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Editorial

EDITORIAL: Asymmetry Indexes, Behavioral Instability and the Characterization of Behavioral Patterns

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A change in a behavior is often the first and fast reaction to an environmental (external) or physiological (internal) *stimulus* that animals (and plants) are exposed to. Behavioral responses are thus important for the ability of organisms to survive and reproduce in constantly changing environments. Differences between individuals in behavior are due to differences in the environmental *stimuli* that they are experiencing or have experienced and their interactions with the genetic profile of the individuals, which in turn can affect the way in which individuals experience the environment.

Several behavioral studies have been conducted disregarding the individuality of the behavioral phenotypes (sometimes referred to as personalities) of animals. This can reduce the reproducibility of the results and lead to the incorrect conclusion that behavioral changes are random processes. An insufficient understanding of behavioral changes is also caused by the unpredictability of animal behavior, i.e., behavioral instability. Behavioral instability is subsequently a behavioral component that should be incorporated into behavioral studies.

Behavioral studies typically describe behavioral traits in (i) a qualitative way (presence/absence); (ii) a semiquantitative way (minor, medium, and maximum expression of a certain trait); or (iii) fully quantify the behavior by measuring, for example, the speed and the distance travelled by an individual or by estimating the frequency at which a given behavior is occurring during a specified time interval. The time interval is sometimes randomly chosen, and in this way the interdependence of the behaviors is neglected.

There is an urgent need for more quantitative studies covering large periods of observations, and there is also a need for a standardized statistical pipeline and ways of presenting behavioral patterns, in order to make different studies comparable. Statistical procedures should include methods that avoid the reduction of the variation of a given parameter. This can be achieved by using suitable statistical transformations, in order to make the distributions of the data normally distributed and to homogenize the variances as much as possible (assumptions required by several parametric tests). Such quantitative studies will generate important information about the variability (due to different personality of the individuals) and/or the predictability of behavioral traits that are currently often ascribed to inconvenient noise, i.e., variation of behavioral traits is often considered random noise and the extreme values are typically considered outliers and therefore removed.

For the above-mentioned reasons, we propose a change of research direction that will complement the classical approaches so far used in behavioral studies. We propose a holistic concept of behavioral instability that comprehends a series of parameters that describe the variation of a distribution using modified indices that are traditionally used to investigate developmental instability (like fluctuating asymmetry, asymmetry index, and directional asymmetry).

Behavioral instability can be utilised for described behavioral traits like, for example, changes in directions during a movement, or the time spent on a certain activity, but can also be applied to physiological measures and to molecular and cellular mechanisms (if they are quantifiable e.g., in terms of duration and/or intensity of a process).

Behavioral instability can be described in terms of time, i.e., the distribution of the time-intervals in which a given behavior occurs. Moreover, it can be described in terms of spatial distributions, i.e., how individuals are distributed in a population/patch, or can be described in terms of binary distribution (Bernoulli distribution) where the frequency of two binary *status* of a behavior can be quantified.

When distributions of a trait are obtained from investigations, the four moments of distributions (mean, variance, skewness, and kurtosis) and some modified measurements (depending on the kind of distribution and its characteristics) can be utilised for describing the behavioral characteristics. In particular, variance, skewness, and kurtosis can provide accurate estimates of the probability that a given behavior will occur and with which intensity. In addition, the analysis of the distribution can give indications about the heterogeneity of the individuals and can allow an estimation of the number of different personalities present in a group of individuals. This analysis, called "admixture analysis", can provide important information about the population's capacity to adapt in a plastic way through behavioral means. The presence of different personalities in a population is comparable to genetic variability in the population, and hence higher variability can be translated into higher capacity or higher resilience of the population versus sudden and unpredictable environmental changes.

The individual personality can be shown by behavioral reaction norms, and the concept of behavioral instability can be applied. This method can provide researchers with a relatively unbiased assessment of behavioral responses, thus enabling the reproducibility of results.

The fact that behavioral instability does not need bilateral traits to estimate instability is clearly expanding its scope for different applications.

Several previous behavioral studies have been conducted disregarding the personalities of the animals. This approach has considerably reduced the reproducibility of the results, thus causing the misapprehension of the conclusion that behavioral changes are random processes.

The novel concept of behavioral instability presents new perspectives in the field of quantitative genetics and in associated fields. Studying behavioral traits using the suggested approaches could have significant potential in evolutionary studies to evaluate, e.g., the plasticity and genotypic difference between individuals and in psychological human studies.

Several techniques such as proteomic tools and next-generation sequencing have been applied with the attempt to discover the molecular and cellular mechanisms of phenotypic plasticity and canalization. Similarly, several genome-wide association studies are trying to associate genetic variation with variation in behavioral traits. These studies will clearly be beneficial for future research given the potential to associate the concept of behavioral instability with genetic variation in order to estimate the heritability of the different aspects of behavioral instability.