The Coordination between the Direction of Progression and Body Orientation in Normal, Alcohol- and Cocaine Treated Fruit Flies

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Background

In studying the gene/brain/behavior relationship, detailed quantitative descriptions of the behavior of the animal's behavior is required. Especially important are descriptions of behavior in terms of the dynamics of the coordination between the direction of progression of the animal and the animal’s body orientation, for these provide fundamental insight into motor control. For mouse locomotor behavior these measures have been well-developed, yet such descriptions are still sparse for Drosophila, the model system of choice for behavior geneticists. Here we present a dynamic description of the coordination between these two variables, as they change throughout different temporal segments of the motion.

Methodology/Principal Findings

Using intrinsic statistical and geometrical properties of a fly’s movement, we have uncovered six fundamental modes of motion related to translation and rotation of a fly’s body. Assignment of the frame-by-frame instantaneous movement into one of the six modes, followed by clustering and algorithmic classification, allows us to quantify the behavior in terms of the proportions and dynamic sequencing of each mode. The analysis uncovered that for normal flies, the angle between the direction the animal walks and the direction it faces is quite small. Under the influence of alcohol and cocaine, however, the angular interval between these two variables increases.

Conclusions/Significance

For several decades the representation of movement, indispensable for studying the interface between genes brain and behavior, suffered from the use of ad hoc building blocks such as “behavior patterns” or “response categories” assumed to be performed unblock by the whole organism, one at a time. The ethological and psychological schools using such representations, were based on expert (indeed, subjective) decisions. In the vast majority these alleged building blocks could not be shown to have a physiological reality in the brain; the school using them has been described as the “school of immaculate perception”. These ad hoc units were used as “black boxes” and their variable kinematic content has been disregarded. Disregarding the coordination between translation and rotation, for example, sidestepped the problem of coordination, which is at the heart of the brain/behavior interface.

The huge progress in tracking and storing technology allowed the recording of continuous kinematic variables such as the location and orientation of the organism, thus bringing about a most significant change, allowing, for the first time, the study of coordination between these variables in long stretches of behavior lasting hours or even days. This time scale is necessary for the study of e.g., drug effects on behavior, or for the phenotyping of genetic mutants exploratory and locomotor behavior. The pioneers utilizing this technology use, however, the continuous data they obtain to reinstate the static old time behavior patterns, this time based on explicit criteria, but ignoring again their variable content. These patterns are useful for scoring the behavior of closely related phenotypes, or animal models and their corresponding wild types, or males and females. They are useless, however, for comparing organisms across remotely related taxonomic groups or across apparently very different drug effects on behavior.

What signifies the present study is that it not only tracks kinematic variables continuously, but also sticks to a dynamic representation of their coordination all the way. In other words, both initial and final results are formulated in a dynamic fashion, the building blocks of behavior are segmented on the basis of their intrinsic dynamics, and the results summarize their variable kinematic content. We select 3 apparently very different behavioral preparations – that of intact flies, of flies with alcohol and of flies with cocaine – and show that they lie on a continuum:

1. Examination of the dynamic management of the angular interval between the direction of translation of a fly and the direction it faces yields 6 modes of coordination (Figure 1). These modes are intrinsic. They reflect the actual dynamics of locomotor behavior and are not superimposed from without.

2. The 3 groups differ in the dynamics of management of the angular interval between these two variables. In intact flies the angular interval is small and short lived (high gain), with alcohol it increases (smaller gain) and with cocaine it is vastly increased (smallest gain and hence large misalignment between the direction the animal walks and the direction it faces.

Description of the six modes

Fixed-Front-on-Straight-Path (Figure 1a). This is one of the two most common modes of untreated movement. Flies usually move along relatively straight paths over long distances with close alignment of the body axis and the direction of progression. Net sideward/backward translation episodes are very short in duration and path length in untreated flies (~0.12 s and no more than 5 mm long).

Rotation-on-Straight-Path (Figure 1b). At the start of this mode, the fly's body is typically misaligned with the direction of progression. In the course of the mode, the body rotates toward the direction of progression, typically converging to the same direction. This rotation is superimposed on forward, sideways, or backward progression, all performed along a relatively straight path traced by the center of the fly's body.

Fixated-Front-on-Curved-Path (Figure 1c). The fly maintains a more-or-less fixed orientation while moving on a curved path. We use the term fixated rather than fixed to highlight the active, compensatory fixation, as opposed to the fixed orientation of a fly whose body axis is aligned with the direction of progression on a straight path. This mode is typically performed during a short intermediate state between Fixed-Front-on-Straight-Path and Rotation-on-Curved-Path modes.

Rotation-on-Curved-Path (Figure 1d). In the course of this mode, the body of a fly typically rotates toward the direction of progression, the rotation and direction of displacement sign being the same. This is the second of the two most common modes in untreated fly locomotor behavior.

Lingering (Figure 1e). Lingering episodes include at least one arrest and may also include small below-threshold displacements. Lingering duration ranges between short interruptions in movement and long (presumably sleeping) episodes.

Rotation-in-place (Figure 1f). Rotation of the fly's body axis around a vertical axis located at the fly's body center is mostly performed in untreated flies between two lingering episodes.

While the results are presented in the context of fly behavior, the implications relate to any dynamic description of movement in any organism having a rigid body with bilateral symmetry.

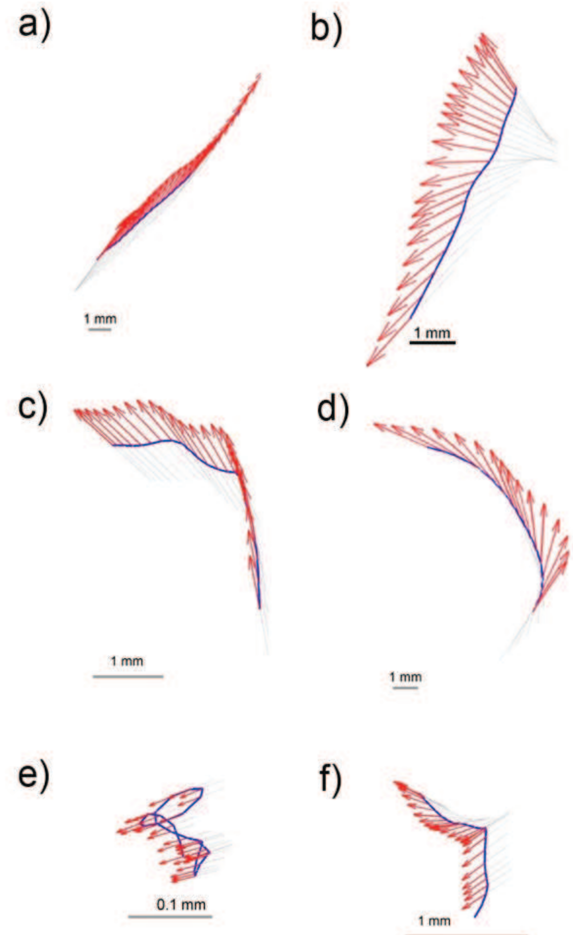

Figure 1. Examples of the six elementary modes of fly locomotor behavior. a) Fixed-front-on- Straight-Path ('A'), b) Rotation-on-Straight-Path ('B'), c) Fixated-Front-on-Curved-Path ('C'), d) Rotation-on-Curved-Path ('D'), e) Lingering ('L') and f) Rotation-in-place ('R'). Quiver plots: blue lines represent the path traced by the fly's centre. The arrows represent the orientation of the fly's body axis.

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References

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