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# From myths to metrics: a preliminary new look at measuring coiled, preserved snakes

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**Abstract.** Accurate length measurements of preserved snakes are fundamental for morphological, ecological, and taxonomic research. However, specimens stored in three-dimensional coils present a significant methodological challenge, and a lack of measurement standardization will likely lead to unquantified errors that compromise data comparability. Based on our dissatisfaction with the state of the science, we conducted a brief investigation into the accuracy and consistency associated with snout–vent length (SVL) measurements on two coiled, preserved Amazon False Coralsnakes (*Oxyrhopus rhombifer*). We evaluated the impact of measurement surface (dorsal vs. ventral), specimen size, implement type, and measurer experience. Five measurers with varying levels of scientific expertise took repeated SVL measurements using four different implements (three braided polyester strings and one flexible wire). Using "Objective Length" (OL), the mean of all measurements, as a reference, our results reveal a previously overlooked and substantial systematic error: dorsal SVL measurements were consistently 20–25% longer than ventral measurements on the same coiled specimen. Implement choice also affected accuracy, with one of the braided polyester strings performing best (mean error: 0.2% below OL) while the wire consistently underestimated length (2.2% below OL). Measurer experience did not predict accuracy but was associated with higher consistency in some cases. There was no overall effect of specimen size on measurement error, but individual measurers performed worse on the smaller snake. We conclude that the true length of a coiled, preserved snake is unknowable, let alone with high precision, but that the associated errors can be characterized and minimized. While we acknowledge that our limited study cannot be a definitive work on how to optimize this methodology, it is undeniable that a problem exists. We therefore advise caution when using and making measurements, and we strongly recommend that future studies explicitly report whether measurements are taken dorsally or ventrally and which with type of implement, as these factors appear to be those most critical for data comparison and reproducibility.

**Keywords.** Snout–vent length, measurement error, *Oxyrhopus rhombifer*, standardisation, allometry.

## Introduction

Body length is one of the simplest characteristics of a snake, and allometry, the relationship of body size to shape, has become a recognized research field (e.g., Shine et al., 1998a; Feldman and Meiri, 2013; Borczyk et al., 2024). Both body size and shape are related to many aspects of a snake's biology, including its anatomy, physiology, ecology, and behaviour (e.g., Dwyer and Kaiser, 1997; Shine et al., 1998b; Barends and Naik, 2023). While overall body size can also be measured in terms of weight, this is less reliable than length for comparative studies in snakes because a snake of a given length may feed on a heavy prey item (even exceeding its own body weight) or become dehydrated (Azzolini et al., 2023), and weight changes based on preservation can certainly have an impact on a specimen (Maayan et al., 2022). Instead, a snake's snout–vent length (SVL), tail length (TL), or total length (TTL) have been used since the early days of herpetology (e.g., Boie, 1826; Duméril et al., 1854) to record the sizes of snakes, and these measurements can even be used as an estimate for body weight (Feldman and Meiri, 2013) and play a central role in squamate databases (Meiri, 2024; Oskyrko et al., 2024). The proportion of tail length as part of total length has been used as a useful value in sex determination (Sivan et al., 2023), and while it can also be a relevant taxonomic characteristic (e.g., Clark, 1966; Shine, 1994), relative tail length determined using the subcaudal scale ratio

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($SC_R$ = number of subcaudal scales divided by the sum of ventral scales and subcaudal scales) is a more useful quantity (Kaiser et al., 2018b). This is, in part, because snake length measurements lack standardization.

One might think that the principle of taking length measurements on a snake is simple. After all a snake's body essentially has the same linear dimension as a ruler or a tape measure. However, snakes are irregularly cylindrical, not exactly linear and with a slightly bulging centre, and vertebral connective tissue is very elastic in a living snake (Ehrsam and Barker, 2022; Cundall et al., 2024). This makes the process of measuring a snake more challenging, and measurements can be influenced by known and unknown measurement errors. Furthermore, rarely are measurements on a museum specimen repeated often enough and by several measurers (Cundall et al., 2016), to estimate measurement error. The differences obtained in measurements of anesthetized and unanaesthetised snakes by different measurers led Cundall et al. (2016) to state that high levels of accuracy were unwarranted when reporting sizes of snakes, and that live snakes have no exact size. With this perspective in mind, snake length might always be considered an estimate, but knowing the size of any measurement error would allow for a more correct assessment of the role length plays in the ecology and evolution of a group of snakes. However, how does this realization about measurements of live snakes with malleable bodies translate to measurements on preserved snakes? After all, understanding what we do not yet know may sometimes be just as important as appreciating what we do know (Grant, 2023).

One particularly tricky problem involves snake specimens preserved in a three-dimensional coil (a shape similar to a metal spring; Fig. 1B, B'). If attempting to preserve a linear animal in a linear preparation, then the glassware used for specimen storage presents a clear length limitation. The option of two-dimensional coiling (as a flat, circular or elliptical coil, similar to a cinnamon roll; Fig. 1A, A') can be used to mitigate the body length problem for storage, but bigger animals would require specimen jars with impossibly wide necks or storage in large, unwieldy stainless-steel tanks (see Simmons, 2015 for a review of storage options). This is why in many herpetological collections one finds snakes preserved as three-dimensional coils, which allowed placement of larger snake specimens into relatively narrow-mouthed jars. The central goal of this study is to answer the question of whether it is ever possible to accurately measure a coiled, preserved snake, and what the associated errors might be – including the variation in measurements among different people.

A secondary problem related to snake measurements is how to best obtain measurements once one has determined which measurements to consider. With a preserved snake, 3D-coiling is clearly the most challenging shape in this regard. After removal of the specimen from its jar, what tools should be used, and how should the measurements be made? Unless this procedure is known (and recounted in a publication), it is impossible to replicate either methods or measurements and the reported results will in most cases preclude meaningful direct comparison. Our secondary goal therefore includes proposing a suitable methodological standard for measuring these coiled, preserved snakes to ensure that time and resources are not wasted by making measurements that cannot be broadly useful for comparative studies.

It is noteworthy that improved methods have been developed for measuring live snakes, such as the Confining-Box Method (Tsai et al., 2018) or the Tube-Restraint Method (Atkins and Larsen, 2020). Options for anesthetized snakes (Setser, 2007; Cundall et al., 2016) and two-dimensional preserved snakes from digital images (Kaiser et al., 2018a) have been published. Measurement of live snakes appears to be generally less of a concern, and a small body of work exists in which the effectiveness of these techniques was assessed (Penning et al., 2013; Cundall et al., 2016, 2024).

While the efforts to assess the accuracy (or inaccuracy!) of length measurements on live snakes in morphological research have been laudable, improvements have not yet been made for measuring coiled, preserved snakes. Snakes preserved in coils and twists are challenging to evaluate if they cannot be straightened against a ruler or tape measure. The exception to this is the tail, whose length is easier to measure, and with a higher degree of accuracy and reproducibility, no matter how the rest of the body is fixed, because the tail is short and more flexible and can almost always be straightened out along a ruler for a measurement accuracy of ± 1 mm (Kaiser et al., 2018b); this is not an option for the rigid body. Snake specimens are often not preserved in a linear preparation, or even in a round or oval, two-dimensional spiral. Since preservatives cause a snake's ordinarily flexible body to become fixed in position, researchers have few strategies to accurately determine snake body length. A common approach is to follow the entwined length of a snake's body with string, tubing, or wiring, which can then be laid out against a tape measure (Natusch and Shine, 2012).

This process is highly inconsistent, however, because the specific material used to take the length from the snake's body may introduce an indeterminate degree of error, and often there is no comment on whether the dorsal or ventral surface of the snake is measured: in their experiment, Natusch and Shine (2012) obtained both ventral and dorsal measurements of their specimens but did not relate these to each other – only to an earlier data set. Specimen size (small vs large) is also not a variable taken into consideration, and it is unknown whether a larger snake can be measured with lesser or greater accuracy than smaller ones.

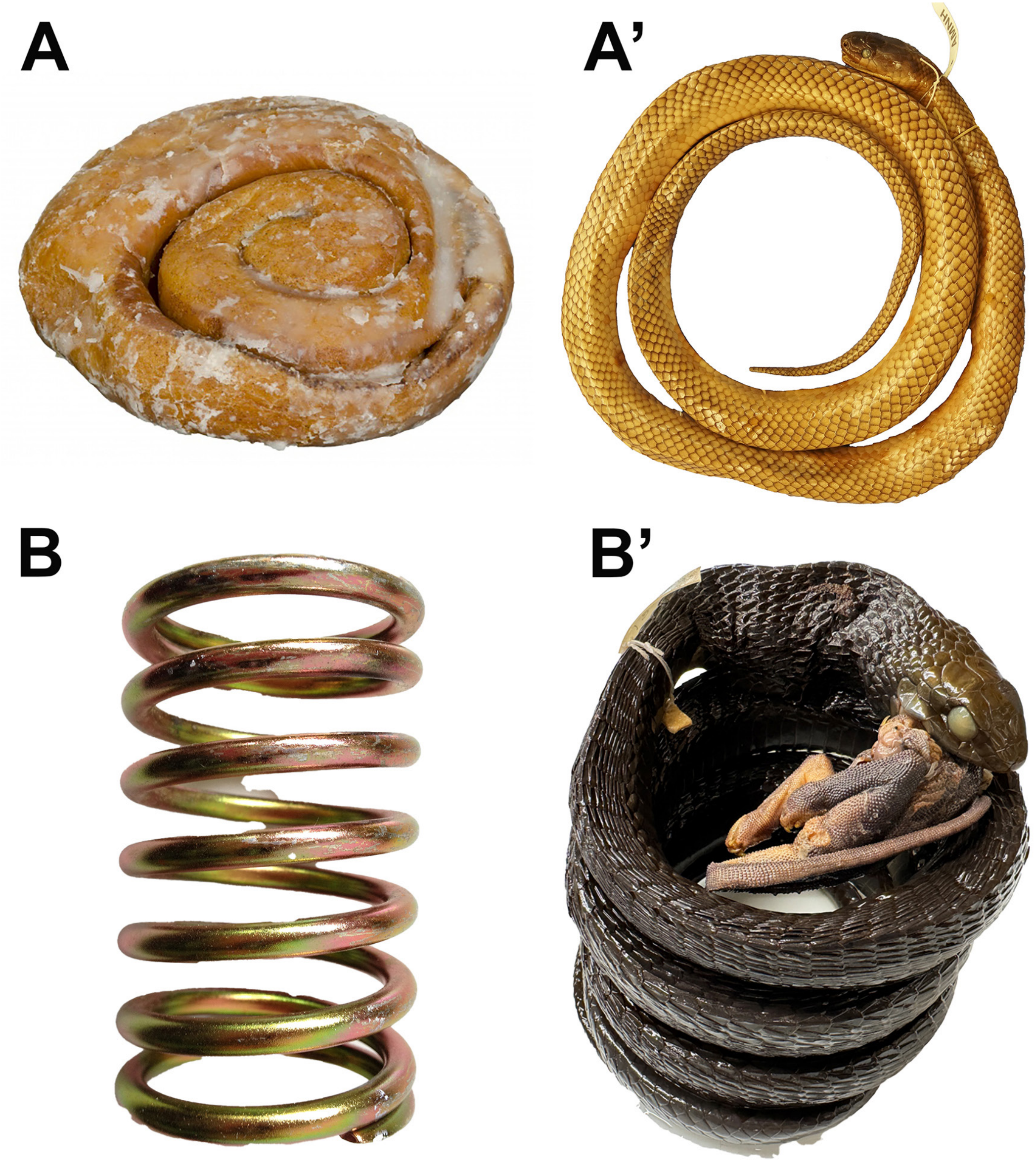


**Figure 1.** Non-linear preservation of snakes in museum collections. (A) The two-dimensional spiral (of a cinnamon roll), exemplified by (A') a specimen of *Stegonotus reticulatus* from Papua New Guinea (American Museum of Natural History, New York, USA, AMNH 73967). (B) The three-dimensional coil of an industrial spring, seen in (B') a preserved boomslang (*Dispholidus typus*) that was captured in the process of consuming a chameleon (Museum of Comparative Zoology, Cambridge, Massachusetts, USA, MCZ 18225).

It is evident from this brief review that measuring processes for coiled specimens must be better defined, but currently no standard exists. As a result, there are inconsistencies in methodology, and inaccurate values may be published in good faith without knowing the extent of any inaccuracies. This is a flaw that can greatly impact data interpretations. For example, an underestimation of size at sexual maturity could lead to less stringent conservation measures for a species because there is a lack of accurate information for size at sexual maturity (e.g., Manjarrez et al., 2013; Vishnu et al., 2021; Rose et al., 2022). This means an endangered species may be predicted to reproduce earlier in life than it actually does. The need for uniformity in measuring methodology is therefore pertinent, or at least there needs to be a better understanding of any errors that accompany measurements of preserved, coiled snakes.

Some research in this direction already exists. A comparison of measurement techniques on anesthetized, unanaesthetised, and preserved snakes ultimately showed that live snakes do not have an exact size (Cundall et al., 2016) and thus a range for each measurement should be provided. However, their recommendations lacked a direct evaluation of measurement methodology. Only by measuring as many variables as possible can general guidelines for how to measure snakes be established, especially coiled, preserved specimens.

We decided to investigate this relevant and potentially perplexing issue with a deliberately limited sample size to determine whether a larger study would be worth conducting. Cognizant of these limitations, we decided to present our analysis now to encourage others to examine the relationships between measuring materials, measurers, and the resulting measurement errors when measuring coiled, preserved snakes.

## Materials and Methods

Given that one key aspect of the difficulty with measuring museum specimens, particularly coiled, preserved snakes is the lack of a comprehensive, unified methodology, the following section is necessarily long and detailed. While we acknowledge that ours is not the only possible approach to this topic, we aimed to produce a small data set to determine the extent of the uncertainty these measurements might produce in research so that our data could serve as a departure point for additional work.

**General design considerations.** In order to create an experiment to properly assess the length of coiled, preserved snakes, we strived to account for as many unrelated variables as possible. To control for taxonomic bias, we selected two snakes of different sizes from a single species from the same location (see below). Smaller organisms may typically be more difficult to measure with high accuracy than larger ones since measurement errors constitute larger percentages of snake length. Both selected specimens were preserved as irregular coils, which we consider the most difficult shape to measure, rather than in a circular or U-shaped position. Irregular coils are a typical preservation style of historic museum specimens, for which measurements in life may not have been taken at the time of collection, or for which the reproducibility of a reported measurement is questionable.

Although it was clear the experiment would involve measuring the lengths of these snakes, the specific measurement, total body length (TTL) or snout–vent length (SVL), needed to be defined. The key difference between these two measurements is that SVL excludes tail length. While both are relevant, SVL is more important for providing information about a snake's life history, such as feeding ecology and sexual maturity. Furthermore, sexual size dimorphism is quite common in snakes (Madsen and Shine, 1993; Feldman and Meiri, 2013), and this can usually be determined by relative tail length (Clark, 1966; Shine, 1994). This means that any measurement of snake length is more valuable when TTL is broken up into SVL and tail length (TL). With SVL the favoured measurement for many research questions, it made the most sense to restrict our measurements to recording SVL. Lastly, we deliberately limited the time and scope of this experiment in order to avoid any changes to specimens or measurer attitudes during the course of the activity.

**Measurers.** Inaccuracies result from inconsistency and insufficient rigor in measurement techniques, especially when different researchers are involved. It was thus critical to have multiple individuals measure each specimen. Five individuals each repeatedly collected the entire set of measurements to provide a suitable sample size in the time available. The measurers included one individual without experience in snake morphology, two with limited training, and two professional snake researchers who had collectively measured over 1500 snakes. Of these five individuals, only the professional researchers were familiar with the measuring process while the remainder had no relevant experience. Each measurer used the same specimens, and individuals measured independently at times of their choosing to reduce the burden of their time commitment.

Only one set of the four measuring implements (see below) was used by the measurer group to limit potential irregularities if multiples of the materials were used.

**Measuring setup.** Workspace was provided in a laboratory at the Leibniz-Institut zur Analyse des Biodiversitätswandels, Museum Koenig, Bonn, Germany (ZFMK), and all measurements were taken on the same table. The room was well illuminated and ventilated and the table-top had enough space so that measurers could spread out the tools and specimens to conduct the work. A cloth tape measure was taped to the edge of the table so that lengths obtained (see below) could be converted to measurements.

After washing hands and following suitable safety procedures, two dissecting trays were set up for specimen placement out of their jars. While working with specimens, gloves were worn to protect measurers from coming into contact with preservative and to keep the specimens uncontaminated. Specimens were patted dry with clean paper towels to absorb any excess surface preservative and to allow less slippery, more confident handling. Moist paper towels were used to cover specimens when not in use.

**Specimens.** The two snake specimens were Amazon False Coralsnakes, *Oxyrhopus rhombifer* Duméril et al., 1854 (the larger ZFMK 102147, the smaller ZFMK 102151), collected in Centralia, Amapá State, Brazil, and preserved in 70% ethanol. These specimens were selected because they had significant coiling and were fair representations of a typical snake in terms of overall morphology and size (Fig. 2).

**Implements.** The type of material used by scientists to obtain a length measurement is generally one of convenience, sometimes even a random piece of string found during fieldwork or in a lab. However, the specific implement used can be critical to data accuracy. We tested four materials, including three braided polyester strings of different colour (white, orange, and pink) and flexible loudspeaker wire (Fig. 3). The strings varied slightly in thread thickness and were primarily chosen for their low elasticity and local availability. The white string had the thickest braid and was made from the softest polyester type among our strings, which displayed no amount of stiffness but picked up the most moisture during the measuring process. The orange string had a more compact weave with smaller fibres and some intrinsic stiffness. The pink string had the tightest weave with the smallest fibres and was also relatively stiff. Orange and pink strings picked up less moisture than the white string. A knot was tied on one end of each string to prevent fraying and to provide a consistent starting point for measuring. No knot was made in the wire, whose end provided a straightforward non-fraying starting point. String elasticity can affect the data collected for preserved snake lengths (Natusch and Shine, 2012), yet this is difficult to quantify and is frequently overlooked. By exploring the different materials, it could be decided whether or not implement material made a measuring difference and, if so, which material generated the least amount of error. For each implement, the tendency of over- and underestimation in comparison to an established reference value was calculated (see Objective Length below).

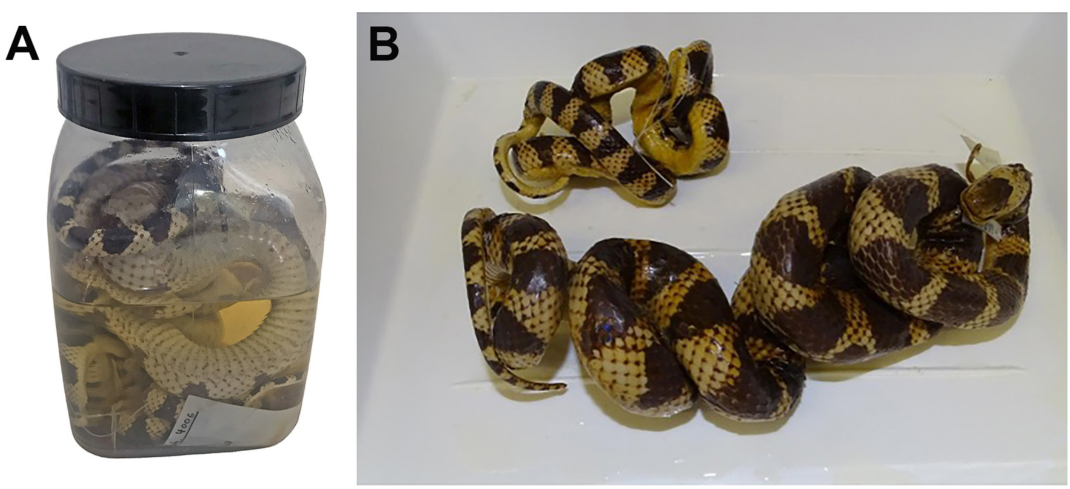


**Figure 2.** (A) The two specimens of *Oxyrhopus rhombifer* preserved together in their specimen jar. (B) The two snakes taken out of the jar and placed in a dissecting tray, showing ZFMK 102151 on the top and ZFMK 102147 on the bottom. While their coiling is different, both present the tricky task of determining their length measurement. Photos by Isabel Kaiser.

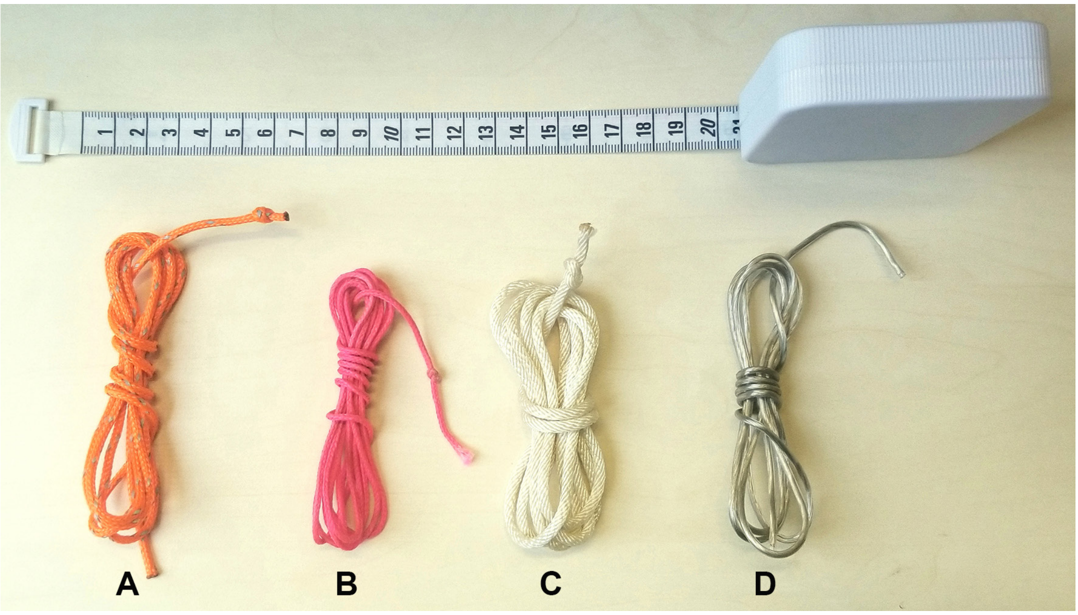


**Figure 3.** The four different measuring implements used for this experiment, with the tape measure shown for size. All three strings (orange, A; pink, B; white, C) were made of braided polyester of slightly different strengths (diameters) while the wire (D) is a stereo loudspeaker wire whose double wires were separated. Photo by Hinrich Kaiser.

**Measuring protocol.** The exact process of measuring was standardized by the measurers who were professional snake researchers (the second and third authors), who agreed on a common technique and demonstrated it to the untrained measurers. Each measurer was required to align the knot of the implement (or, in the case of the wire, just the end of the implement) with the snout of the snake and measure by holding the implement tightly against the body of the snake in the required position (dorsal or ventral; see below), and without sliding the implement work towards the tail (Fig. 4). Once the end of the SVL measurement was reached at the posterior edge of the cloacal plate, the implement would be pinched with two fingers at the measurement's end point and lined up along the tape measure to be measured to the nearest mm.

Two different types of SVL measurements can be taken on the body of a snake, the dorsal measurement, which follows the vertebral scales on the topside of a snake, and the ventral measurement, which follows the gastrosteges on the belly of the snake. Just as Natusch and Shine (2012), we decided to measure both ways in order to be able to make direct comparisons of these two measurements, with particular attention to the accuracy each would produce. Each measurer therefore needed to take a total of 48 measurements, including replicates. These were 12 for each of the four implements (six for each snake, three dorsal and three ventral replicates). The order in which measurements were taken was not regulated and two measurers could work at the same time, one per specimen. Each measurer would choose one of the implements and record dorsal and ventral SVL. Then, switching specimens, a measurer could continue collecting measurements for that specific implement type. Once all 12 measurements for the given implement were collected, participants would repeat the process for the remaining implements. The process for measurers to collect the 48 lengths took 2–3 h.

**Objective lengths.** In order to generate a stand-in for the true, yet potentially unknowable lengths of these snakes, we calculated Objective Length (OL), defined as the average dorsal or ventral measurement across all measurements taken with all implements by every measurer. This variable provided a benchmark against which the different measurements were evaluated. The error in all measurer-produced measurements was defined as the degree of deviation from OL, calculated by dividing the difference between OL and a measurement by OL and expressing it as a percentage.

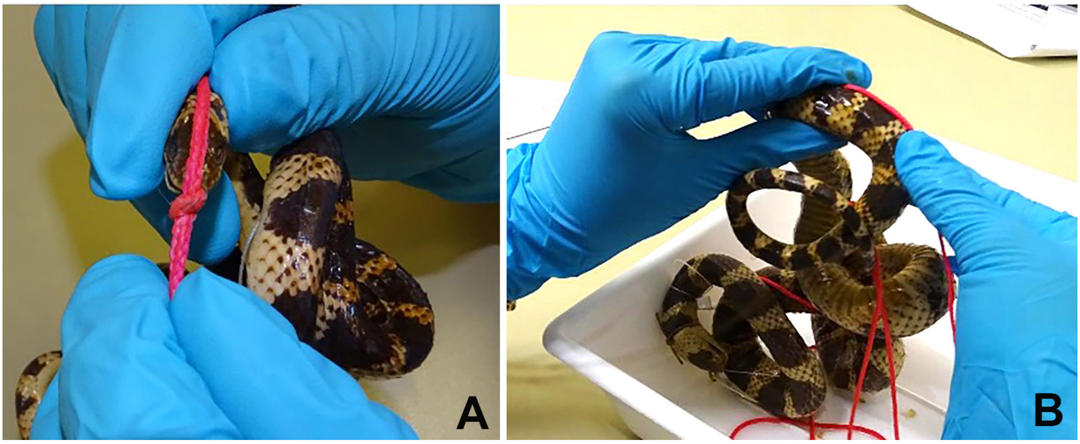


**Figure 4.** How we measured two *Oxyrhopus rhombifer* in this experiment. (A) The knot is aligned with the tip of the snake's snout. (B) The measurer presses the string against the body of the snake and moves along the body towards the tail while maintaining the string in a position close to the midline of the snake's body. This image shows the measurer measuring along the dorsal surface. Photos by Isabel Kaiser.

## Results

**Qualitative observations.** Ventral length was measured to be substantially shorter than dorsal length in all cases. The pink string was found to be the stretchiest, as evident from the larger lengths recorded compared to the other strings or the wire. Conversely, the metal wire had the least flexibility and tended to provide the shortest lengths. Handling of the metal wire caused some issues due to its stiffness and the related difficulty to keep it aligned against the slippery, smooth surface of the preserved snakes.

The coiled shape of the two specimens differed somewhat, with the smaller snake preserved in a less tidy coil than the larger snake. About three-quarters along the body of the larger snake was a fracture in the vertebral column, which made that section of its body softer and slightly more difficult to measure consistently. Both snakes shed some scales, but this was anticipated due to the frequent handling.

**Dorsal vs. ventral measurements.** The data revealed a difference between dorsal and ventral values for OL, with dorsal OL always longer than ventral OL. The OL values were 983 mm and 787 mm, respectively, for the large snake and 573 mm and 458 mm, respectively for the small snake (Fig. 5).

Irrespective of measurer or implement, there was a difference between dorsal and ventral length measurements, with a 196-mm range for the larger specimen and a 115-mm range for the smaller one, with the dorsal measurements larger than ventral ones. Rounded to the nearest whole percent, this difference is 20% for both measurements when compared with the dorsal measurement and 25% when compared with the ventral measurement.

**Small vs. large snake.** Based on the OL values and the differences in dorsal and ventral measurements, there was no effect of snake size on the measurement process. The percentage differences between dorsal and ventral measurements in the large snake were the same as in the small snake. As a consequence, the following calculations group the values for the large and small snake lengths and dorsal and ventral lengths to increase sample size, since there is no difference in the measurement process of large and small snakes.

**Implements.** In terms of accuracy, the pink string always overestimated lengths (by 1.8% on average), whereas the wire gave the largest underestimation (2.2% on average). The remaining two implements had mixed over- and underestimations, and although the white string had a low overestimation of 1.0%, the orange string had the least average estimation error of only a 0.2% underestimation (Fig. 5).

When looking at consistency, a similar conclusion was reached. The range in percentage error was smallest for the pink string (1.5–2.0% overestimation, a spread of 0.5%). The white string had the largest error spread of 1.1%, while the wire and orange string had spreads of 1.0% and 0.8%, respectively.

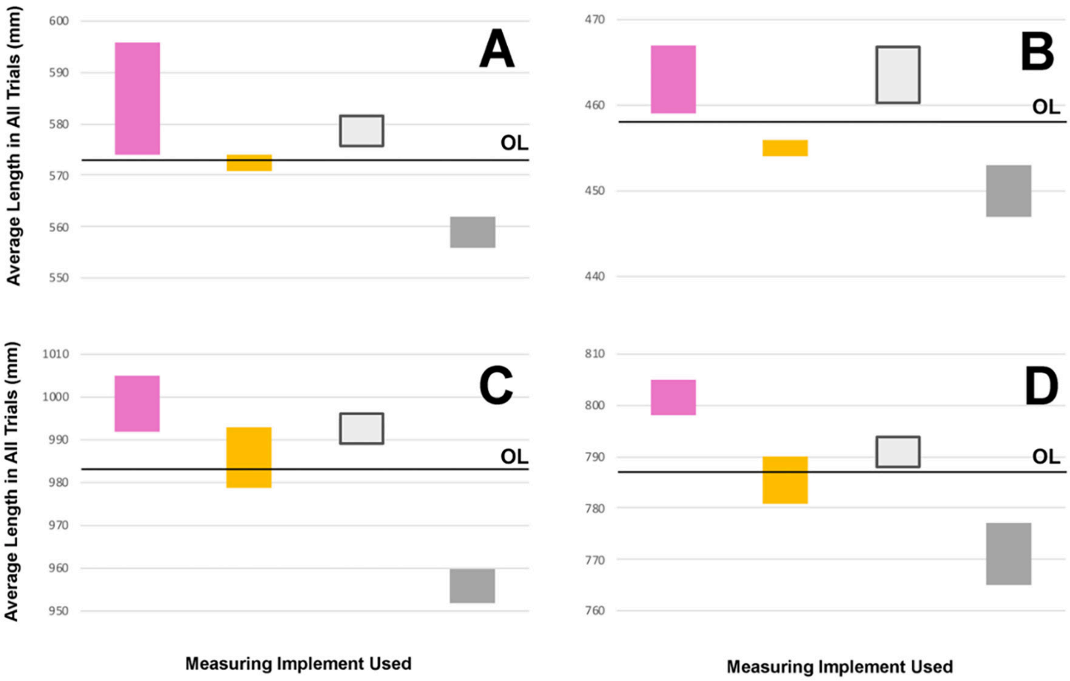


**Figure 5.** Graphic representations of measurement averages (in mm SVL) from snake measuring trials of *Oxyrhopus rhombifer*, in which five measurers measured two snakes of different lengths with the use of four qualitatively distinct implements. Implements included pink, orange, and white braided polyester strings (with their colours indicated on the respective bars in the graph), as well as loudspeaker wire (dark grey). In each graph, bar height represents the range of average measurements for the three times each measurer measured each snake. The black line in each graph is the objective length (OL; the overall average across all implements and measurers). (A) Dorsal lengths of the smaller specimen. (B) Ventral lengths of the smaller specimen. (C) Dorsal lengths of the larger specimen. (D) Dorsal lengths of the larger specimen.

**Measurers.** In order to assess whether or not individual measurers impacted the measuring process, their accuracy and consistency were investigated. For this purpose, only the values for the orange string were used since it was found to be the best-performing implement of the analysis. Overall, measurer accuracy (Fig. 6) ranged from an error of only 0.1% above OL (Measurer E) to 2.2% above OL (Measurer A). Measurers A and B, with doctoral degrees and experience measuring coiled, preserved snakes, had the highest errors, with a 2.2% overestimate and a 1.9% underestimate, respectively.

Accuracy, however, did not necessarily translate into consistency. Measurers A and C were the most and least consistent, with error spreads of 3.3 and 6.5%, respectively. Whereas Measurer A was an experienced measurer, the second experienced measurer (Measurer B) was not the second-most accurate measurer (error spread of 3.8%), becoming eclipsed by the inexperienced Measurer D (error spread of 3.7%).

There was some variation between different trials when comparing all five measurers and how they measured the small vs. large snake. Specifically, the highest value recorded for the dorsal SVL of the small snake was 683 mm (Measurer C), whereas the smallest was 532 (Measurer D), a difference of 151 mm (22% of the larger value and 28% of the smaller value). For the dorsal SVL of the large snake, the greatest value was 1034 mm (Measurer A) and the smallest was 914 mm (Measurer D), a difference of 120 mm (12% of the larger value and 13% of the smaller value). Thus, there was a difference between measurers when it came to the larger and smaller snake, even though this did not appear when overall averages were considered. The measurement error in smaller snakes (above 20%) has potentially more influence on an investigation than that in larger snakes (near 10%).

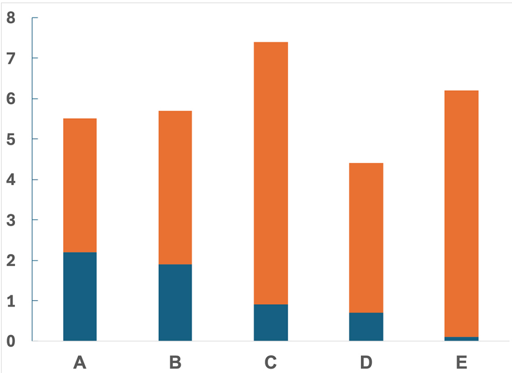


**Figure 6.** Accuracy and consistency (in %) in measurements of two *Oxyrhopus rhombifer* for five measurers (A–E). Greater accuracy (indicated by a smaller blue bar) should ideally pair with greater consistency (a smaller orange bar), and the lowest stack (D) indicates the best performance among our measurers.

## Discussion

**What we know about lengths.** The intent of this preliminary experiment was to collect just enough data to evaluate the ability (or inability) of scientists to obtain accurate measurements from coiled, preserved snakes. Although the subject has not been given much attention, the data collection revealed significant information about the precision of these processes. We quickly recognized that measurements varied substantially, as evidenced by their wide ranges (Appendix). These differences showed that it may be impossible to determine the true length of a preserved, coiled snake, just as Cundall et al. (2016) concluded for live snakes.

Objective lengths (OLs) were developed as reference measurements to evaluate implements and measurers and to be the general basis of the analysis. As "averages of averages," we considered these values an optimal experimental representation of each snake's length. Taking the averages from the measurers' collective 240 measurements resulted in two OLs for each snake, one for the dorsal and one for the ventral measurement.

Along with the raw data, the OLs indicated there was an evident difference between measuring a snake along the dorsum compared to the venter. It was sensible to further examine this, as ventral and dorsal lengths have been considered equivalent in a majority of publications. Mistakes related to this can be seen in the study by Natusch and Shine (2012), who remeasured museum specimens along the venter and compared their results to previously recorded measurements. They reported an error range of 2–56% below current measurements, an average error of 22%. This was explored in their study by taking the difference between dorsal and ventral measurement for each snake (using OLs) and obtaining the average percent difference between dorsum and venter (20–25%). This suggests that the older measurements of the museum specimens used by Natusch and Shine may have been taken dorsally, since their average error value of 22% falls into the range of differences we found in our data. Perhaps they had earlier assumed that dorsal and ventral measurement were equal, meaning it was unnecessary to specify whether an SVL measurement was from the dorsal or ventral part of the snake. If snakes are preserved in a less twisted manner, these two lengths may be more similar given that each twist increases the measurement on the dorsal side by enlarging the space between vertebrae and decreases it along the more contractile ventral side. Our data confirm that a distinction between dorsal and ventral measurements must be made and reported in the methodology used for measuring the lengths of preserved snakes.

The Natusch and Shine study referenced another report on average SVL for the python *Morelia viridis*, with average lengths reported as 84 cm and 99 cm in males and females, respectively (Shine and Slip, 1990). However, the measurement process was not described in that paper, and it is unknown whether these values were gathered from the dorsum or venter. When Natusch and Shine (2012) remeasured these specimens, their average values were 114 mm for males and 123 mm for females. Applying the value of 25% for the difference between dorsal and ventral length, it can be seen that the differences in the *Morelia* specimens are 26% for males and 20% for females when considering the longer measurement, indicating that these authors may simply have measured along the venter the first time (the shorter measurement) and the dorsum the second time (the longer measurement).

The reason for involving two different specimens in this experiment was to determine if specimen size was a factor that affected measurement accuracy. It was speculated that the smaller snake might be more difficult to measure accurately, since a measurement error would have a relatively greater effect. This was not the case on average, as results from the dorsal and ventral comparison revealed the exact same percentage difference (20 and 25%, respectively), meaning snake size was not a detriment to accuracy. But we did find a larger maximum difference between measurers on the smaller snake than on the larger snake, indicating that, beyond averages, there may be individual measurer difficulties with obtaining data from smaller snakes.

As stated at the beginning of this paper, there is no regulation regarding the type of implement researchers should use to measure the SVL of snakes. To optimize the type of implement was a focus of this paper, by evaluating some common available materials. After calculating the averages and determining the tendency of each implement to overestimate or underestimate snake length (in comparison to OL), the differences between materials became clear. Some problems were already uncovered during the experiment, as outlined in the qualitative observations, but data processing helped quantify it. The wire was the least effective, averaging an underestimation of 2.2%. The most reliable implement was the orange string, underestimating the OL by only 0.2% and providing results that were both the most consistent and most accurate.

It was necessary to involve multiple measurers in order to strengthen the accuracy of the experiment and determine if prior experience in the process of measuring impacted the results. Measurer A and B had experience measuring coiled, preserved snakes, but it appears this had no significant impact in the investigation. In fact, Measurer A was least accurate, measuring on average 2.2% above OL. However, this measurer was simultaneously the most consistent participant with the smallest error spread, ranging from 0.7–4.0% overestimation. As shown by this single individual, while experience does not necessarily translate into the best measurement, as others who were inexperienced could obtain more accurate measurements, it may make the measurement more consistent.

**Limitations.** Although this investigation identified key problems with the current assumptions of measuring coiled, preserved snakes and provided conclusive evidence about obtaining an accurate SVL measurement, there are areas for improvement. With regard to the conclusion of differing dorsal and ventral measurements, it cannot be assumed that the same may hold for all coiled, preserved snakes. The coiling of a snake involves the bending of the spine, which makes the underside of a snake appear shorter than the stretched topside. If measured snakes were to be preserved in a different manner, this may change the result that ventral length is consistently shorter than dorsal length.

The use of only two specimens in this study was clearly limiting. With access to the Museum Koenig, two adequate specimens were found to be used in this experiment and to limit the number of variables in the analysis. More consideration could go into this choice, however, as it eventually became clear that the larger specimen had a slight defect in its condition (likely a broken spine). Also, despite finding no influence of snake size, this may have been due to an insufficient difference in snake size. Perhaps if a much larger snake were to be included, or if snakes of different species were added, different outcomes might be possible. However, given that all snakes are essentially cylindrical in shape, such differences are not predicted to be large and likely would not affect the overall conclusions.

Other limitations existed in the access to implement materials. The decision on the four materials was partially based on the type of implements the experienced measurers had used (the white and pink strings), in addition to some items conveniently found in a local hardware store (orange string and wire). It also must be recognized that the specifics of each material (e.g., thread weight and braiding technique on the strings) or "implement handling" (i.e., whether a measurer displayed a greater acuity with one implement over another) were not assessed. Further testing is therefore advisable (e.g., elasticity tests, handling trials). We also did not consider whether the order in which implements were used could have an impact on measurements. We did not stipulate a specific sequence for implement use, so measurers may have used them in an arbitrary order.

Convenience also came into play when recruiting individuals to participate in the study. There were limited opportunities to connect with individuals at the museum who could participate due to COVID restrictions and research schedules. It was also impossible to account for the variability in the physical and mental condition on of each individual measurer at the time measurements were taken, including level of hand-to-eye coordination, general health, condition on the day of data collection, and diverse personal backgrounds. We also did not attempt to collect data on any potential "measurer fatigue," given that each individual may have been working on their measurements for 2–3 h.

In recognition of these limitations, we propose that future examination of this problem heed the following recommendations: (1) Experimental design should include a series of at least ten snakes of different sizes in the same species to reduce biological variation.

(2) At least ten measurers should be involved to further increase the sample size. (3) Measurers should be asked to complete three replicate measurements on different days (i.e., they complete the entire suite of measurements on different days) to further evaluate differences between measurers. (4) In order to standardize the process and eliminate additional variables a specific order for measurements should be established and 5-min breaks with short activities (e.g., walking around the room) should be instituted to reduce the effect of fatigue. We envision that this experimental design could be part of any herpetology or even general biology course so that data collection is distributed across a variety of skill levels.

## Conclusions

Our results show that even measuring only two coiled, preserved snakes is a tricky process, prone to errors based on the measured surface (dorsal vs. ventral), implement choice (strings vs. wire), and individual measurers. While there was no overall difference between measuring long or short snakes, we found that ventral measurements of SVL differed from dorsal measurements by 25%, which is a problem that involves a large proportion of a snake's body length that had heretofore not been fully recognized. There is indeed a difference in the selection of measuring implement, with the orange braided polyester string performing best; the specific choice of measuring implement should therefore always be listed in detail in a methods section. There are differences in the ability of measurers to make accurate and consistent measurements, but these are not related to the research experience of a measurer. Measurer accuracy was quite high (always < 4% relative to OL), and the spread of measurement error was at most just > 6%. Whereas it is possible to know the extent of errors when measuring snakes using a variety of implements or measurers, it is really not possible to accurately determine the real length of a coiled, preserved snake. As we strive for greater accuracy in scientific processes, a study like ours, its limitations notwithstanding, shows that there are many opportunities to improve, test, and standardize even methods that appear simple at first glance. We encourage others to continue this line of research by including additional species and materials, so that we can create a proper standardized best practice. At least at this point we can say that we now know what we don't know.

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**Appendix.** Average SVL (to the nearest mm) by implement material (pink: pink string; orange: orange string; white: braided polyester string; grey: loudspeaker wire) and snake size. Objective length (OL) is calculated as the mean of each measurement column.

| Colour and Trial No. | Small Snake | | Large Snake | |
|---|---|---|---|---|
| | Dorsal | Ventral | Dorsal | Ventral |
| pink 1 | 596 | 459 | 1005 | 798 |
| pink 2 | 574 | 467 | 992 | 805 |
| pink 3 | 578 | 464 | 998 | 805 |
| orange 1 | 574 | 456 | 979 | 781 |
| orange 2 | 571 | 455 | 979 | 790 |
| orange 3 | 574 | 454 | 993 | 782 |
| white 1 | 582 | 467 | 994 | 793 |
| white 2 | 576 | 466 | 995 | 788 |
| white 3 | 577 | 460 | 989 | 788 |
| metal 1 | 562 | 450 | 960 | 765 |
| metal 2 | 561 | 447 | 957 | 775 |
| metal 3 | 556 | 453 | 952 | 777 |
| OL (mean) | 573 | 458 | 983 | 787 |