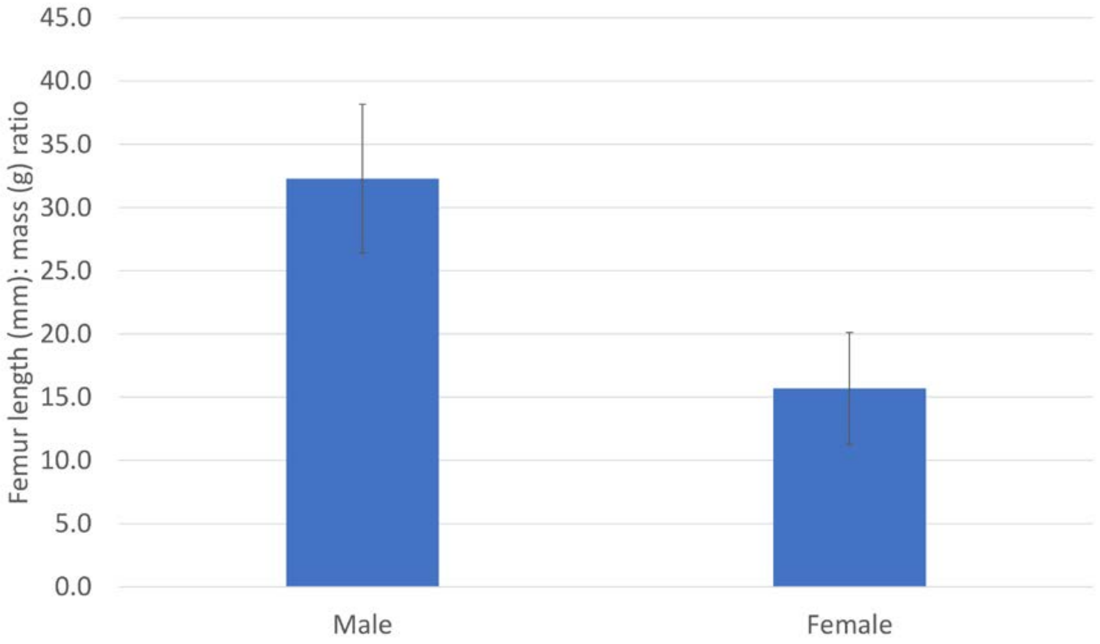

Figure 4: Comparison between male and female femur length:mass ratios of *M. concinna*. Error bars represent ±1 SD.

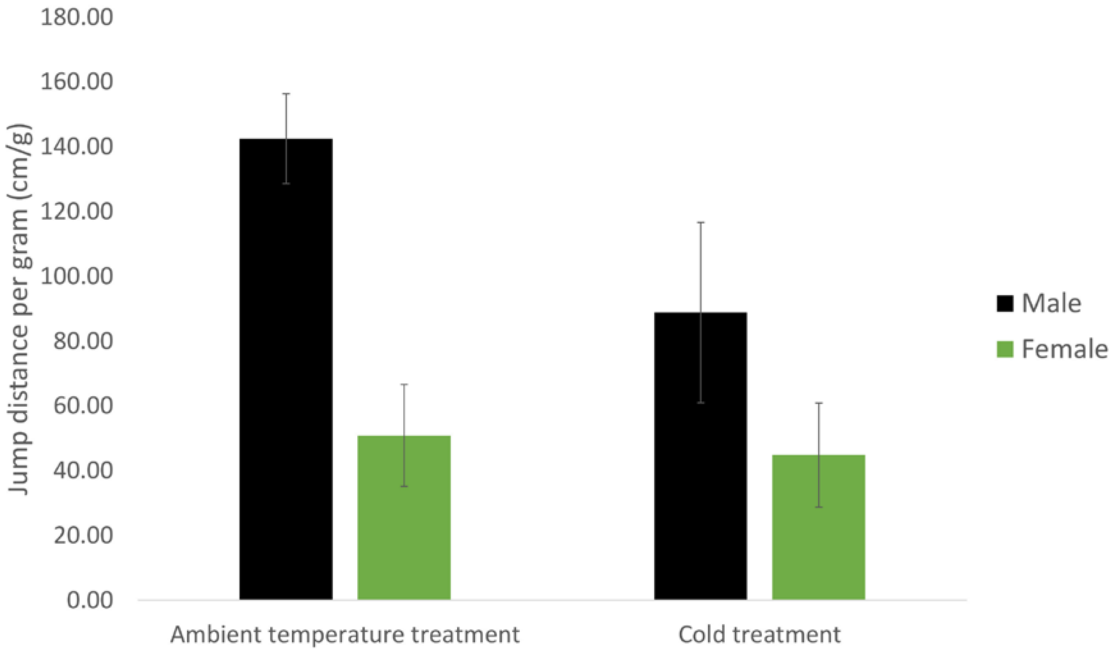

Figure 5: Comparison between male and female jump distance per gram of *M. concinna* for the cold treatment (~10–19°C) and the ambient temperature treatment (~19–21°C). Error bars represent ±1 SD.

Discussion

Femur length:mass ratio

The femur length:mass ratio did not demonstrate any correlation with jump distance in *M. concinna*, regardless of temperature. This was an unexpected result. We expected that with a greater femur length:mass ratio, the grasshoppers would be able to jump further. We demonstrated the results for both the cold treatment (~10–19°C) and ambient temperature treatment (~19–21°C), as the data for both was recorded. However, there was no reason to expect that the correlation between femur length:mass ratio and jump distance should not be present at any temperature.

The lack of correlation could be due to variation in jump performances of the grasshoppers. For each grasshopper, the distance of only three jumps was recorded in each treatment. There was no way to know whether a maximum effort jump was exerted. That is, one grasshopper may have been jumping as far as it could each time, and another could have been using as minimal effort as possible. This would have confounded the results. To reduce this problem, we could record more jump distances for each grasshopper. Alternatively, we could take the furthest distance jumped, rather than averaging the three (Gabriel 1985).

Other factors may have also affected the jump distance of *M. concinna* – for example, muscle mass or age. We did not know whether the grasshoppers were juveniles or adults. For *Schistocerca americana*, adult grasshoppers have higher powered jumps than juveniles, but reduced endurance (Kirkton and Harrison 2006). Similarly, for *Locusta migratoria*, adult locusts have greater mass-specific jumping abilities than juveniles (Snelling *et al.* 2013). Adult locusts have a more optimal take-off angle, reduced drag and greater femur muscle volume (Snelling *et al.* 2013). *M. concinna* may have these same differences between adults and juveniles, which could have affected the results and prevented us from seeing a trend between femur length:mass ratio and jumping ability. However, both *S. americana* and *L. migratoria* adults fly, whilst their juveniles do not (Kirkton and Harrison 2006; Snelling *et al.* 2013). Adults need to maximise their jumps to initiate flight and the differences in jumping abilities of juveniles and adults have largely been attributed to this (Kirkton and Harrison 2006; Snelling *et al.* 2013). As *M. concinna* do not fly (Bland 1991), future research should address whether adult and juvenile *M. concinna* do have differing morphologies and jumping abilities. Our experiment should be repeated taking this into account.

Temperature

The different temperature treatments did not significantly affect the metabolic rate of *M. concinna*. This was unexpected, as the relationship between temperature and metabolic rate is a well-known trend – an increase in temperature should result in an increase in metabolic rate (Whitman 1988). However, this general trend was shown, with the p-value only just outside a significant range.

We suspect that the two treatments were not different enough in temperature to demonstrate significant differences in metabolic rate. Despite being left in the cold room (~0°C) for approximately five hours, the grasshoppers in the cold treatment were initially only between 10 and 15°C. They then warmed up to ~17–19°C after their three jumps. The temperature of the grasshoppers in the ambient temperature treatment remained around 19–21°C. Thus, the temperatures of the grasshoppers ended up overlapping. Ideally, the grasshoppers would have been cooled to ~0°C and remained at temperature. Leaving the grasshoppers in the cool room for longer, or measuring the metabolic rate and jump distance in the cold room, may have allowed them to cool to a lower temperature. We also had low sample sizes. With even a few more grasshoppers, we would likely have reached significance.

The grasshoppers in the ambient temperature treatment jumped significantly further than the grasshoppers in the cold treatment as was predicted. However, as there was no significant difference in metabolic rate, we could not attribute this to differences in metabolism (although this would be highly likely). Increased temperatures of *L. migratoria* result in increased tension of the femur muscle during contraction, and increased energy stored in the femur's springs (Snelling *et al.* 2013). Thus, jump distance may have been affected by metabolism, but also by changes in mechanical properties.

The greater jumping distances of *M. concinna* at higher temperatures implies improved performance levels in warming climates. However, further research should be done into the effects of acclimatising to rising temperatures. The mortality rates of the cricket *Acheta domesticus* increase with acclimation to higher temperatures (Lachenicht *et al.* 2010). Heat knockdown time was also not significantly affected by acclimation (the crickets were heated to 50°C and the time taken for them to permanently lose coordination was recorded) (Lachenicht *et al.* 2010).

Sexual dimorphism

Males had significantly higher femur length:mass ratios than females for *M. concinna*. There had been no previous studies comparing female and male femur length:mass ratios in grasshoppers. However, females are typically larger. For *Schistocerca americana*, males and females have equivalent jumping abilities but males have a higher mass-specific jumping ability (Queathem 1991). If *M. concinna* follow a similar trend, we predicted that the higher mass-specific jumping ability of males may be due to a higher femur length:mass ratio. Our results were in line with these predictions. Males had higher mass-specific jumping abilities and femur length:mass ratios, but males and females had equivalent jumping abilities.

It would be interesting to see whether the sexes also differ on physiological traits – for example, mass-specific metabolic rates. Male *Dermacentor variabilis* (ticks) have higher mass-specific metabolic rates than females (Krasnov *et al.* 2003). This may also be the case for *M. concinna*.

Conclusions

In this experiment, we studied the effects of femur length:mass ratio (morphology) and metabolism (physiology) on the jump distance of *M. concinna*. We did not find morphology to be related to jump distance, though physiology had some effect. There was sexual dimorphism in their morphology and in their mass-specific jumping abilities, but equivalence in their jump distances. Our experiments act as a starting point in understanding the effects of jump distance on *M. concinna*. Jump distance reflects performance levels of grasshoppers. *Monistria concinna*'s performance is important to understand due to their large influence on KNP's ecosystem. Especially in changing climates, the effects of temperature on *M. concinna* should be researched. Our results indicate that warming temperatures could improve the jumping abilities of *M. concinna*. Other research could look into the acclimation of *M. concinna* in warming temperatures.

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