Methods Developed for Ocean Data Applied to Study of Fruit Flies and Free Will

International study describes measurements of spontaneity in Drosophila

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A new study coauthored by researchers at Scripps Institution of Oceanography at UC San Diego suggests even the humble fruit fly can behave spontaneously, rather than merely in reaction to external stimuli.

In the groundbreaking study, the flight paths of flies in a completely featureless environment were shown to be neither random nor predictable, but followed a complicated fractal pattern generated within the fly's brain. Thus the scientists say free will and true spontaneity could exist, at least in fruit flies. The study appears in the May 16 issue of the open-access journal *PLoS (Public Library of Science) One*.

The power to willfully behave differently in identical settings has recently been questioned by neuroscientists.

"Animals, especially insects, are usually seen as very complex robots which only respond to external stimuli," said senior author Björn Brembs from the Free University Berlin. "They are said to be input-output devices. When scientists observe animals responding differently even to the same external stimuli, they attribute this variability to random errors in a complex brain."

Using a combination of automated behavior recording and mathematical analyses, the international team of researchers showed for the first time that such variability cannot be due to simple random events but generated spontaneously and non-randomly by the brain.

"If even flies show the capacity for spontaneity, can we really assume it is missing in humans?" Brembs wonders.

The results of the new study caught computer scientist and lead author Alexander Maye from the University of Hamburg by surprise: "I would have never guessed that simple flies who keep bouncing off the same window otherwise have the capacity for nonrandom spontaneity if given the chance."

Previous studies have shown that in nature, flies do not buzz about aimlessly but forage according to a sophisticated search strategy (this is how they find our wine glasses). The new research now suggests that such strategies can arise spontaneously rather than being induced by spatial cues.

The researchers tethered fruit flies (*Drosophila melanogaster*) in completely uniform white surroundings and recorded their turning behavior. In this setup, the flies did not receive any visual cues from the environment and since they were fixed in space, their turning attempts had no effect.

Thus lacking any input, if the flies were input-output devices, their behavior should resemble random noise, similar to a radio tuned between stations. However, the analysis showed that the temporal structure of fly

behavior is very different from random noise. The researchers then tested a plethora of increasingly complex stochastic computer models, all of which failed to adequately model fly behavior.

Only after the team analyzed the fly behavior with methods developed by co-authors George Sugihara and Chih-hao Hsieh of Scripps Institution of Oceanography at UC San Diego did they realize the origin of the fly's peculiar spontaneity. Using the so-called "S-Map Procedure," the researchers detected a non-linear signature in the fly behavior. Such a signature can only be found in systems whose indeterminate behavior is not due to noise but originates in their design.

"This signature indicates that there is a function in the fly brain which evolved to generate spontaneous variations in the behavior," Brembs said. "This function appears to be common to many other animals and could form the biological foundation for what we experience as free will."

"Our subjective notion of 'free will' is essentially an oxymoron: we would not consider it 'will' if it were completely random and we would not consider it 'free' if it were entirely determined," said Brembs. "Nobody would attribute any responsibility to our action if it had happened entirely coincidentally. On the other hand, if our action was completely determined by external factors such that there was no alternative, again the person would not be held responsible. So if there is anything remotely close to free will, it must exist somewhere between chance and necessity-which is exactly where fly behavior comes to lie."

"Our results address the middle ground between simple determinism and randomness that is currently not well understood or characterized," said Sugihara. "We speculate that if free will exists, it is in this middle ground."

"The question of whether or not we have free will appears to be posed the wrong way," said Brembs. "Instead, if we ask, 'where between chance and necessity are we located?' one finds that this is precisely where humans and animals differ."

Humans may not have free will in the philosophical sense, but even flies have a number of behavioral options between which they need to decide between. Humans are less determined than flies and possess even more options. With this small reformulation, the topic of free will becomes a new biological research area of studying spontaneous behavior and can thus be discerned from the philosophical question.

Research on this topic will likely continue for years: "We have only made the first step. We have shown that even a fly brain possesses a function which makes it easier to imagine a brain that creates the impression of free will," said Brembs.

It remains to be shown how this faculty is implemented in the brain and how it is used to create the subjective experience in humans of being able to do what one will. The next step in this direction will be to localize and understand the brain circuits responsible for the spontaneous behavior in flies. Results from this step could lead directly to the development of robots with the capacity for spontaneous nonrandom behavior.

Eventually this research may help treat disorders that lead to compromised spontaneous behavioral variability in humans such as depression, schizophrenia or obsessive compulsive disorder.

Note: Multimedia elements related to this paper are available at http://brembs.net/spontaneous.

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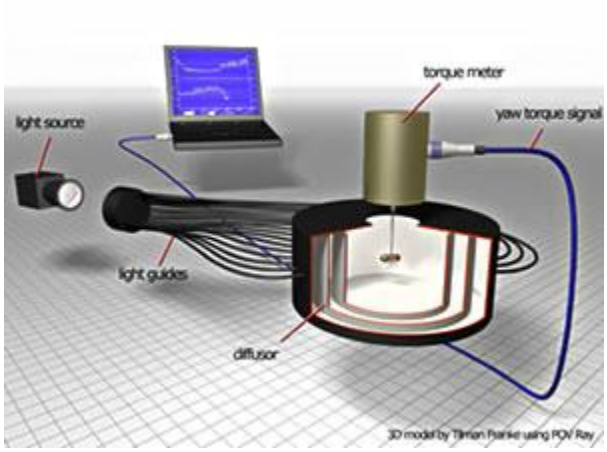
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3D model by Tilman Piehler using POV Ray