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Copulation and sexual size dimorphism in worm-like millipedes

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Abstract
The prediction that copulation duration is shorter when sexual size dimorphism increases was tested in juliform millipedes at the population-level and species-level by tabulating and correlating ratios for mean sexual size dimorphism ranging from 1.0-1.6 (n=310) with mean copulation duration ranging from 34-206 minutes (n=391) in 8 taxa: ord. Spirostreptida fam. Odontopygidae gen. *Odontopyge* (n=2spp.), *Spinotarsus* (n=1sp.) and fam. Spirostreptidae gen. *Calostreptus* (n=1sp.), *Doratogonus* (n=1sp.); and ord. Spirobolida fam. Trigoniulidae gen. *Centrobolus* (n=3spp.). Copulation duration and sexual size dimorphism were inversely correlated across populations (r=-0.5975, N=11, P=0.05) but not species. This study contributes to the allometry of copulation.

Keywords: Copulation, dimorphism, guard, millipede, prolonged

1. Introduction
The form and resolution of mating systems has been reviewed in millipedes and the costs and benefits for males and females to prolong copulation shows a realization that their primary interests in mating are asymmetric [1]. Prolonged copulation is a behavioural adaptation that benefits males by reducing sperm competition and increases paternity assurance [2]. Attempts at explaining why females remain together with a male and maintain genital contact for a prolonged period is the mate-guarding hypothesis [2].
In millipedes, males and females have evolved morphological characteristics that appear to aid in forcing and resisting copulation: males possess tarsal pads for grasping females and various genital processes that function to hold the female anteriorly [3-5], females have spines on the bursa copulatrix that function to exclude males from their sperm stores [6], and are known to engage in recoiling and a reluctance to mate [1]. Millipede copulation is usually prolonged and differs between species and between populations [7].
The present study investigates how copulation duration differs between populations and species [1, 7]. The prediction that copulation duration is shorter when sexual size dimorphism increases was tested in the present study by tabulating and correlating sexual size dimorphism and copulation duration in 11 populations from 8 species of southern African worm-like millipedes.

2. Material and Methods
This study was conducted on southern African millipedes (1/05/2017). Two variables were of interest: sexual size dimorphism (independent) and mean copulation duration (dependent); at the population-level and species-level.

2.1 Sexual size dimorphism
Sexual size dimorphism variable scores in members of the families Spirostreptidae and Odontopygidae were calculated as ratios of female mass divided by male mass (g) [7]. Sexual size dimorphism variable scores in members of the family Trigoniulidae millipedes were calculated as ratios of female volume divided by male volume (mm^3) [8]. Sexual size dimorphism ratios were compared to isometry *i. e.* no dimorphism values using a *T*-Test Calculator for 2 Independent Means by inputting 1.0 as one treatment and the sexual size dimorphism as the other treatment.

2.2 Mean copulation duration
Copulation duration (minutes) data of southern African millipedes were extracted from the literature [1, 7].

To minimize observer bias, blinded methods were used when behavioural data were analysed. Mean copulation duration was calculated for each species.

2.3 Statistical analysis

Analysis was done on http://www.socscistatistics.com. Copulation durations and sexual size dimorphisms were tested for a relationship using the Pearson Correlation Coefficient Calculator (http://www.socscistatistics.com/tests/pearson/Default2.aspx). Sexual size dimorphism was plotted (x-axis) *vs* copulation duration (y-axis) for 11 populations using Statistica 13.2 and converted/saved with Soda Pdf Free. A Probability-value was calculated from the Pearson's correlation coefficient score at http://www.socscistatistics.com/pvalues/pearsondistribution.aspx.

3. Results

Copulation duration was shorter when sexual size dimorphism increased and copulation duration was longer when sexual size dimorphism was absent at the population-level (Fig. 1) but not species-level. In the three families of millipedes both sexual size dimorphism and copulation duration were found for 11 populations (Table 1). Sexual size dimorphism ranged from 0.875-1.621 (females/males). In 9 cases (populations) females were larger than males with 2 exceptions. The 2 exceptions were not significantly different (at $p<.01$) from isometry *i. e.* having no sexual size dimorphism (1.0); as the values were compared with one-tailed (t=-1.27273; n=2; p=0.165527) and two-tailed t-tests (t=-1.27273; n=2; p=0.331054). So effective sexual size dimorphism ranges from 1.0-1.621 because the main sample was significantly different (at $p<0.01$) from 1.0 with one-tailed (t=5.33455; n=9; p=0.000034) and two-tailed tests (t=5.33455; n=9; p=000067). The total sexual size dimorphism was significantly different (at $p<0.01$) from 1.0 with one-tailed (t=3.65483; n=11; p=0.000787) and two-tailed tests (t=3.65483; n=11; p=0.001574). Sexual size dimorphism and mean copulation duration were moderately inversely related (at $p<0.10$) across the populations (r=-0.5975; N=11; P=0.051986; Fig.1) but not significantly at the species-level (r=-0.6187; N=8; P=0.102482).

Table 1: Copulation duration and sexual size dimorphism (SSD) in three families of millipedes. * SSD was female size / male size and significantly ($p<0.01$) different from 1.0.

Family *Species*	Copulation duration Mean±S.D.(n)	SSD	Reference
Odontopygidae			
Odontopyge sp.3 (Vic. Falls)	80.2±25.3(20)	1.125*	[7]
Odontopyge sp.3 (Marondera)	85.6±16.6(19)	1.29*	[7]
Odontopyge sp. 3	82.9±21.0(39)	1.27*	
Odontopyge sp.2 (Marondera)	66.0±11.2(28)	1.357*	[7]
Spinotarsus sp.1 (Marondera)	92.3±18.6(19)	0.875	[7]
Spirostreptidae			
Doratogonus uncinatus (Mazowe)	122.7±49,4(35)	0.985	[7]
Doratogonus uncinatus (Hwange)	205.8±60,8(25)	1.076*	[7]
Doratogonus uncinatus	157.325±54,2(60)	1.031	
Calostreptus sp. (Hwange)	60.3±25,6(22)	1.5*	[7]
Calostreptus sp. (Sengwa)	33.8±22.9(25)	1.5*	[7]
Calostreptus sp.	47.05±24.3(60)	1.5*	
Trigoniulidae			
Centrobolus inscriptus (Mtunzini)	170±49.3(115)	1.219*	[1, 8]
C. fulgidus (Richard's Bay)	66.4±18.6(51)	1.251*	[1, 8]
C. ruber (Port Shepstone)	39.8±13.2(32)	1.621*	[1, 8]

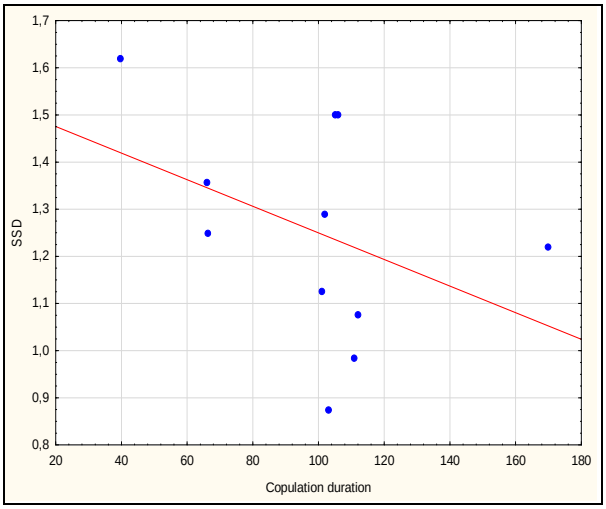

Fig 1: Relationship between sexual size dimorphism ratios (SSD) and mean copulation duration (minutes) at the population-level in Juliformia.

4. Discussion

Sexual size dimorphism and copulation duration varies across populations and species of millipedes with an inverse correlation between sexual size dimorphism and copulation duration across the 11 populations from 8 taxa belonging to 3 families of juliform millipedes. Studies involving sexual size dimorphism in millipedes showed a novel examination of co-variables as these may vary within populations but not species [7, 9-10]. The present study result agrees with the finding of larger males copulating for shorter duration in Polydesmidae [9]. It also supports male control of the copulation duration in Spirostreptidae [10]. Furthermore, the appearance of larger females copulating for longer in Trigoniulidae must be viewed relative to male size [11].

5. Conclusion

Sexual size dimorphism in southern African worm-like millipedes inversely relates to copulation duration because larger males copulate for shorter and larger females copulate for longer.

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5. References

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