20 Gravitational Zoology: How Animals Use and Cope with Gravity

Ralf H. Anken and Hinrich Rahmann

Since the dawn of life on Earth some four billions of years ago, gravity has been a more or less stable environmental factor thus influencing the phylogenetic development of all living organisms. On the one side, gravity represents a factor of physical restriction, which compelled the ancestors of all extant living beings to develop basic achievements to counter the gravitational force (e.g., elements of statics like any kind of skeleton - from actin to bone - to overcome gravity enforced size limits or to keep form). On the other side, already early forms of life possibly used gravity as an appropriate cue for orientation and postural control, since it is continuously present and has a fixed direction.

Due to such a thorough adaptation to the Earthly gravity vector, both orientation behavior as well as the ontogenetic development of animals is impaired, when they have to experience altered gravity (\(\Delta g\); i.e. hyper- or microgravity). Nevertheless, animals still can cope with \(\Delta g\) in a certain range based on their physiological plasticity, which varies among the different animal phyla.

20.1 Gravity as a Factor of Physical Restriction: A Brief History of Evolutionary Challenges To Surmount It

As a matter of fact, the non-linear self-organizing dynamics of biological systems are inherent in any physical theory that satisfies the requirements of both quantum mechanics and general relativity [1]. Gravity therefore has always been a challenge for biological systems to adapt or/and to cope with it. Concerning single cells, the earliest life forms, it has been stated that average cell size results, in part, from the physical equilibrium between the destructive influence of the force of gravity and the protective role of diffusion and the cytoskeleton [2]. At increased forces of gravity the cell size would thus be decreased, whereas at lower gravitational forces and weightlessness cell size would be expected to increase. Mechanisms of protection of giant cells against internal sedimentation are based on protoplasmic motion, thin and elongated shape of the cell body, increased cytoplasmic viscosity, and a reduced range of specific gravity of cell components, relative to the ground-plasma. The nucleolus, due to its higher density, is considered as a possible trigger of mitosis. Although gravity limits the size even of single cells, its impact became especially apparent with the evolution of multicellular animals. There is not much known about the first multicellular animals inhab-
iting our planet in the late Precambrium (earlier than 570 millions of years ago) prior to the so-called “Cambrian explosion”, which showed an extremely rapid evolutionary radiation with the development of almost all nowadays phyla of invertebrate animals. With only a few exceptions, the Precambrian animals (e.g., the forms of the Ediacara-fauna, named after the Ediacara Hills north of Adelaide, Australia) did not have any sort of inner or outer skeleton. All of them were small and many species had a worm- or jellyfish-like appearance (Fig. 20.1). In most cases, their relationships to the nowadays present invertebrate groups is unclear.

Obviously, elaborate anti-gravity systems had not yet been fully evolved, which would have allowed these animals to grow larger, to develop a directed locomotion and even to cope with the terrestrial impact of gravity at the stage of their exit from water to land (Fig. 20.2). Development of a directed locomotion might have been one of the most important evolutionary inventions. When heterotrophic animal life decreased the nutrients (e.g., autotrophic plants) in the oceans, animals were forced to cope with this evolutionary pressure; directed locomotion was therefore developed to predate other animals or, vice versa, to escape from predators. For exercising directed locomotion especially gravity was - besides other environmental factors such as radiation (especially light), atmospheric conditions/composition, sound and electromagnetic as well as mechanical impacts - one of the most important morphogenetic factors of animal evolution which pushed the gene to elaborate adequate mechanisms for surmounting it [3]. Directed locomotion generally requires any sort of skeleton to allow the insertion of muscles; such a skeleton then could (pre-adaptively) act as a prerequisite for animals to turn from their aquatic habitat to a terrestrial life some 440 millions of years ago, then following the green plants as a further source for their heterotrophic lifestyle (the first terrestrial animals were early ancestors of our nowadays spiders, belonging to the arthropods).

The first vertebrate animals which were able to cope with the terrestrial impact of Earth’s gravity were early ancestors of fish some 350-400 millions of years ago. Concerning modern bluefish, it has been found that these animals can accelerate at 3 \(\times g\)

Fig. 20.1 This Ediacara-fossil may possibly represent an early jellyfish.  
Fig. 20.2 Jellyfish certainly cannot cope with the terrestrial impact of gravity.