

Behavioural response of the Slow worm *Anguis fragilis* (Linnaeus, 1758) and the Eastern Slow worm *Anguis colchica* (Nordmann, 1840) to the odour of viperids

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Abstract. The ability of sensing chemical cues is a common way for reptiles to recognize predators, mates and potential competitors. To characterise the model of anti-predatory behaviour of the Slow worm *Anguis fragilis* and the Eastern Slow worm *A. colchica* their response to the odour of the Nose-horned viper, *Vipera ammodytes* and the Balkan adder, *V. berus bosniensis* was studied in laboratory conditions. The experiments were carried out between May and July 2016-2017 with 10 individuals of *A. colchica* (5 adults and 5 juveniles) and 11 individuals of *A. fragilis* (6 males and 5 females, all adults). As stimuli, we used a clean swab as a control and a swab impregnated with scents from the snakes. The behavioural responses of the two slow worms to the stimuli were recorded and compared. The results showed that individuals from both *A. colchica* and *A. fragilis* recognize the odour of both potential predators – *Vipera ammodytes* and *V. berus bosniensis*. However, in *A. colchica*, adult individuals took a higher risk than juveniles, and in *A. fragilis* males took a higher risk than females, probably due to their different life strategies and functions in populations.

Key words: Anguinae, anti-predatory behaviour, odour stimulus, viperids, laboratory experiments.

Introduction

The ability to recognize and identify predators is crucial to the survival of individuals in their natural habitats (Lima & Dill 1990, Ortega et al. 2018, Cornelis et al. 2019). Such adaptations are related to the prey's ability to detect and identify chemical cues left by the predator (Kats & Dill 1998). Snakes are among the most significant predators of lizards (Downes & Shine 1998, Webb et al. 2009). A number of studies prove that lizards are able to recognize the scents of their snakes' predators, and react to them with intense anti-predatory responses (Thoen et al. 1986, Amo et al. 2004a,b, Mencia et al. 2016).

Anguinae are a group of reptiles adapted to a semi-subterranean lifestyle. They prefer habitats with dense vegetation where visibility is poor (Beebee & Griffiths 2000). They are often found under tree barks, flat stones or tiles. The Slow Worm *Anguis fragilis* Linnaeus, 1758 is distributed throughout continental Europe, including Britain and Scandinavia, reaching Asia Minor to the east (Dely 1981, Cabela 1997, Salvador 1998). In Bulgaria, the species is distributed in the south-western part of the country, mainly in the mountainous regions of Rila, Pirin, Rhodopes, West Stara Planina and Vitosha Mountain (Jablonski et al. 2016). The Eastern Slow Worm, *Anguis colchica* (Nordmann, 1840), is distributed mainly in the southeast of Europe (Balkan Peninsula) and Western Asia, and in Bulgaria – in the northern and eastern parts of the country, mainly in the lower regions of Stara Planina, Strandzha, the Danube Plain and the Black Sea coast (Jablonski et al. 2016).

The predators of both *Anguis* species in Bulgaria include the Balkan adder *Vipera berus bosniensis* (Boettger 1889), the Nose-horned viper *Vipera ammodytes* (Linnaeus, 1758), the Smooth snake *Coronella austriaca* (Laurenti, 1768) and the Caspian whipsnake *Dolichophis caspius* (Gmelin, 1789) (Beshkov & Dushkov 1981, Stojanov et al. 2011, Tzankov et al. 2014), but it is not clear to what extent they recognize and react to them. Several lizard species, including *A. fragilis*, are

known to recognize the odour of *C. austriaca* as a threat (Downes & Bauwens 2002, Amo et al. 2003, 2004b, Cabido et al. 2004, Mencia et al. 2016, Ortega et al. 2018). Both *V. ammodytes* and *V. berus* have a very complex and to a great extent similar composition of skin secretions (Andonov et al. 2020, Van Moorleghe et al. 2020), and those of *V. berus* are known to elicit fear responses to another lizard species- *Zootoca vivipara* (Lichtenstein, 1823) (Thoen et al. 1986; Van Moorleghe et al. 2020). In Bulgaria, both *Anguis* species share common habitats with *V. ammodytes* in the lower parts of the country (up to 1450 m a.s.l.), and with *V. berus* – in higher altitudes (between 1000 and 2100 m a.s.l. (Beshkov & Naney 2006, Stojanov et al. 2011, Tzankov et al. 2014). Due to all of the above, it could be assumed that the two *Anguis* species should have developed systems for anti-predatory response to them. According to Landová et al. (2016) the level of threat may depend on the predator's foraging ecology whether the distribution is sympatric and the degree of specialism of the potential predator. In this regard, the aim of the present work is to study the responses of individuals from both species of slow worms, *A. fragilis* and *A. colchica*, to the odour of viperids (*V. ammodytes* and *V. berus bosniensis*) in laboratory conditions. We also aim to characterise the model of anti-predatory behaviour of the two slow worm species. The similar ecology and biology of the two species of slow worms suggests that the behavioural patterns of the two species will be similar, but with some differences arising from their distribution, and hence differences in their behavioural strategies. This knowledge can be integrated into different conservation and management practices having in mind that both species are included in Annex III of the Berne Convention.

Material and Methods

The experiments were carried out between May and July 2016-2017 using 10 male individuals of *A. colchica* (5 adults and 5 juveniles) and 11 adult individuals of *A. fragilis* (6 males and 5 females). The exper-

iments were performed 4-7 days after their capture for a period of about 3-5 days.

Capture and housing

Lizards of both species were captured from their natural habitats in the area of Lakatnik (*A. colchica*) and Vitosha Mtn. (*A. fragilis*). To study the reaction of the slow worms to their population-specific potential predators, an adult *Vipera berus bosniensis* (from Vitosha Mtn) and an adult *Vipera ammodytes* (from Lakatnik) were captured.

The age and sexual dimorphism of the lizards was determined both using the colour patterns as well as their size (Beshkov & Nanev 2006). In both species, adults' body length varies between 34 and 46 cm, subadults' between 25-34 cm, and of juveniles between 16 and 19 cm.

Prior to the experiments, each slow worm was housed in an individual terrarium with a lid (30 cm x 14 cm x 22 cm). Soft paper was used as a substrate and tree barks as a cover. Water was provided ad libitum. The animals were fed twice a week with earthworms (*Lumbricus* sp.) and molluscs. The humidity in the terrariums was maintained by spraying water two or three times a week. The room temperature was maintained in the range of 23-24 °C. The vipers used in the potential predator odour recognition tests were also housed in separate terrariums of the same size (30 cm x 14 cm x 22 cm), with a shelter and a water ad libitum. Their terrariums were kept away from the slow worms to avoid visual and potential odour contact between them.

Experimental design and procedure

The tests were performed in the personal terrariums of the animals. The stimuli (odour of the two viper species) were prepared by placing cotton tips of 1 cm each on top of a 40 cm long copper wire applicator. Before each experiment, the wire, the tweezers, and the cotton tips were sterilized in boiling water. First, the animals were tested with a control - a dry cotton tip treated with boiling water. After drying, the cotton tip was rubbed around the cloaca of the Adder and Nose-horned vipers, where the cotton was impregnated with cloacal fluids and snake faeces. It is likely that in nature these reptile secretions are deposited on the substrate when they move on it. A new cotton tip was used for each experiment. Immediately after preparation of the probe, it was presented directly in the terrariums to the slow worms at a distance of 5-10 cm from the tip of the snout. Depending on whether the lizard was at rest or not, light movements were made with the cotton and tapping on the bottom of the terrarium or on the shelter in order to attract the reptile's attention to the object. Following the initial reaction of the slow worm to the object (movement and tongue-flicks in the direction of the cotton), all behavioural states and events were recorded with a digital camera (Sony Cybershot DSC-HX60) for a period of 3 minutes.

The following behavioural responses were recorded:

- Reaction to the control (Con/Coff) - tongue-flicks directed to the control or in another direction
- Tongue-flicks (TFon/TFOff) - tongue-flicks directed to the stimulus or in another direction
- Standing still (NM - No Movement) - absence of any visible reaction
- Moving away from the stimulus due to loss of interest (LI) - return to the initial position after a brief study of the stimulus
- Looking Around (LA) - movement of the head in different directions, without movement of the body, after providing the stimulus
- Retreat (R) - looking around, followed by active movement with the whole body (torso and tail) and head, in the opposite direction from the provided stimulus.

Statistical analyses.

To assess whether the animals could detect the odour of a potential predator, the frequency of tongue-flicks directed to the control on the one hand, and tongue-flicks to the odour of a predator on the other, were compared using a paired t-test. In addition, one-way analysis

of variance (one-way ANOVA) was used to determine statistically significant differences in the pattern of their anti-predatory behaviour. The variables were tested for normal distribution using the Kolmogorov-Smirnov test. Statistically significant differences were considered at $p < 0.05$. Statistical analyses were performed using the program STATISTICA, Version 12.0 (StatSoft Inc., Tulsa, OK, USA).

Ethic notes

The manipulations of the experimental animals were performed with maximum care to avoid injuries and any other disturbance of the vitality of the animals. After the experiments, the reptiles were released at their capture localities. All trials were substantiated before the law with a permit issued № 656 from 08.06.2015, based on Art. 49, para 1, item 1, in connection with art. 48, para. 2, item 5, of the Biological Diversity Act (BDA) and Order RD-674 / 03.09.2014, with expiration date 31.03.2019.

Results

The results showed that both *Anguis colchica* and *A. fragilis* recognize the odour of the potential predators - *V. ammodytes* and *V. berus*. Number of TFs directed to the odour of the predator was significantly higher than the number of TFs to the control, in both *A. fragilis* ($t_{10} = 3.53, p = 0.005, N = 11$) and *A. colchica* (paired t-test: $t_9 = 2.67, p = 0.02, N = 10$).

To see whether there were age and sex differences, we compared behavioural responses to the potential predator odour in male and female *A. fragilis* and in adults and juveniles in *A. colchica*. In both male and female *A. fragilis*, the number of TFs to predator odour was significantly higher than the number of TFs to control - Table 1 (paired t-test: $t_5 = 3.81, p = 0.01, N = 6$ for males and $t_4 = 3.77, p = 0.01, N = 5$ for females). Similarly, in both adults and juveniles of *A. colchica*, the number of TFs to predator odour was significantly higher than the number of TFs to control - Table 2 (paired t-test: $t_4 = 2.97, p = 0.04, N = 5$ for adults and $t_4 = 4.46, p = 0.01, N = 5$ for the juveniles). In both adults and juveniles *A. colchica* there was no significant difference in the number of TFs directed to the control (Con) and away from it (Coff) (paired t-test: $t_5 = 1.93, p = 0.12, N = 5$ for adults and $t_4 = 0.45, p = 0.67, N = 5$ for the juveniles). The number of TFs directly to the predator odour (TFon) and away from it (TFOff) did not differ statistically in juveniles *A. colchica* (paired t-test: $t_4 = 1.30, p = 0.26, N = 5$). In adults, however, the number of TFs directly to the predator odour was significantly higher than the TFs away from it (paired t-test: $t_5 = 5.66, p = 0.004, N = 5$).

In female *A. fragilis* there was no statistically significant difference either between the number of TFs directed to the predator odour (TFon) and away from it (TFOff) (a pair t-test: $t_4 = 0.35, p = 0.74, N = 5$), nor between the number of TFs directed to the control (Con) and away from it (Coff) (paired t-test: $t_4 = 0.30, p = 0.77, N = 5$). In male *A. fragilis* the number of TFs directed to the control (Con) and away from it (Coff) also did not differ significantly (paired t-test: $t_5 = 0.59, p = 0.057, N = 6$). However, the number of TFs directed to the predator odour (TFon) was significantly higher than the number of TFs away from it (TFOff) (paired t-test: $t_5 = 3.04, p = 0.02, N = 6$).

In addition, we found significant age and sex differences in individuals' behavioural response to the odours of their potential predators. In *A. colchica*, adults showed significantly more TFs to predator odour than juveniles (ANOVA: $F_{1,8}$

Table 1. Mean and standard error of the studied parameters in the test reaction to the predator odour in male and female *A. fragilis*. The minimum and maximum values are given in parentheses. Statistically significant values of t in the paired t-test and of F in the one-way analysis of variance ANOVA are marked with *.

	TF	TF on	TF off	C	C on	C off
Male n=6	21.83±4.36 (11-38)	14.00±2.92 (7-23)	7.83±1.74 (4-16)	4.66±0.71 (3-8)	2.50±0.42 (1-4)	2.16±0.47 (1-4)
t ₅	*t _(TF×C) = 3.81, p = 0.01; t _(TF on×TF off) = 3.04, p = 0.02; t _(C on×C off) = 0.59, p = 0.57;					
Female n=5	9.00±1.09 (6-12)	4.60±1.63 (1-9)	3.80±1.06 (1-7)	5.00±0.83 (3-8)	2.60±0.50 (2-4)	2.40±0.50 (1-4)
t ₄	*t _(TF×C) = 3.77, p = 0.01; t _(TF on×TF off) = 0.35, p = 0.74; t _(C on×C off) = 0.30, p = 0.77;					
F _{1,9}	*F _{TF} = 6.79 p = 0.02	*F _{TFon} = 7.01 p = 0.02	F _{TFoff} = 3.51 p = 0.09	F _C = 0.09 p = 0.75	F _{C on} = 0.02 p = 0.88	F _{C off} = 0.11 p = 0.74

Table 2. Mean and standard error of the studied parameters in the test reaction to the predator odour in adult and juvenile *A. colchica*. The minimum and maximum values are given in parentheses. Statistically significant values of t in the paired t-test and of F in the one-way analysis of variance ANOVA are marked with *.

	TF	TF on	TF off	C	C on	C off
Adults n=5	43.20±9.05 (25-78)	31.20±4.77 (15-45)	7.40±1.56 (4-13)	10.8±3.99 (3-21)	7.20±2.85 (1-14)	3.60±1.24 (1-7)
t ₅	*t _(TF×C) = 2.97, p = 0.04; *t _(TF on×TF off) = 5.66, p = 0.004; t _(C on×C off) = 1.93, p = 0.12;					
Juveniles n=5	10.20±1.68 (6-16)	6.40±0.81 (4-9)	4.00±1.58 (1-10)	5.60±1.53 (3-11)	3.00±0.44 (1-6)	2.60±0.67 (1-5)
t ₄	*t _(TF×C) = 4.46, p = 0.01; t _(TF on×TF off) = 1.30, p = 0.26; t _(C on×C off) = 0.45, p = 0.67;					
F _{1,8}	*F _{TF} = 12.84 p = 0.007	*F _{TFon} = 26.17 p = 0.0009	F _{TFoff} = 2.33 p = 0.26	F _C = 1.47 p = 0.25	F _{C on} = 1.90 p = 0.20	F _{C off} = 0.49 p = 0.5

= 12.84, p = 0.007), with directed TFs to predator odour (TFon) being also significantly higher (ANOVA: F_{1,8} = 26.17, p = 0.0009). In *A. fragilis*, the number of TFs to predator odour (TF) in males was significantly higher than in females (ANOVA: F_{1,9} = 6.79, p = 0.02), as well as directed TFs to predator odour (TFon) (ANOVA: F_{1,9} = 7.01, p = 0.02).

Although both species recognized the odour of the predator, the reaction of individuals after identifying it, was different. Some individuals retreated; others stood still, and other individuals moved away. In *A. colchica*, most juvenile individuals moved away, while adults retreated or stood still (Fig. 1).

In *A. fragilis*, there was no significant difference in the pattern between males and females, but it is noteworthy that females were less likely to retreat than males (Fig. 1).

When comparing between the two species, *A. fragilis* showed more states of standing still than *A. colchica*, although no statistically significant difference was found $\chi^2 = 3.57$, DF = 1, p = 0.058 (Fig. 2).

Discussion

The high exploratory activity is usually considered as a characteristic of the proactive and bolder individuals (Wolf & Weissing 2012, Brodin et al. 2013). In general, it is assumed that in complex, changing environments, the ability of animals to identify possible changes in the environment through exploration is very important for their survival. In this context, Burger (1998) points out that all animals that are exposed to the presence of predators must correctly distinguish between dangerous and non-dangerous threats. In our laboratory experiments, the slow worms did not change their normal behaviour when provided with a control stimu-

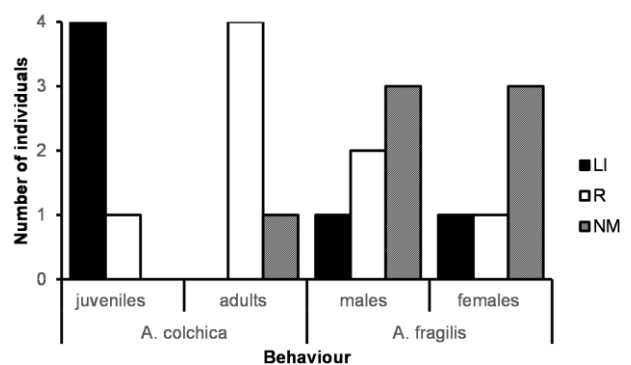


Figure 1. Locomotor activity in juvenile and adult *A. colchica* and in male and female *A. fragilis* after recognising the predator odour. Legend: LI - moving away from the stimulus (losing interest); R - retreat; NM - standing still (not moving).

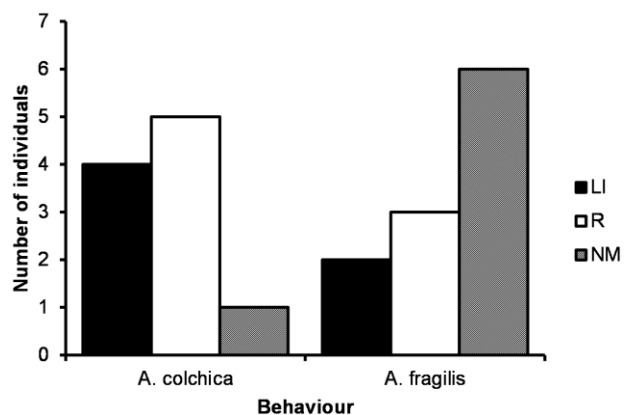


Figure 2. Locomotor activity in *A. colchica* and *A. fragilis* after recognising the predator odour. Legend: LI - moving away from the stimulus (losing interest); R - retreat; NM - standing still (not moving).

lus and did not exhibit stressed behaviour. However, when the odour from the vipers was provided, they either moved away from the stimulus, retreated, or stood still, indicating that they recognized the odour of the potential predator. This result is similar to that found by other authors (Van Damme et al. 1995, Cooper 2000, Van Damme & Quick 2001, Amo et al. 2004b, Mencía et al. 2016). In the present work, one of the main types of behaviour exhibited by both *Anguis* species was a clear increase in the number of tongue-flicks, similar to what is found in other lizard species (Thoen et al. 1986, Graves & Halpern 1990, Amo et al. 2004a, b, Cabido et al. 2004, Van Moorlegghem et al. 2019, Williams et al. 2020). For instance, in *Podarcis muralis* (Laurenti, 1768) the greater tongue-flick rate as well as shorter latency to first tongue-flick in response to predator scents indicates that lizards are able to detect the snakes' chemical cues (Amo et al. 2004a). According to Williams et al. (2020) the tongue-flick response of *P. muralis* depends on the different species' scent. Cerini et al. (2020) established that individuals in a population of *Podarcis siculus* (Rafinesque-Schmaltz, 1810) preyed by *Hierophis viridiflavus* (Lacépède, 1789) show higher activity and a tendency to analyse and explore the stimuli and the environment more than lizards in another population of *P. siculus*, where no snakes occur. The ability to distinguish between the scent of their predators and that of other snake species has also been proven for many other lizard species. Usually the chemo-assessment of snake predation risk is modulated by the predation pressure experienced by lizards in their natural habitats (Ortega et al. 2018, Amo et al. 2004b, Mencía et al. 2016, 2017, Labra & Niemeyer 2004, Van Moorlegghem et al. 2019). It could be speculated that the higher interest towards snake scents could be triggered by their complexity, which requires more tongue-flicks to analyse the scents. In various Squamates, active exploratory behaviour also correlates positively with the rate of oscillating tongue-flicks, ensuring the transmission of chemical signals from the environment to the vomeronasal organ (Chiszar & Carter 1975, Chiszar et al. 1978, Greenberg 1985, Graves & Halpern 1990). Along with sight, this behaviour is closely related to obtaining information from the environment and its exploration. A number of authors also revealed that lizards are able to detect, recognize prey and discriminate between types of prey by using both chemical and visual cues (Amo et al. 2004a, Amo et al. 2006, Recio et al. 2020).

Many species of lizards use different tactics against their predators (Landová et al. 2016). The most common tactic used is to escape towards and hide in the nearest shelter. However, when avoiding the immediate danger of some predators, they ignore others. Thus, *Podarcis muralis* often gets into conflict behaviour, trying to escape from the attack of birds and hide, but then encounters the Smooth snake (*Coronella austriaca*) which hunts from ambush in their hiding places. In this way, many species of lizards become prey to this predator. That is why some individuals choose an escape route, away from their shelters (Amo et al. 2003). Investigations on chemosensory predator recognition in *Anguis fragilis* showed differential tongue-flick rates towards *C. austriaca*, which suggests that scents of this snake are recognized by the species (Cabido et al. 2004). Besides, scents of *C. austriaca* are quickly avoided and elicited defensive behaviours much more often than any other scent, suggesting that

chemical cues are a reliable means of assessing the snake's presence. According to the authors, these chemosensory capacities would be evolutionarily advantageous to avoid predation by snakes and are likely to represent a component of the suite of adaptations associated with low-visibility habitats. Our experiments with *A. colchica* and *A. fragilis* showed different escape strategies. Some slow worms, especially from the eastern species, started to move when approached by the applicator with viper odour, trying to move away or retreat. This response is similar to that recorded in salamander larvae (*Ambystoma* sp.), which intensify their movement trying to find shelter in response to traces of predators (Sih & Kats 1991). Similarly, *Podarcis siculus* also increases its escape movements, when exposed to the odour of *C. austriaca* (Downes & Bauwens 2002). In contrast to this strategy, other lizard species reduce their activity in the presence of chemical traces of predators (Thoen et al. 1986, Van Damme et al. 1995, Van Damme & Castilla 1996, Labra & Hoare 2015, Ortega et al. 2018). The standing still behaviour, which we observed, especially in *A. fragilis*, accords with findings of these authors. This gives reason to assume that the different strategies used are probably related to the species-specific characteristics of the prey and to the hunting strategy of the predator, as well as the characteristics of the habitats. Probably, in order not to be noticed, the lizards reduce their movements. Age and experience may also have an impact on the strategy used. In general, standing still behaviour was recorded only in adults and the frequency of tongue-flicks was significantly higher in this age group. This leads us to assume that the risk-taking of adults is greater than that of juveniles. This difference may be due to the different function of female and young reptiles in the population (Burger 1998, Amo et al. 2007, Carazo et al. 2014, Bajer et al. 2015, Woolrich-Piña et al. 2015).

Conclusion

Both *Anguis colchica* and *A. fragilis* recognize and react to the odour of the potential predators – *Vipera ammodytes* and *V. berus*. However, in *A. colchica*, adult individuals took a higher risk than juveniles, and in *A. fragilis* - males than females, probably due to their different life strategies and functions in populations.

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