Available online at www.sciencedirect.com
ScienceDirect
Neurocomputing 70 (2007) 1079–1084
NEUROCOMPUTING
www.elsevier.com/locate/neucom

Letters

Data mining neural spike trains for the identification of behavioural triggers using evolutionary algorithms

Richard Stafford, F. Claire Rind*

School of Biology and Psychology, Ridley Building, University of Newcastle-upon-Tyne, NE1 7RU, UK

Received 30 January 2006; received in revised form 1 September 2006; accepted 1 September 2006
Communication by W.L. Dunin-Barkowski
Available online 10 November 2006

Abstract

We analysed spike trains from the descending contralateral movement detector (DCMD) neuron of locusts. The locusts either performed jumps or did not jump in response to visual looming stimuli. An evolutionary algorithm (EA) was employed to sort spike trains into the correct behavioural categories by optimising threshold parameters, so jump behaviour occurred if the spike-train data exceeded the threshold parameters from the EA. A candidate behavioural trigger appeared to be prolonged high-frequency spikes at a relatively early stage in the approach of the stimulus. This technique provides a useful precursor to a full biological analysis of the escape jump mechanism.

Keywords: DCMD neuron; Locust; Behaviour; Neural coding; Evolutionary algorithm

1. Introduction

Escape or startle behaviours in some animals are triggered by a single spike in an identified interneuron. For example, a single spike in the Mauther neuron of teleost fish causes the C-start escape behaviour ([7]), and a single spike in one of the crayfish's giant interneurons causes a tail-flip escape response ([3]). However, most escape behaviours are not so obviously coded, relying instead on particular features from within complex trains of spikes.

The descending contralateral movement detector (DCMD) neuron of locusts responds most vigorously to small, fast-moving stimuli that may best represent the locust's natural avian predators [9,10]. Of these, the DCMD neuron responds most strongly when the object looms, or appears to approach the eye. In flight, the DCMD neuron is thought to trigger a gliding behaviour that may cause a locust to dive and evade capture by an approaching predator [11,12]. DCMD neuron activity may also be involved in the locust's evasive steering behaviours that occur earlier during a predator's approach [12,5].

The spike-train feature of the DCMD neuron that triggers a glide is thought to be complex. DCMD neuron spikes must occur in sufficient number above an instantaneous threshold so as to allow them to summate and elicit action potentials in a motor neuron that is involved in the elevation of the wings into the gliding posture [11]. Furthermore, this trigger feature must occur within the correct phase of the wingbeat cycle so as to be summed with ongoing flight motor activity and to allow the glide to occur at the appropriate wingbeat phase [11].

Determining the features of a neural spike train that trigger a particular behaviour can be a complex and time-consuming process. In demonstrating the role of an identified neuron in behaviour two approaches are common: Classically, necessity and sufficiency can be demonstrated by first 'killing' the neuron and demonstrating that behaviour no longer occurs in response to a normally effective stimulus, and secondly, exciting the neuron electrically and eliciting the behaviour artificially [7]. However, often the invasive techniques required may themselves result in an alteration of the animal's natural

---

*Corresponding author.
E-mail address: claire.rind@ncl.ac.uk (F. Claire Rind).

0925-2312/$ - see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.neucom.2006.09.011

behaviour, obscuring any effect of the perturbed neuron itself. An alternative method is to correlate spike-train and behavioural features in order to indicate a possible causal relationship [11,12]. However, obtaining neural and behavioural data simultaneously are highly demanding and determining the correct features of the behaviour and spike train to correlate is largely a trial and error process.

In this study, we present an objective method of data analysis that may help identify features of a spike train important in behavioural triggering, allowing the collection and analysis of more focussed biological data in subsequent experiments.

We correlate neuronal and behavioural features using an evolutionary algorithm (EA), which simultaneously optimises a range of parameters associated with DCMD neuron spike trains recorded from locusts either jumping in response to a looming stimulus, or producing no response to it. The parameters are then used, without reference to the locust's behavioural response, to divide the spike trains into 'jump' or 'non-jump' prediction groups, in a similar way to EA-based clustering methods in bioinformatics [4]. These predictions are then compared with the behaviour known to have occurred during each spike train, with correct predictions increasing the 'fitness' of the set of parameters used to divide the trials. An optimal set of parameters is finally obtained that correctly divides jumping and non-jumping spike trains based on particular response features. These spike train features may, therefore, be important in triggering the jump itself.

2. Methods

2.1. Experimental methods

We used recorded data of DCMD activity and behavioural responses in two locusts challenged with computer-generated visual stimuli looming from their right sides (data originally presented in [2]).

Visual stimuli were displayed on a high-speed computer monitor with a refresh rate of 180 Hz. The stimulus was a computer-generated circular object of diameter 80 mm, which loomed towards the locust at a constant speed of 1 m/s. The monitor screen was positioned 70 mm from the locust's right eye and the simulated trajectory of object approach was 90° to the locust's long axis. Initially, the looming stimulus was simulated to be 2.07 m from the eye of the locust (including the 70 mm between the position of the screen and the locust) and approached over 2 m, finally subtending an angle of 60° on the locust's eye at its final simulated position level with the monitor screen.

Activity in the left DCMD was recorded from its axon in the cervical connectives using implanted hook electrodes as described in [12]. Electrodes were attached to 50 μm diameter insulated copper wires and signals amplified. The copper wires acted as a loose tether. Other than the wire tether, locusts could move and jump freely. For each trial, DCMD activity was processed off-line in Spike2 (CED) to obtain the timing of each spike, relative to the start of looming stimulus movement. Spike timings were recorded in seconds to an accuracy of five decimal places. Each spike train was also classified as a jump-producing spike train or a non-jump-producing spike train based on whether the locust jumped during or immediately after the presentation of the looming stimulus in that trial.

Jumping in response to a looming stimulus occurred in $\leqslant 25\%$ of trials; however, the frequency of jumping in response to a looming stimulus was far greater than that when no stimulus was shown, when the locust rarely jumped unless in response to a disturbance in the laboratory (e.g. opening a door and entering the laboratory). In addition, the timing of the jumps coincided with the final phase of looming stimulus expansion, from 0.2 s before the end of stimulus movement until its end. This indicates the locust did jump in response to the looming stimuli when jumping behaviour occurred.

Due to the difficulty in collecting electrophysiological data from locusts able to freely jump, data were obtained from just two locusts. Locust 1 had four clear DCMD neuron recordings during jumps and 12 clear DCMD neuron recordings during no jumps. Locust 2 had two clear recordings during jumps and 11 clear recordings during no jumps. Since it is possible that subtle differences may occur between the behavioural triggers of different animals, data were analysed separately for the two locusts.

2.2. Parameters used to divide spike trains into jump and non-jump groups

A total of six parameters were used by the evolutionary algorithm to attempt to separate spike trains recorded during jumps from those recorded during non-jumps. The first two parameters defined a time window of interest and were (1) start time and (2) end time. These parameters were designed to focus on a specific window of important neural activity, which could, in theory, include the whole record of the DCMD neuron response. The limits of these parameters, when adjusted by the EA, were between the start of the loom, and the last recorded spike in the DCMD neuron response.

Three interlinked parameters were also used to determine differences between spike trains. The parameters were (3) a threshold instantaneous spike frequency (the reciprocal of a single inter-spike interval), (4) a number of consecutive spikes occurring above the threshold frequency, (5) a time for which the instantaneous frequency of the spike train exceeded the threshold frequency. Parameters 4 and 5 are closely correlated, but subtly different. For example a time of 0.1 s above a 100 imp/s threshold must equate to at least 10 spikes above the threshold, but could mean more spikes than this if the instantaneous frequency rose during this period. Unlike in statistical analysis, there is no need for the parameters to be fully independent. However, correlated variables must be interpreted with care. Parameter (6) was the maximum