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Review

Daphnia swimming behaviour as a biomarker in toxicity assessment: A review

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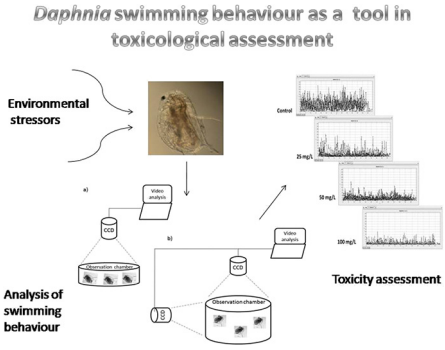
HIGHLIGHTS

- Swimming behaviour of *Daphnia* is affected by various toxicants.
- Parameters of daphnid swimming behavior may useful tool for toxicity assessment.
- Automated systems based on *Daphnia* swimming behavior allow quick evaluation of toxicity in water samples.

GRAPHICAL ABSTRACT



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ABSTRACT

Daphnia is a motile common model organism widely used in ecotoxicological testing. Although mortality and immobilisation are the main endpoints used for determination of toxicity, detection of subtle alterations induced by some chemicals particularly at lower levels may require more sensitive biomarkers. As a number of studies indicated that swimming behaviour may be altered by pesticides, nanoparticles, bacterial products or other chemicals, analysis of its various parameters is considered as a novel methodological approach for toxicity assessment and monitoring of water quality. This paper presents the current state of knowledge on the effects induced by various chemical compounds on the parameters of swimming behaviour of *Daphnia* and systems developed for its analysis. Advantages and limitations of swimming behaviour as a tool in toxicological studies are also discussed.

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1. Introduction

Daphnia also called "water flea" is a very common planktonic invertebrate organism inhabiting freshwater ecosystems such as lakes and ponds (Mergeay et al., 2006). These microcrustaceans have developed specific organs that facilitate them to move in water. Regular beating with the second set of antennae enables these crustaceans to swim with characteristic hops (Dees et al., 2008). *Daphnia* swimming is dependent on body size (Dodson and Ramcharan, 1991) and may also be affected by various factors such as light, water temperature, presence of food and predators (Baylor and Smith, 1953; O'Keefe et al., 1998; Hamza and Ruggiu, 2000; Ziarek et al., 2011).

Daphnia are sensitive to various substances and can be easily cultured in laboratory conditions, therefore they are found to be very useful model organisms in toxicology. Most of toxicological research with these crustaceans are based only on acute toxicity data for evaluation of lethal concentration (LC50) for mortality or effective concentration (EC50) for immobilisation. However, in order to provide more detailed information on toxicity, particularly sublethal effects induced by lower concentrations of toxicants, more sensitive biomarkers are required. Although life history traits, grazing rate, reproductive effects and a number of physiological and biochemical parameters are reliable endpoints (Dodson et al., 1995), more sensitive biomarkers such as swimming activity has recently drawn more attention of scientists. Mobility of daphnids may be affected by various substances, therefore swimming endpoints have been widely used in toxicology. For example, Restani and Fonseca (2014) tested the acute effect on *Daphnia laevis* mobility fed with a saxitoxin- and neosaxitoxin-producing cyanobacteria *Cylindrospermopsis raciborskii* strain, CYRF-01, and compared the effects with those induced by the non-toxic strain. It was found that the animals exposed to the STX-positive strain were immobilized. A similar approach was made in a study by Ferrão-Filho et al. (2008) in which mobility of daphnids exposed to *Cylindrospermopsis raciborskii* was determined. Although these two experiments showed the influence of the toxic factors on mobility, no movement parameters were determined. Another study showed abnormal swimming of *Daphnia magna* induced by silver nanoparticles (Asghari et al., 2012). The animals treated with the nanoparticles were categorized to the following groups according to their swimming type: normal swimming, erratic swimming, *Daphnia* mainly at the bottom, and *Daphnia* mainly at the surface. The method used in this study enabled to determine the influence of toxicants on daphnid swimming however, was ambiguous and not quantitative. Since changes of swimming behaviour induced by some toxicants may be very subtle and differences of animal reactivity between experimental groups may not be noticed by ambiguous observations with a naked eye, an approach providing more detailed toxicological information with a wide range of quantitative and very sensitive parameters has been developed. This paper is a review of the current knowledge on the use of *Daphnia* swimming behaviour as a biomarker in ecotoxicological studies. In the first section of this work various swimming parameters and their alterations induced by different agents will be presented. Further, available systems for motion analysis will be discussed in terms of their specificity, limitations and applicability for the analysis of *Daphnia* swimming endpoints.

2. Parameters of *Daphnia* swimming behaviour

Daphnia swimming behaviour is complex, multiparametric and considered as one of the most sensitive biomarkers of toxicity (Duquesne and Küster, 2010). It may be characterized by several parameters reflecting changes induced by various compounds on sensitive (i.e. nervous and endocrine) systems. Most of behavioural parameters are determined with the use of digital analysis of video recording (Dodson et al., 1995). This section presents major *Daphnia* swimming parameters that may potentially be used in ecotoxicological testing and reviews the literature on the effects of various compounds on swimming behaviour of these microcrustaceans.

2.1. Swimming time

Swimming time is a parameter indicating the period of time (seconds, hours or days depending on a type of testing and toxicity of a tested agent) in which *Daphnia* exhibit the ability to move. Observation of mobility is easy even without video recording, however noticing the moment of immobilisation requires permanent observation which may be rather difficult and time-consuming. A few reports indicated that some chemical compounds may alter this parameter. For example, daphnids subjected to saxitoxin-producing *Cylindrospermopsis raciborskii* showed a decreased swimming time (Ferrão-Filho et al., 2014). Another study indicated that copper shortened average duration of swimming in *Daphnia magna* in a concentration-dependent manner (Untersteiner et al., 2003).

2.2. Swimming speed

Swimming mobility expressed by scalar quantity- speed and its vector quantity-velocity (usually expressed in millimetres per second or s^{-1}) is one of the most reliable and widely used parameter of *Daphnia* behavioural activity. As these two quantities seem to be used by authors interchangeably, standardization is required. It is to note that cladoceran movement is not constant since acceleration occurs after each hop generated by a single beat with the second antennae and subsequently the animal slows down when the second