### TABLE 1 Isotope data for Macdonald seamount

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Value</th>
<th>Uncertainty</th>
<th>Value</th>
<th>Uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Th (p.p.m.)</td>
<td>4.3 ± 0.3</td>
<td></td>
<td>2.6 ± 0.5</td>
<td></td>
</tr>
<tr>
<td>U (p.p.m.)</td>
<td>1.7 ± 0.1</td>
<td></td>
<td>2.1 ± 0.2</td>
<td></td>
</tr>
<tr>
<td>(230)U</td>
<td>1.25 ± 0.07</td>
<td></td>
<td>1.5 ± 0.1</td>
<td></td>
</tr>
<tr>
<td>(234)U</td>
<td>1.30 ± 0.07</td>
<td></td>
<td>1.04 ± 0.06</td>
<td></td>
</tr>
<tr>
<td>(232)Th</td>
<td>1.04 ± 0.05</td>
<td></td>
<td>1.2 ± 0.1</td>
<td></td>
</tr>
</tbody>
</table>

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Our general methods for monitoring unit activity and eye position in alert, behaving monkeys are derived from those devised by Wurtz et al. and our psychophysical methods were based on those described by Newsome and Paré. In brief, animals were trained to report the direction of motion of a random dot display in which some dots moved coherently while the remainder moved at random. We varied the strength of the motion signal by varying the proportion of the dots moving coherently: at 0% correlation, all the motion was random; at 100% correlation, all the motion was coherent. Near threshold, the stimulus resembled the dynamic noise seen on a domestic television set tuned between stations, combined with a barely perceptible sensation of global motion. We recorded single-neuron activity from area MT (V5), a region of the extrastriate visual cortex concerned with motion processing, where most neurons respond optimally to visual stimuli of a particular direction and speed of motion. Because efficient extraction of motion signals from this stimulus requires considerable integration over space, it seemed likely that neurons in MT, which have relatively large receptive fields, would be particularly suited to this task. Newsome and Paré have recently shown that lesions of MT elevate perceptual thresholds for this task.

We used a two-alternative forced-choice procedure to measure thresholds. We placed our stimulus so that it just covered the receptive field of the neuron under study, and adjusted the speed to match that preferred by the neuron. Motion was presented either in the neuron's preferred direction or in the 'null' direction 180° away. On an individual trial, the monkey was required to hold fixation for 2 seconds while the motion stimulus was presented. At the end of the trial, the monkey indicated his judgment by transferring his gaze to one of two small light-emitting diodes, corresponding to the preferred or null direction of motion. We presented at least 30 trials (15 in each direction) for each of several correlation values chosen to elicit performance that varied from chance to near perfection, and compiled these data into psychometric functions. Recalling that performance would be 50% correct by chance, we defined the threshold as the correlation required for the monkey to judge the direction of motion correctly on 82% of the trials.

While measuring the psychophysical threshold, we recorded the activity of the MT neuron for which the stimulus parameters were optimized. The computer counted the action potentials elicited on each trial, and compiled distributions like those shown for a typical neuron in Fig. 1a. In these distributions, filled bars represent trials in which the motion was in the null direction, and cross-hatched bars indicate trials for the preferred direction. It is evident that at a correlation of 0.8% the two distributions were not different, whereas at a correlation of 12.8%, where the neuron was strongly direction-selective, they barely overlapped. To compare these neuronal data with the psychophysical data, we postulated that performance depended on a comparison between the activity of two neurons, the one under study and another differing only in that it preferred the opposite direction of motion. Under this assumption, we could use the distributions in Fig. 1a to represent the responses of the neuron under study and its 'antoneuron'; we simply reversed the preferred and null directions for the antoneuron. On any individual trial, therefore, the observer would compare a response drawn from the distribution represented by the hatched bars in Fig. 1a with one drawn from the distribution represented by the solid bars. The direction chosen would be the preferred direction of the neuron giving the larger response. The performance of an MT neuron could then be characterized as the probability that a randomly selected response from the hatched distribution in Fig. 1a was larger than a randomly selected response from the solid distribution. We chose this method for analysing physiological data because it most directly related neuronal performance to the directional discrimination task that the monkey was engaged in.

For the data in Fig. 1a, at a correlation of 0.8%, this decision rule chose the correct direction only on about half the trials (random performance), whereas at a correlation of 12.8% it performed nearly perfectly. We used a method based on signal detection theory to estimate this choice probability for each correlation value, and plotted the results as 'psychometric functions' formally equivalent to the psychometric functions representing the psychophysical data. The two functions for this example neuron are shown in Fig. 1b; filled circles represent psychometric data, open circles represent psychometric data. Evidently the two curves are very similar, with the psychometric
data points lying slightly to the left of the psychometric data points; in this case the neuronal threshold was slightly lower than the psychophysical one. We used a likelihood-ratio statistic to test the hypothesis that the psychometric and neurometric functions were the same. For this neuron, this hypothesis could not be rejected ($P > 0.05$).

We performed this analysis for 45 neurons recorded from one monkey, and 15 neurons from a second. Figure 2 shows a histogram of the distribution of the ratio of neurometric to psychometric thresholds for these 60 neurons. Values of this ratio of $<1$ represent cases where the neuron's threshold was lower than the monkey's; values $>1$ represent cases where the monkey's performance was better than the neuron's. Intuitively, it might be expected that the behavioural threshold would be lower than any particular neuronal threshold but, in most cases, neuronal thresholds and perceptual thresholds were similar. Indeed in some cases, neuronal thresholds were substantially lower than perceptual thresholds. For 20 of the 60 neurons in our sample, the psychometric and neurometric functions were statistically indistinguishable ($P > 0.05$); in 18 of the 40 remaining cases, neuronal thresholds were lower than perceptual would substantially improve psychophysical performance by averaging out the noise that obscures weak signals. Our data show that in most cases, the neuronal and psychophysical performances are similar, indicating that signals from many neuronal sources are not pooled to reduce perceptual thresholds.

One way to account for the absence of either pooling or uncertainty effects is to suggest that the variability in the responses of similarly tuned neurons is correlated. Both pooling and uncertainty act as we have stated only if different neuronal signals are perturbed by independent sources of variation. If the sources are not independent, then uncertainty does no damage and pooling provides no benefit, because different neurons are carrying similar signals. The rich network of shared connections that link MT neurons with the retina might well produce correlation among neurons with related selectivities, but this possibility has not been studied. Our lack of information about the degree of shared variability makes it impossible for us to assert that the neurons whose responses we have recorded are the ones that contribute to the monkey's perceptual judgements. Nonetheless, our results show that a reasonable account of the monkey's performance can be constructed using a simple