Journal of Experimental Marine Biology and Ecology 474 (2016) 185–194

Contents lists available at ScienceDirect

Journal of Experimental Marine Biology and Ecology

journal homepage: www.elsevier.com/locate/jembe

Sensitivity of *Pagurus bernhardus* (L.) to substrate-borne vibration and anthropogenic noise

Louise Roberts [a,*], Samuel Cheesman [b], Michael Elliott [a], Thomas Breithaupt [c]

[a] *Institute of Estuarine and Coastal Studies (IECS), University of Hull, Hull HU6 7RX, United Kingdom*
[b] *Salisbury, SP2 7DS, United Kingdom*
[c] *School of Biological, Biomedical and Environmental Sciences, University of Hull, Hull HU6 7RX, United Kingdom*

ARTICLE INFO

Article history:
Received 13 May 2015
Received in revised form 14 August 2015
Accepted 23 September 2015
Available online 3 November 2015

Keywords:
Vibration
Sensitivity threshold
Crustacea
Anthropogenic noise

ABSTRACT

Despite the prevalence of vibration produced by anthropogenic activities impacting the seabed there are few data and little information as to whether these are detected by crustaceans and whether they interfere with their behaviour. Here the sensitivity of unconditioned *Pagurus bernhardus* to substrate-borne vibration was quantified by exposure to sinusoidal vibrations of 5–410 Hz of varied amplitudes using the staircase method of threshold determination, with threshold representing the detection of the response and two behavioural responses used as reception indicators: movement of the second antenna and onset or cessation of locomotion. Thresholds were compared to measured vibrations close to anthropogenic operations and to the time in captivity prior to tests. Behaviour varied according to the strength of the stimulus with a significant difference in average threshold values between the two behavioural indicators, although there was an overlap between the two, with overall sensitivity ranging from 0.09–0.44 m s^{-2} (root mean squared, RMS). Crabs of shortest duration in captivity prior to tests had significantly greater sensitivity to vibration, down to 0.02 m s^{-2} (RMS). The sensitivity of *P. bernhardus* fell well within the range of vibrations measured near anthropogenic operations. The data indicate that anthropogenic substrate-borne vibrations have a clear effect on the behaviour of a common marine crustacean. The study emphasises that these vibrations are an important component of noise pollution that requires further attention to understand the long term effects on marine crustaceans.

1. Introduction

There is an increasing concern that man-made noise is having a marine ecological impact, hence its inclusion in the OSPAR and HELCOM Regional Seas Conventions and within the European Marine Strategy Framework Directive (2010), which includes noise as a Descriptor to achieve Good Environmental Status (GES) (Borja et al., 2013). Although there has been recent progress, there are still insufficient data on the levels of noise causing injury or responses in fish and invertebrates (Hawkins et al., 2014a; Popper et al., 2014). Within this, the impact of seabed vibration upon marine organisms has been largely neglected even though many activities involve direct contact with the seabed, for example pile driving and drilling. These produce substrate-borne vibrations which can travel as compressional (longitudinal), transverse (shear) or surface (Rayleigh or 'ground roll') waves (Aicher and Tautz, 1990; Hazelwood and Macey, in press; Markl, 1983), with energy being transmitted in one or multiple waveforms depending on the substrate type, boundary layers, and connection to the substrate (Aicher and Tautz, 1990). The energy of low frequency Rayleigh waves in particular, may travel large distances from the source (Brownell, 1977), trapped within the surface seabed with minimal attenuation (Hazelwood and Macey, in press). Thus animals may detect, and be affected by vibration at large distances from anthropogenic sources. However there are few data on levels of detection and the levels produced by such sources (reviewed in Roberts, 2015), this makes the impacts of such vibrations on marine organisms difficult to ascertain.

Whilst sound comprises both pressure waves and particle motion (water and substrate-borne), crustaceans appear to respond to particle motion only (Breithaupt and Tautz, 1988, 1990; Goodall et al., 1990; Monteclaro et al., 2010; Plummer et al., 1986; Roberts and Breithaupt, in press; Tautz and Sandeman, 1980). Such detection is likely since sound production is widespread in crustaceans, from snapping shrimp (Johnson et al., 1947; Knowlton and Moulton, 1963; Schmitz and Herberholz, 1998; Versluis et al., 2000) to lobster and crab stridulation (Aicher et al., 1983; Field et al., 1987; Henninger and Watson, 2005; Horch, 1971, 1975; Moulton, 1957; Patek, 2001; Patek et al., 2009),

---

* Corresponding author.
E-mail addresses: Louise.Roberts@hull.ac.uk (L. Roberts), Samuelcheesman@gmail.com (S. Cheesman), Mike.Elliott@hull.ac.uk (M. Elliott), T.Breithaupt@hull.ac.uk (T. Breithaupt).

http://dx.doi.org/10.1016/j.jembe.2015.09.014
0022-0981/© 2015 Elsevier B.V. All rights reserved.

rumbling of mantis shrimps (Order Stomatopoda) (Patek and Caldwell, 2006; Staaterman et al., 2011) and shell rapping in hermit crabs (Briffa and Elwood, 2000).

Substrate-borne vibration detection studies have been predominantly directed towards semi-terrestrial fiddler crabs, which use vibration for communication and courtship (Aicher and Tautz, 1990). Thresholds of sensitivity have been determined using electrophysiological techniques (Aicher and Tautz, 1984; Salmon and Horch, 1973; Salmon et al., 1977) and behavioural observations (Salmon and Atsaides, 1969) or a combination of both (Salmon, 1971; Salmon et al., 1977). These studies have demonstrated greatest sensitivity between 0.02–0.07 m s^{-2} (30–400 Hz, RMS) and 0.01–0.02 m s^{-2} (50–90 Hz, RMS) (Salmon, 1971; Salmon and Atsaides, 1969; Salmon and Horch, 1973) for behavioural and electrophysiology work respectively. Of the few data available for aquatic decapod crustaceans exposed to vibration, behavioural work with *Crangon crangon* has indicated thresholds of 0.4–0.81 m s^{-2} (20–200 Hz, peak) (Berghahn et al., 1995; Heinisch and Wiese, 1987). Thresholds for water-borne particle motion have been found in the range of 0.0002–1.4 m s^{-2} (3–400 Hz) but work has mostly focussed upon freshwater crayfish such as *Orconectes limosus* and *Procambarus clarkii* (Breithaupt, 2002; Breithaupt and Tautz, 1990; Goodall et al., 1990; Horch, 1971; Offutt, 1970; Tautz and Sandeman, 1980; Wiese, 1976). Most recently, Hughes et al. (2014) demonstrated sensitivity of the mud crab *Panopeus* spp. to water-borne stimuli in the range of 0.025–0.2 m s^{-2} (75–1600 Hz, RMS).

Establishing the sensitivity of an organism to an acoustic or vibratory stimulus typically involves producing a threshold curve spanning a range of frequencies (Fay and Popper, 1974), measuring electrophysiological responses from individual sensory detectors (Breithaupt and Tautz, 1988; Mellon, 1963; Monteclaro et al., 2010; Tautz and Sandeman, 1980) or measuring the auditory evoked potential (AEP). For cephalopods, and some crustaceans, AEP has been successfully applied (Lovell et al., 2005; Mooney et al., 2010), but thresholds determined in this manner are less accurate than those determined by behavioural methodologies (Ladich and Fay, 2013; Sisneros et al., in press). Response may also be affected by handling time and the possibility of acclimation to background noise levels and disturbance stimuli. This has been demonstrated in fishes (Chapman and Hawkins, 1969; Knudsen et al., 1992; Peña et al., 2013) but needs to be considered for other organisms when investigating behavioural sensory thresholds.

The present study aimed to determine to what extent the common marine intertidal hermit crab, *Pagurus bernhardus* L. (Family Paguridae) is sensitive to substrate-borne vibration, and to fully define the sensitivity range and behavioural responses in relation to levels produced by anthropogenic activities. The data were also related to the sensitivity of other species to vibration. Variation in threshold was investigated in relation to time spent in the laboratory prior to tests.

It is hypothesised that the sensitivities of *P. bernhardus* to vibration would fall within the high levels produced by anthropogenic activities and within the range documented for other species. However the precise sensitivity of *P. bernhardus* to vibrations (natural or anthropogenic) is undocumented, although it may be similar to that of semi-terrestrial crabs (Aicher and Tautz, 1990; Salmon and Atsaides, 1969), or marine species such as *Nephrops norvegicus* and *C. crangon* (Goodall et al., 1990; Heinisch and Wiese, 1987) due to similar receptive mechanisms.

Hermit crabs were chosen due to the clear anti-predator mechanism (withdrawal into the shell) they undertake in stressful conditions (Chan et al., 2010a, 2010b; Elwood and Briffa, 2001), and their coastal distribution which means they are likely to encounter anthropogenic activities. Small behavioural changes (antenna movement, and changes in locomotion) were used to indicate vibration reception as in studies with other crustaceans (Berghahn et al., 1995; Breithaupt, 2002; Goodall et al., 1990; Heinisch and Wiese, 1987; Tautz, 1987), rather than a conditioning approach.

2. Materials and methodology

Hermit crabs, *P. bernhardus,* occupying *Littorina* sp. shells (shell height 15.9–23.3 mm, defined as the total distance between the apical and basal extremities of the shell), were collected from Scarborough shore (54° 16′ 15.3″N 0° 23′ 17.1″W) and kept in a temperature controlled room with minimal disturbance and a 12 h light 12 h darkness regime, with an average water temperature of 11–12 °C. The crabs were fed every 48 h on a diet of mixed shellfish and kept in small groups, and starved for 24 – 48 h before tests. Partial water changes (25%) were undertaken every 2–3 days and water quality was monitored throughout. Within the holding tanks, crabs were free to move and interact. To reduce conflicts, the tanks contained shelters and spare shells. Post-moult individuals and those with missing appendages were not used. A minimum acclimation period of 24–48 h was allowed between collection and testing.

2.1. Experimental setup and threshold determination

The experimental setup consisted of a tank (with external vibration dampening) with a stinger rod descending vertically to the sandy substrate, which transmitted vibrations from an electromagnetic shaker (LDS v101, 8.9 N, 5–12,000 Hz) (Fig. 1). Full details of the experimental setup are provided in Roberts et al. (in press), Roberts (2015). At the opposite end of the tank, a circular plastic arena (100 diameter, 50 mm height, opaque) was situated, within which the subject moved freely. A camera (Microsoft Lifecam) above the arena allowed behaviour of the subject to be monitored remotely by the experimenter without disturbance. Sine waves of 8 s duration (1 s rise and decay time to prevent signal distortion) were presented at 11 amplitudes (in increments of 6 dB below the maximum level) and seven frequencies (5–410 Hz). Signals were generated in AUDACITY (version 2.0.5), exported on an SD card and played back through a Roland R-09HR MP3 recorder connected to an amplifier (JL Audio XD 200/2 200 W, 12–22 kHz) and the shaker.

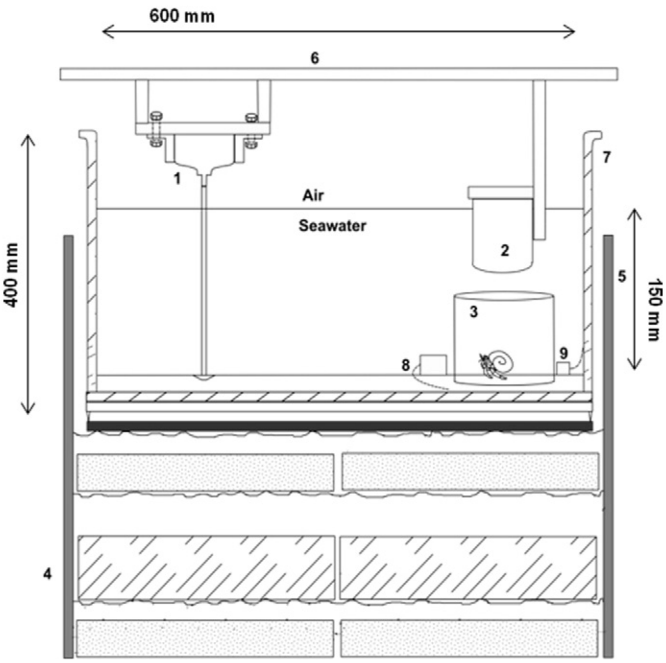

Fig. 1. Schematic of experimental setup, consisting of electromagnetic shaker and stinger rod (1), underwater camera (2), experimental arena (3), layered base made up of mixed hard and soft insulation and concrete (4), wooden support structure (5), steel frame completely separate from the base (6), experimental tank with needlepoint legs and 30 mm sandy substrate (7), position of geophone system (8), position of accelerometer (9). Figure adapted from Roberts et al. (in press).