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Assessment of attention in animals provides information about the neural mechanisms involved in attention, which can help develop computational and cognitive models that describe in detail the systematic steps mediating different types of attention. In order to increase the applicability of the results from these experiments to those of humans, the behavioral testing procedures have been designed to be as similar as possible to those used for humans. The initial behavioral experiments indicate strong operational and psychological validity of these tests of attention, providing the opportunity to pursue the neural mechanisms in the subsequent funding period.

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This project is designed to develop procedures to measure attention in rats so that neural investigations can identify the brain mechanisms involved in attention, and relate these to current cognitive descriptions of attentional processes. Particular emphasis is placed on the use of behavioral testing procedures and cognitive analyses that are common in the human literature. Two important dimensions are considered in evaluating the validity of the procedures and guide the development of the experiments. Operational validity assesses the manipulations of the independent variables and measurements of the dependent variables. Psychological validity assesses the psychological processes involved in performance.

The preceding year has been successful for both of our main projects. In the divided attention project, single unit recordings have been almost completed. Data are now available from 105 units in 14 rats. Analysis of these data is now in progress, and a manuscript should be submitted during the next funding period. The activity of single units in the frontal cortex was correlated with several components of the task: onset of stimuli, responding, and variations in the attentional demands.

In the reaction time project, one procedure for testing reaction time has been fully established. Data have been collected from rats and humans, and the manuscript describing these results has been submitted for publication to Perception and Psychophysics. The successful development of tests to measure reaction time establishes new projects in the area of attention, using animals to provide an integrated neurocognitive description of attentional processes. Although many idiosyncratic procedures to assess attention in animals have been developed, these have typically not been integrated with the cognitive approaches used to examine attention in humans. This lack of integration has restricted the applicability of the data from animals to issues that are important in the study of humans. A major contribution of the current project has been the development of the apparatus and testing techniques to permit accurate measurement of two-choice reaction time. This procedure is similar to that in many human experiments, providing operational validity that permits the results of the present experiments to be closely integrated with those from humans.

Expectancy can allocate attention and alter information processing so that a response to an expected stimulus is quicker and more accurate than that to an unexpected stimulus. Because expectancy effects are so important for theories of information processing, intensive research has been conducted to determine its mechanisms. Two hypotheses have been proposed to account for the

effects of expectancy. The first states that expectancy primarily affects perceptual processes. According to this hypothesis, expectancy directs attention to the more probable stimulus so that the subject can encode or identify it more effectively. The second hypothesis states that expectancy primarily affects response processes. Here, expectancy alters the response selection process so that the subject is likely to select the more probable response. These hypotheses need not be mutually exclusive. Both mechanisms of expectancy may occur with the relative magnitude of each process depending on task demands.

Neurobiological mechanisms of cognitive processes have been studied in human subjects using event related potentials, positron emission tomography and brain damaged patients. However, the analyses of cognition at the single cell level still require good animal models. In order to be most useful, human and animal studies should be directly comparable. This comparison is facilitated by manipulating the same independent variables and measuring the same dependent variables for all subjects.

The present line of research is focused on developing a rat model of human attention, expectancy and information processing so that neurobiological mechanisms of these cognitive processes can be examined. As a first step toward this goal, the present study was undertaken to validate the usefulness of the rat for a model of human attention and expectancy. A behavioral procedure was developed to measure expectancy in rats with the constraint that the procedure be directly comparable to human studies. Similar simple and choice reaction time tasks were performed by rats and humans. Expectancy to one of two stimulus-response pairs was manipulated by varying the frequency of each pair. The similar data obtained for rats and humans provide evidence that the behavioral procedure described here is a useful approach for further studies in examining neurobiological substrates of expectancy, and may prove useful in studies of attention.

Experiment 1: Rats

Introduction

Studies of expectancy in humans have traditionally measured reaction time and choice accuracy, and manipulated the number of stimuli and responses. Studies of similar phenomena in rats should accurately measure reaction time and choice accuracy and be able to manipulate the number of stimuli and responses. The present experiment used a procedure that allowed rats to place one forepaw on each of two levers. This position permitted two, independent responses, one from each paw. This design formed the basis for a choice reaction time task that could be used in rats and was very similar to procedures used to examine expectancy and attention in humans. In this experiment the effects of expectancy were examined in rats by manipulating stimulus probability.

Methods

Six male Long-Evans rats began the experiment with body weights ranging from 250 - 350 grams. The design of the operant boxes encouraged rats to stand on their hind legs, use their forepaws to depress two levers simultaneously, and place their mouth near a water spout. The levers, water spout and visual stimulus were positioned so that the visual stimulus was clearly visible to the rat and water reinforcement could be collected with minimal movement. The auditory stimulus was clearly audible from everywhere within the box.

Each trial was started when the rat pressed both levers. One of the two stimuli was presented 0.5 sec following the start of the trial. Light trials were trials in which the visual stimulus was presented. Tone trials were trials in which the auditory stimulus was presented. A correct response was a release of the left lever on light trials or a release of the right lever on tone trials. Following a correct response, the stimulus was turned off and water reinforcement was delivered. An incorrect response was a release of the right lever on light trials or a release of the left lever on tone trials. Following an incorrect response, the stimulus was turned off, the buzzer was activated for 1 second, and a punishment period occurred for 10 seconds. During the punishment period, the houselight was turned off and no trials were given. At the end of the punishment period, the house light was turned on and the next trial began. A premature response was a release of any lever prior to stimulus onset. Each premature response was followed by activation of the buzzer for 0.5 second and a punishment period of 10-20 seconds. The houselight was turned on at the end of the punishment period and the trial was repeated (correction trial). Premature responses on correction trials were treated in the same manner as premature responses on regular trials. The time between the start of the trial and the stimulus onset was 1, 2 or 3 seconds.

One test session was given each day. Each session lasted 45 - 60 minutes and consisted of 100 - 200 trials. The stimulus probability remained constant within a session, but changed from session to session. Five different stimulus probabilities were used and presented in the following order (expressed as probability of tone/probability of light): 0/100, 10/90, 50/50, 100/0, 90/10, 50/50. This series was repeated throughout the study.

Reaction time and choice accuracy were recorded for each trial. Data from regular trials and from correction trials were analyzed separately. Mean reaction time and choice accuracy were calculated for all trials without a premature response for each type of stimulus and each stimulus probability. The proportion of trials with at least one premature response was calculated.

Reaction time (RT) was the time from the onset of the stimulus to the onset of the response. Visual RT was the reaction time to the visual stimulus. Auditory RT was the reaction time to the auditory stimulus.

Probability of correct responses (CORR) was determined separately for each stimulus and was calculated by dividing the number of correct trials for a particular stimulus by the total number of trials with the same stimulus. Visual CORR was the probability of correct responses obtained with the visual stimulus. Auditory CORR was the probability of correct responses obtained with the auditory stimulus.

The signal detection parameters of discriminability and response bias were calculated for the tone/light probability pairs (tone/light): 90/10, 50/50, 10/90.

Discriminability (d), a measure of the ease with which the stimuli can be differentiated from each other, was calculated using the following equation.

$$d = \ln\left(\frac{\text{Visual CORR} \times \text{Auditory CORR}}{(100 - \text{Visual CORR}) \times (100 - \text{Auditory CORR})}\right)$$

A value of 0 indicates total confusion between the two stimuli and larger numbers indicate better discriminability between the two stimuli.

Response bias criterion (c), a measure of the tendency to respond to one stimulus-response pair, was expressed as the criterion for tone and calculated using the following equation (Estes, 1982)

$$c = 0.5 \times \ln\left(\frac{\text{Visual CORR} \times (100 - \text{Auditory CORR})}{\text{Auditory CORR} \times (100 - \text{Visual CORR})}\right)$$

Positive values indicate a predisposition to respond as if the light had been presented. Negative values indicate a bias to respond as if the tone had been presented.

Within each stimulus type and probability, the data from each of the delays were pooled and analyzed together. RTs and choice accuracy were compared using a two-way analysis of variance (ANOVA) with repeated measures in which the factors were stimulus type (light or tone) and stimulus probability (90%, 50%, 10%). Discriminability and response bias for the 90/10, 50/50 and 10/90 (tone/light) conditions were compared using a one way ANOVA with repeated measures. Post-hoc analyses were performed with the Newman-Keuls' Multiple Range Test using critical differences calculated at the $p < 0.05$ level.

Results and Discussion

Expectancy, as manipulated by the relative probability of an auditory or visual stimulus, altered response bias, shifting it toward the response associated with the more frequent stimulus. As the visual stimulus became more prevalent, the bias to respond on the left lever increased. As the auditory stimulus became more prevalent, the bias to respond on the right lever increased. In the 50/50 condition where both stimuli occurred with equal probability, response bias was not significantly different from zero, indicating an absence of response bias. In contrast, discriminability between the visual and auditory stimuli did not change as the stimulus probability was manipulated.

The shift in response bias to the more frequent stimulus was associated with changes in RT and CORR. RTs were faster and CORR was higher when the probability of the visual stimulus was high. Human subjects also respond faster to frequent stimuli than to infrequent stimuli. This pattern of results may be generated by a reduction in response criterion as the stimulus probability increased.

Auditory stimuli, as compared to visual stimuli, produced a similar pattern of results for CORR, but not RT. Increasing the probability of the tone increased CORR, but did not change RT. The constant RT to tone at all stimulus probabilities may be due to a "floor" effect. Evidence for this is the observation that RTs to infrequent auditory stimuli (10% condition) were faster than RTs to frequent visual stimuli (100% condition). Another possibility is that the auditory stimulus may be more significant than the visual stimulus because the stimuli were not equated psychophysically. If the auditory stimulus were psychophysically intense, it may capture attention, as proposed for human subjects.

In summary, expectancy produced in a shift of response bias to the more frequent stimulus, but did not alter discriminability. As the probability of a stimulus increased, the CORR increased and the visual RT decreased.

Experiment 2: Humans

Introduction

The goal of Experiment 2 was to measure the effects of expectancy in humans using the same procedure as those used for rats in Experiment 1. If humans and rats have similar processes of expectancy, Experiment 2 should produce the following results in humans: As stimulus probability increases,

(1) RTs should decrease,
(2) choice accuracy should increase,
(3) response bias should shift to the more frequent stimulus, and
(4) discrimination should remain constant.

Methods

Methods were the same as in Experiment 1, except as noted below. Key terms and abbreviations are the same as described in Experiment 1. Three female employees and one male of the Johns Hopkins University participated in this experiment. All subjects had vision that was normal or corrected to normal and normal hearing. An IBM PC-AT compatible computer controlled the experiment and recorded the data. Configurations of the hardware and software allowed millisecond resolution from the internal computer clock; this clock was used for measuring reaction time and delay intervals. A home-made response box had two push button switches on the top of the box; the switches were located 4 cm apart. The response box was connected to the computer game port. A color monitor (Princeton Graphics SR-12) with a Sigma-400 graphics card (Sigma Designs) displayed the visual stimulus. The visual stimulus was a filled light grey rectangle (8cm(H) x 12cm(W)) presented in the center of the monitor screen. The rectangle subtended an angle of 11.3° x 16.7° from a typical viewing distance of 40 cm. The contrast and brightness of the monitor were adjusted to provide a background illumination of 0.22 cd/m^2. The luminance of the visual stimulus was 136 cd/m^2. The internal computer speaker delivered the auditory stimulus and the negative secondary reinforcer (NSR). The auditory stimulus was a 3 kHz tone with a peak amplitude of 80 dB. The NSR was a 500 Hz tone with a peak amplitude of 55 dB.

Training took place in an isolated, enclosed room. Each subject was comfortably seated directly in front of the monitor, speaker and response box. The right and left index fingers of the subjects were placed on the right and left switches, respectively, of the response box. Trials were initiated by pressing both buttons simultaneously. A stimulus was presented following a random interval of 1, 2 or 3 seconds. Following a <u>correct response</u>, the stimulus was turned off and an intertrial interval of 0.5 seconds began. Following an <u>incorrect response</u>, the stimulus was turned off, the NSR was activated for 1 second and a punishment period of 5 seconds was initiated. At the end of the punishment period, an intertrial interval of 0.5 seconds began. Following a <u>premature response</u>, the NSR was activated for 0.5 seconds and a punishment period of 5 seconds was initiated. At the end of the punishment period, an intertrial interval of 0.5 second began.

Each subject had one practice session. Subjects were told to respond accurately to the stimuli and as rapidly as possible. The practice session consisted of six blocks of 50 trials; each of the six blocks utilized one of six stimulus probability conditions in the following order: (probability of tone/probability of light) 0/100, 10/90, 50/50, 100/0, 10/90, 50/50.

One test session was given each day, with 250 trials per session; each session consisted of a single probability condition. A total of 18 sessions (three sessions at each stimulus probability) were given to each subject. No breaks were required

within a session, but subjects were encouraged to rest as long as desired between trials. Each test session lasted about 15 minutes.

Results

Expectancy was strongly influenced by relative stimulus probability. Expectancy shifted response bias toward the more prevalent stimulus. Disriminability remained unchanged as stimulus probability was altered.

The shift in response bias to the more frequent stimulus was associated with changes in RT and CORR. RTs to highly probable stimuli were faster than RTs to less probable stimuli for both visual and auditory stimuli, even though RTs to auditory stimuli were faster than RTs to visual stimuli. CORRs to highly probable stimuli was higher than to less probable stimuli for both visual and auditory stimuli. In fact, CORRs for the two stimulus modalities were similar. In essence, the results from Experiment 2 agree with a long history of studies that demonstrate a faster RT to frequent stimuli as compared to RTs to infrequent stimuli (Hick, 1952; Hyman, 1953). However, both Experiments 1 and 2 were necessary in order to determine similarities in expectancy between rats and humans.

General Discussion

In rats and people, the probability of a stimulus altered response bias but not stimulus discriminability, and changed reaction time to the visual stimulus. Both species shifted their response bias and decreased reaction time to the more probable stimulus. Similar results have been obtained for pigeone. This pattern of results demonstrates that rats and people use the probability of previous events to develop an expectation about the probability of future events.

Expectancy may influence both perceptual and response processes. Perceptually, expectancy can alter the amount of information received by the subject. By directing attentional processes to the expected stimulus, the individual can extract more information from that stimulus, reducing reaction time and increasing choice accuracy. This beneficial effect of expectancy may have an associated cost of withdrawing attention from unexpected stimuli so that less information is extracted from them. Expectancy can also have its effects at the response stage. At this level, expectancy may alter the criterion for a response (Fitts, 1966), so that the response is made more quickly. Again, this beneficial effect of expectancy may have an associated cost, manifested as an increased reaction time to an unexpected stimulus.

The present experiment makes two contributions. First, it introduces an experimental procedure to measure two-choice reaction time in rats. Although experiments have measured the reaction time of a single response in rats this procedure is the first that allows measurement of reaction time for two independent responses

in rats. Because this type of procedure is so widely used in the investigation of attentional processes, the development of such a procedure for animals can provide the opportunity to answer important questions about the cognitive and neural mechanisms involved in different types of attention.

The second contribution is to demonstrate that expectancy has similar effects in rats and humans. Animal models of cognitive processes are particularly important in ascertaining the neural bases of these cognitive processes because only animals allow direct manipulation and measurement of brain activity at the cellular level. Creating good animal models is assisted by having similar independent and dependent variables in both species, as was done here. The similar effects of expectancy on bias and discriminability in both rats and people indicates that the two species may well have some common mechanisms underlying the effects of expectancy, and the procedures described in this manuscript provide a means to examine further the cognitive similarities, and their underlying neural mechanisms.

Although these projects are still in the early stages of development, the information has already been presented in two scientific meetings (Society for Neuroscience, 1989; American Psychological Association, 1990), one manuscript has been submitted for publication, and other manuscripts are being prepared for publication in scientific journals. Consequently, the progress made here is already available to influence other scientists, and will be disseminated more broadly during the future funding period.

Presentations

Pang, K., Olton, D.S., Egeth, H. Frontal cortical cells of rats are activated in a divided attention task. Society of Neuroscience, 19th Annual Meeting, Phoenix, Arizona, November 3, 1989, 314.13, part I, page 790.

Olton, D.S. Cognitive neuroscience and the error of the diagonal: Brain mechanisms of memory and attention. American Psychological Association, Division 3 Invited Address, Boston, Massachusetts, August 10, 1990.

Manuscripts Submitted

Pang, K., Merkel, F., Egeth, H., Olton, D.S. Expectancy and attention: A comparative analysis in rats and humans using two-choice reaction time procedures. Submitted to Perception and Psychophysics.