Encoding of correct and incorrect responses by ventral prefrontal cortex neurons in an audio-visual discrimination task

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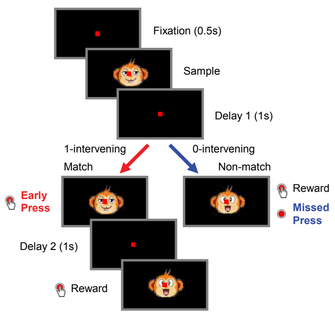
Introduction

We have recorded the activity of single neurons in the ventrolateral prefrontal cortex (VLPFC) while monkeys performed an audiovisual discrimination (non-match to sample) task in which face-vocalization movie clips were used as stimuli. We found that neurons are modulated during particular task epochs (88%) and that the activity of some neurons (25%) is related to stimulus properties, i.e., which audio-visual stimulus was presented or whether auditory, visual or both auditory and visual stimuli were altered in the non-match period. In order to better understand how prefrontal neurons participate in the discrimination of audio-visual communication signals we have analyzed neuronal activity during several instances of correct and incorrect trials.

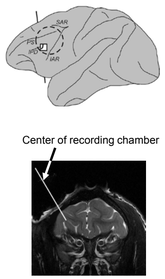
Methods

In our task, an audio-visual stimulus was presented in the sample period while the animal fixated. Subsequent presentations would either match or not-match the sample. The task required the animal to press a button if the second audio-visual stimulus differed from the sample in either the audio or the video track, or both (non-match stimulus). In some trials the second stimulus was the non-match (0-intervening trials), while in other trials the sample was repeated and the third stimulus was the non-match (1-intervening trials). Successful detection of the non-match with a button press resulted in a juice reward. A trial was aborted when the animal broke fixation during stimulus presentation or when an early button press occurred (i.e. before the non-match stimulus appeared). Incorrect responses occurred when 1) the animal failed to respond to a non-matching stimulus (missed press) or 2) incorrectly pressed the button during a matching stimulus (early press). Single-neuron activity was recorded from the VLPFC while the animal performed the task.

Non-match to Sample Task



Recording Site



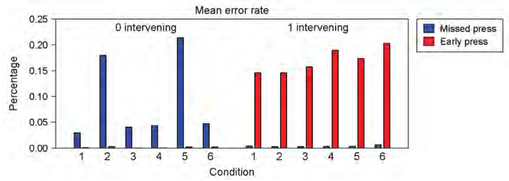
Manipulation of Non-match Stimuli

A1 : audio track of movie 1
V1 : video track of movie 1
A2 : audio track of movie 2
V2 : video track of movie 2

Condition	0-intervening		1-intervening			
	Sample	Non-match	Sample	Match	Non-match	
1 :	A1V1 →	A1V2 or N1V1	A1V1 →	A1V1 →	A1V2 or N1V1	····· Video (or Noise) switch
2 :	A1V1 →	A2V1	A1V1 →	A1V1 →	A2V1	····· Audio switch
3:	A1V1 →	A2V2	A1V1 →	A1V1 →	A2V2	····· AV switch
4 :	A2V2 →	A2V1 or N2V2	A2V2 →	A2V2 →	A2V1 or N2V2	····· Video (or Noise) switch
5 :	A2V2 →	A1V2	A2V2 →	A2V2 →	A1V2	····· Audio switch
6 :	A2V2 →	A1V1	A2V2 →	A2V2 →	A1V1	····· AV switch

Results

BEHAVIORAL PERFORMANCE. We performed 226 recording sessions. The average error rate was 14.7%. Typically our subject made missed-press errors in condition 2 & 5 (audio switch) of 0-intervening trials and early-press errors in all conditions of 1-intervening trials.



ANALYSIS OF NEURAL DATA. We tested neural activity of several task epochs with the following model. This model includes the variables for stimulus-related properties such as movie type, non-match type, and their interactions which were effective in our previous analysis. It also includes a variable for correct or incorrect responses. Since the type of error the subject typically made differed between 0-intervening and 1-intervening trials, we analyzed them separately.

Model : Neural activity = a0 + a1*MT + a2*NM1 + a3*NM2

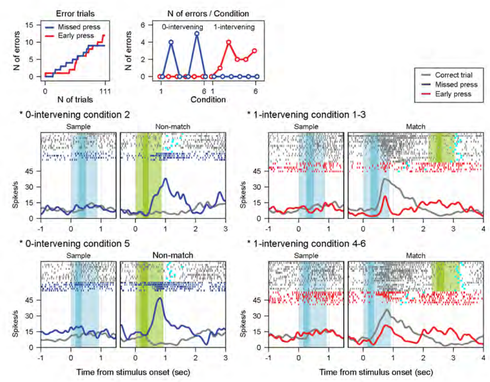
Movie type 0 : Movie 1, 1 : Movie 2

Non-match type -1 : Video (or Noise) switch 1, -1 : Audio switch -1, 2 : AV switch 0

+ a4*MT*NM1 + a5*MT*NM2 + a6*IR

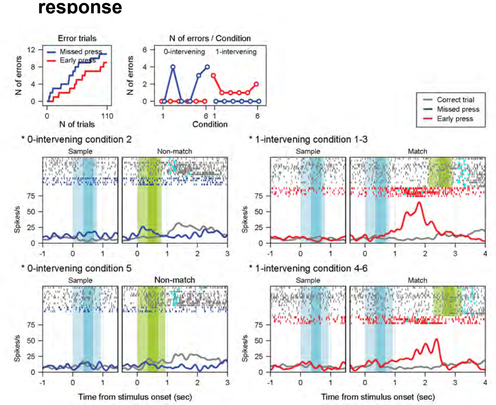
Incorrect response 0 : Correct trial, 1 : Missed or early press

Fig 1. Neuron with enhanced activity while subject withheld a button press



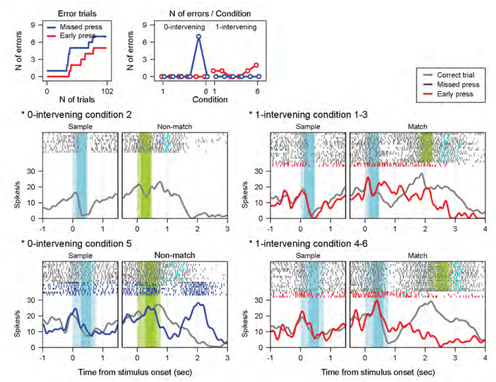
This is one of the example neurons in which the variable for incorrect responses (coefficient a6 of our model) was significant. The cyan dots (■) in the raster plot of correct trials and early press trials are the time of the button press. The activity of this neuron was enhanced when the animal withheld a button press, whether it was the correct response or not.

Fig 2. Neuron with enhanced activity after a button press response



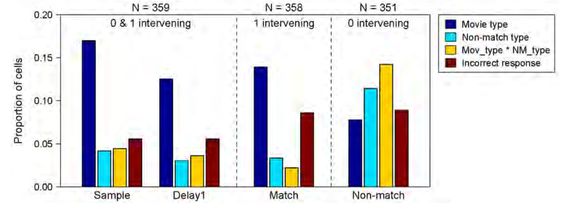
This is another example in which the incorrect response term (coefficient a6) was significant. The activity of this neuron was enhanced right after the animal pressed the button, whether it was the correct response or not.

Fig 3. Neuron with delayed enhanced activity after subject withheld a button press

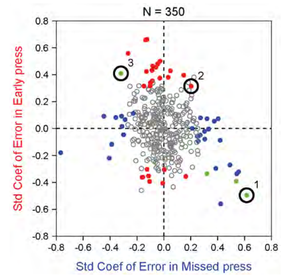


The activity of this neuron was also enhanced when the animal withheld a button press as shown in the example in Fig 1, however the time course of the activity is very different. This enhancement occurred almost a second later than the neuron in Fig1.

Population Result



We compared the effect of incorrect responses with those of stimulus-related parameters such as the sample movie type (MT), the non-match type (NM), and their interaction (α=0.05). The overall proportions of cells which respond to stimulus-related properties are similar before and after the incorrect response term is included. However, the proportion of cells modulated by incorrect responses increases during the period when the subject decides whether to press the button.



Blue dots : cells in which the effect of a missed press was significant.
Red dots : cells in which the effect of an early press was significant.
Green dots : cells in which both effects of a missed press and an early press were significant.
Gray circles : cells in which neither the effect of a missed press or that of an early press was significant.
Black circles and numbers : positions of the example cells shown in the previous section.

There is a negative correlation between the effect of the two different incorrect response types (r = -0.20, p < 0.001), which means that the activity of the neurons tends to increase in missed press trials and to decrease in early press trials, and vice versa.

Conclusions

1. We have previously shown that neurons in VLPFC respond during particular task epochs of an audio-visual discrimination task (sample, delay, non-match, reward periods).
2. Some neurons in VLPFC show changes in activity that occur during particular types of responses. In particular, some proportion of cells showed enhanced activity while "withholding a press" (whether it was a correct or incorrect response).
3. Our neurons appear to encode the response goal (press the button or withhold the press) rather than whether it is the correct response.

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