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Spatial generalization and peak shift in humans

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Abstract

Using a computer betting game, five experiments tested university students on spatial generalization and peak shift. On each trial, one location was marked and the subject was invited to bet 0–4 points. At the winning location (S+), bets won four times the points betted. At nearby losing locations (S−s), points betted were lost. Generalization gradients were exponential in shape, supporting Shepard's (1987), law (Experiment 1). With peak shift manipulations, three kinds of peak shift or area shift were found. (1) Subjects betted more on the S+ side than on the S− side (Experiments 2–4). (2) When asked if a location was the winning location, subjects responded "yes" more often to locations on the S+ side than to locations on the S− side (Experiments 3–5). (3) When asked to point to the winning location on the screen, subjects' errors indicated peak shift (Experiment 5). © 2002 Elsevier Science (USA). All rights reserved.

When an organism has been rewarded for a particular behavior in a particular stimulus situation, it is likely to exhibit the same behavior in similar stimulus situations that are nevertheless different. This ubiquitous phenomenon is known as stimulus generalization. Experimentally, generalization is studied by first training a subject to perform a response to one stimulus (the S+). Unrewarded tests are then given with a range of stimuli, including the

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S+. Typically, only one dimension of the stimulus is varied, and the amount of responding the organism makes to each stimulus is recorded.

In a classic example, Guttman and Kalish (1956) reinforced pigeons for pecking a key in the presence of a particular wavelength of light. Different animals were trained with different wavelengths as S+. After training, the pigeons were tested in extinction with a range of wavelengths, including S+. The pigeons pecked most to S+ and pecked less to stimuli with increasing wavelength difference from S+. Mechanisms proposed for generalization, going back to Spence (1937), rely on the notion of spreading activation. Basically, excitation or activation of a representation of S+ spreads to representations of stimuli similar to S+. The spreading process has been implemented in diverse ways (e.g., Blough, 1975; Cheng, Spetch, & Johnston, 1997; Ghirlanda & Enquist, 1998, 1999; Gluck, 1991; Reid & Staddon, 1998; Saksida, 1999; Shepard, 1958a; Spetch & Cheng, 1998; review: Cheng, 2002).

Based on functional considerations, Shepard (1965, 1987) proposed a law of generalization. The gradient should have an exponential shape when plotted over the appropriate scale of stimulus values (discussed shortly). The equation for the universal law is $y = \exp(-kx)$, where y is a measure of the amount or probability of responding relative to responding at S+, k is a scaling parameter, and x is the psychological distance between the test stimulus and S+. It is important to note the conditions under which the law is said to hold (Shepard, 1986). The stimuli tested in generalization must be clearly discriminable to the subject. If discriminating between stimuli is a problem, the shape of the generalization gradient may turn out Gaussian (Ennis, 1988; Nosofsky, 1986, 1988; Shepard, 1986, 1988).

When the stimuli are discriminable, the task of generalization is to classify which stimuli belong in the same functional class as the S+. Shepard (1987) noted that the probability that two stimuli belong in the same class is likely to reflect the exponential function over a wide range of assumptions about the structure of the world. This provides a functional reason for his law of generalization. Mechanistically, a variety of models, with the right parameters, can generate exponential gradients (e.g., Cheng et al., 1997; Reid & Staddon, 1998; Saksida, 1999; Shepard, 1958a,b; Spetch & Cheng, 1998; review: Cheng, 2002).

To derive the psychological scale, two methods may be used. One is multidimensional scaling (Shepard, 1965). A number of overlapping generalization gradients with different S+s are obtained (such as the data of Guttman & Kalish, 1956, which featured as an example in Shepard, 1965). The spacing along the physical scale is then adjusted by multidimensional scaling, subject to monotonicity, to render the gradients as similar as possible when their S+s are lined up. The resulting scale is taken to be the psychological scale, and the form of their common gradient the generalization function. A different approach is to take a theoretically specified scale for the stimulus dimension in question. The appropriate scale is derived from extant theory, and not adjusted to fit data as in multidimensional scaling. Evidence for the exponential law has been found in humans and pigeons (Cheng et al., 1997; Shepard, 1987) and recently in an invertebrate animal, the honeybee (Cheng, 1999, 2000, 2002).

The steepness of the generalization gradients depends very much on the training experience. Gradients become steeper if subjects are given discrimination training in which periods of reinforced responding in the presence of the S+ are randomly alternated with periods during which responding is not reinforced in the presence of a different stimulus, called the S−. For example, Jenkins and Harrison (1960) tested pigeons on generalization across tonal frequency. The birds were tested following either: (1) non-differential training in the presence of a 1000-Hz tone, (2) interdimensional training, in which the S+ was a 1000-Hz tone and the S− was silence, or (3) intradimensional training, in which the S+ was a 1000-Hz tone and the S− was a 950-Hz tone. The generalization gradient was steepest for birds given intradimensional training, and flattest for birds given nondifferential training.

Intradimensional S−s can sometimes affect the location of the peak of the generalization gradient as well as the steepness of the gradient. In the classic demonstration of this *peak-shift effect*, Hanson (1959) gave four groups of pigeons intradimensional discrimination training on the wavelength dimension. The S+ for all groups was 550 nm, and the S− was 555, 560, 570, or 590 nm. A control group received nondifferential training with the S+ only. Following training, all groups were given generalization tests with stimuli ranging from 480 to 620 nm. Only the control group showed a peak of responding at the S+. The other groups responded more to wavelength values below the S+, with the size of the peak shift varying inversely with the magnitude of the difference between the S+ and S− values.

Peak shift has been shown in many dimensions of experience (for reviews, see Honig & Urcuioli, 1981; Purtle, 1973; Rilling, 1977). Sometimes, the peak of the generalization gradient does not shift, but the distribution is asymmetric, with subjects responding more to the S+ side than to the S− side. This effect is called the *area shift* (Rilling, 1977). While the term *peak shift* is sometimes used to refer to effects including both area shift and peak shift proper, we will make a terminological distinction between the two terms in this paper, as both kinds of effects were found in the experiments. Some models of generalization can produce peak shift or area shift (e.g., Blough, 1975; Cheng et al., 1997; Ghirlanda & Enquist, 1998, 1999; Reid & Staddon, 1998; Spence, 1937; Spetch & Cheng, 1998). For example, Spence's classic (1937) theory of generalization assumes that an excitatory gradient forms around the S+ and an inhibitory gradient forms around the S−. If the S+ and S− are close together, the gradients will overlap and responding is assumed to depend on the net excitation that results from summation of these opposing gradients. This leads to a prediction that the peak of responding should be shifted away from the S+ in the direction opposite from the S−, a prediction which has been supported by numerous studies in animals.

In experiments on peak shift in humans, response range effects have been more common (e.g., Thomas, 1974; Thomas, Mood, Morrison, & Wiertelak, 1991; review: Thomas, 1993). Response range effects refer to findings in which the location of the peak of responding depends on the range of stimuli used in testing. Thomas et al. (1991) showed subjects a number of samples of S+ and S−. Dimensions of experience included brightness and line tilt. Subjects were then presented a range of stimuli. They were asked to respond yes (it was the S+) or no (it was not the S+) without feedback. Results showed that where subjects peaked in responding depended largely on the response range used. The interpretation Thomas et al. gave for the response range effects was that subjects coded stimuli relatively. For instance, if S+ was brighter than S−, S+ was coded as brighter than average, while S− was coded as dimmer than average. As tests were given, the average was determined more and more by the range of stimuli found on tests, and thus the range influenced where the peak of responding was found.

Thomas (1993) reviewed stimulus generalization in humans, including generalization, go/nogo (peak shift), and choice paradigms. He claimed that a model of adaptation level can account for many findings in each paradigm. Briefly, an adaptation level is some average value of the stimuli encountered, including possibly stimuli encountered before the experiment proper. Stimuli are coded relatively, in terms of their relation to the adaptation level. The adaptation level is hypothesized to change gradually during testing, from the average of the training stimuli to the average of the test stimuli. The relation to the adaptation level might also be in part relative. For example, suppose that S+ is coded as something like "adaptation level plus a bit." That "bit" might become larger if the range of test stimuli is much larger than the range of training stimuli.

Thomas (1993) reviewed much evidence in support of adaptation level theory in human stimulus generalization. Little support was reported for any other account. In fact, only one cited study (Newlin, Rodgers, & Thomas, 1979) produced some evidence for processes other than those posited by adaptation level theory. Our purpose in these studies is to see if humans show peak shift when adaptation level theory is 'controlled for.' We took steps to keep the adaptation level constant throughout training and testing, and we tested for range effects, which we did not expect to find. We were interested in finding out whether peak shift can arise in part from misperceiving or misremembering the nature of S+. In doing so, we are not attempting to rule against adaptation level theory. We take the evidence for adaptation level to be solid. Rather, we wanted to find out if other processes can also contribute to peak shift in humans.

The dimension for the experiments was spatial location. In earlier work, we reported on generalization, peak shift, and area shift in the spatial domain in pigeons (Cheng et al., 1997). Pigeons were presented with locations marked on a computer monitor by a blue square. In all, 11 locations ranging horizontally across the middle of the monitor were presented. During initial training, the location just to one side of center was the S+, while the location just on the other side was the S− (that is, locations 5 and 7 counting from the left). When S+ was marked, the pigeons were rewarded on an FI 5 s schedule; when S− was marked, no reward was dispensed. After initial training with S+ and S−, the birds were tested without reward occasionally on all locations, including S+ and S−. Training trials continued throughout the test phase. Except for one data point, generalization gradients were exponential in shape, supporting Shepard's law. An area shift was found in two experiments. The area shift faded quickly (in six tests). Consistent with Spence's theory, when the S+ and S− were moved closer to one another, a lasting peak shift was found.

In this paper, we report experiments on spatial generalization and peak shift in humans, in paradigms similar to those used on pigeons by Cheng et al. (1997). Experiment 1 tested Shepard's law, while the rest of the experiments examined peak/area shift. We were careful to control for and examine the effect of test range in our experiments, and we tested peak/area shift in three different ways. Subjects participated in a computer betting game. A location on a computer monitor was marked, and the participant was invited to bet 0–4 points. The winning location (S+) won them four times the points betted. S− locations lost them the points betted. Subjects were only occasionally tested while S+ and S− training trials continued to be presented. Across experiments, three different kinds of tests were given. (1) Unrewarded betting tests were occasionally given. (2) Subjects were sometimes presented a location and asked verbally (in writing) whether it was S+ (the location that had won them the most points). (3) Subjects were asked to point to the location on the monitor that had won them the most points.

Experiment 1

Experiment 1 tested spatial generalization. Our goal was to verify Shepard's law in this paradigm, and to ensure that the methods of the betting game produced sensible results. The range of stimulus locations consisted of 11 evenly spaced locations along a horizontal row. Four different groups of subjects had different S+ locations, those being the third, fifth, seventh, and ninth locations. After some initial training with S+, all locations were presented on tests interspersed with S+ training. In testing Shepard's law, our a priori hypothesis was that the appropriate spatial scale for humans is linear. This means that equal physical distances on the monitor correspond to equal perceived or psychological distance. This in turn predicts that the shapes of generalization gradients will be similar (when lined up at their respective S+s) for all groups of subjects (with different S+ locations). We thus compared the shapes of gradients for different groups to ensure that our linear hypothesis was correct. Shepard's law can then be tested by using a linear (untransformed) x axis.

Methods

Participants

Students studying introductory psychology at the University of Alberta participated for course credit. Out of 26 who participated, we used the data from 21 subjects (14 female, 7 male, ranging in age from 18 to 26 years) whose discrimination scores (see below) were above 0.64.

Materials

Stimuli were presented on a 486 PC with a color monitor and keyboard. The display area of the monitor screen consisted of a light grey background, measuring approximately 24.3 cm wide by 18 cm high, bordered by a black frame. The location stimulus was a dark blue square (approximately 1.1 cm^2). The square was centered on the screen vertically and was presented at one of 11 horizontal locations, spaced approximately 1.1 cm apart (center to center). The 6th location was centered on the screen so that there were 5 locations left of center and 5 locations right of center. Responses (bets) were recorded using the number pad of the keyboard.

Design

Participants were assigned in mixed order to one of four conditions ($N = 5$ or 6 per condition) that differed in the location of the S+. Of the 11 locations presented during the experiment, the S+ was located at positions 3, 5, 7, and 9. All groups received non-differential training with the S+ only. Sessions consisted of a training phase followed by a test phase.

Procedure

At the beginning of the experiment, participants were given the following instructions: (1) Your goal is to earn as many points as possible. (2) Each trial will start with a blue square. At that time you may place your bet. (3) You can bet 0, 1, 2, 3 or 4 points. Enter your bet using the number keys. (4) Either you will win 4 times the number of points you bet, or you will lose the points you bet. If you bet 0, you will neither win nor lose points. (5) Your chances of winning are determined by something on the computer screen. You should try to figure out what this is and then bet accordingly.

After confirming that the participant wished to continue, the experimenter then started the program and left the room. Ten training trials with the S+

location were given. The blue square remained on until a bet was placed (i.e., the subject pressed number 0, 1, 2, 3, or 4 on the keyboard). If one or more points were betted, a message was displayed on the screen that stated "You win *x* points." Zero bets were followed simply by the message "0 points" (i.e., the message did not provide feedback about whether points would have been earned or lost had the participant bet points). In all cases, a second message was displayed below the first to indicate the cumulative total of points for the session. In addition, a message at the bottom of the screen instructed participants to hit the enter key to advance to the next trial.

During testing, participants received 5 blocks of trials in which generalization tests were interspersed among the training trials. Each block during testing consisted of 14 S+ trials and one trial at each of the 11 test locations used. On all test trials (including test trials with the S+ location) points betted were lost. The message "You lose *x* points" appeared on the monitor.

To determine whether subjects met the criterion for inclusion in the experiment (discrimination ratio of 0.64 or greater), we calculated discrimination ratios for the test portion of the session. These ratios were calculated by dividing bets made on test trials at the S+ location by the sum of bets made on test trials at the S+ location and a location 2 units away. Statistical tests are considered significant at the .05 level.

Results

The generalization gradients are presented in Fig. 1. Points betted were first averaged across subjects, and then relativized as a proportion of betting at S+. Each gradient shows the classic drop as a function of distance from S+. What is not shown in Fig. 1 is that betting levels dropped off after the first test at each location except S+. This pattern is shown in subsequent experiments.

For statistical purposes, we divided the five rounds of tests into three blocks: test 1, tests 2 and 3, and tests 4 and 5. Before curve fitting, we analyzed whether the gradient about S+ was similar for all S+ locations. For this purpose, we lined up all the functions at their respective S+s, and considered only five locations for each function, two locations on each side of S+ plus S+ itself. In the mixed-model analysis of variance (ANOVA), S+ location was a between-subjects factor, and block and location were within-subjects factors. The ANOVA found significant main effects of block ($F(2,30) = 14.14$) and location ($F(4,60) = 36.26$), and no other significant effects. The lack of interaction with S+ location suggests that all the gradients are similar. To test if the gradients were symmetric about S+, a priori contrasts were then conducted to compare corresponding locations on either side of S+, that is, the two locations one unit from S+, and the two locations two units from S+. Neither contrast was significant. This justifies averaging both sides of all the gradients to increase sample size, as we do in our curve-fitting exercise.

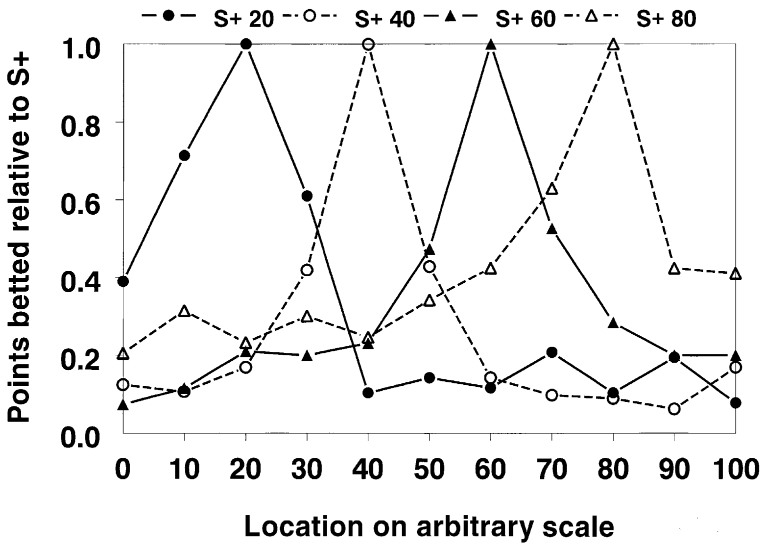

Fig. 1. Generalization gradients from four groups with different S+ locations. Points betted were averaged across subjects and then relativized to amount betted at S+.

Curvefitting

The statistical analyses showed that when lined up at the S+, the different gradients do not differ statistically. If we attribute differences between functions to sampling errors, it follows that the gradients are the same when plotted on the linear (untransformed) scale. We thus examined the form of the generalization function on a linear scale. For each subject, we expressed the data as a proportion of betting at S+, averaging over all tests. One reviewer pointed out that it is unclear how the scale of points betted translates to willingness to bet. We thus transformed data to probability of responding by recoding bets of 0 or 1 as 0 (no bet), and bets of 2, 3, or 4 as 1 (bet). The probability of betting at six distances from S+ were calculated. In cases with locations on two sides of S+ at the same distance, the two were averaged. In cases with only a location on one side of S+ (e.g., at 6 units distance from S+), we used just that value. We thus ended up with one gradient, averaged over all subjects and both sides (Fig. 2).

In Fig. 2, the x-axis was expressed as arbitrary units, with the distance between successive locations being set at 1. Data points, with 95% confidence intervals shown, were fitted by two functions using the least-squares criterion. The exponential fit took the form of $y = \exp(-kx)$, while the Gaussian fit took the form of $y = \exp(-kx^2)$. The scaling (free) parameter k was estimated to the nearest 0.01. Using the least absolute deviation rather than the least-squares criterion produced similar results.

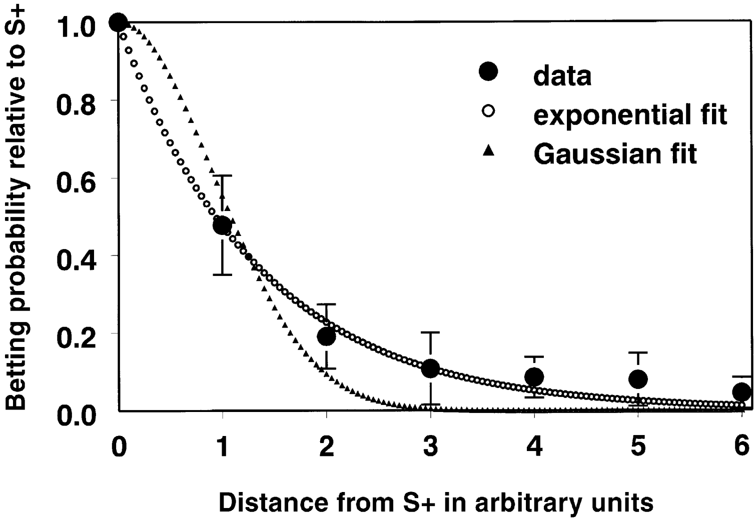

Fig. 2. Exponential and Gaussian fits of spatial generalization data. Data were expressed as a proportion of bets at S+ for each subject, and then averaged across subjects and both sides of S+. Error bars show 95% confidence intervals. Exponential ($y = \exp(-0.74x)$) and Gaussian ($y = \exp(-0.59x^2)$) fits, with the scaling parameter to the nearest 0.01, were the best by the least-squares criterion.

The best exponential fit ($k = 0.74$) has a root mean square error of 0.036, and Fig. 2 reveals no systematic errors in curvefitting. The best Gaussian fit ($k = 0.59$) has a root mean square error of 0.091, and has misfits (outside of the 95% confidence interval of the data) at five data points. An analysis using points betted instead of probability of betting produced similar results (not shown). We can conclude that an exponential function over a linear scale fit the data from human spatial generalization, supporting Shepard's law.

Discussion

The exponential fit in spatial generalization comes as no great surprise since Shepard (1987) found that many other cases of generalization in humans are in accord with an exponential gradient. Spatial generalization in pigeons (Cheng et al., 1997, Fig. 6) and honeybees (Cheng, 1999, 2000, 2002) also supported Shepard's law.

Experiment 2

The betting paradigm produced sensible generalization gradients, making it a suitable paradigm for studying peak shift (Experiments 2–5). Experiment 2 tested for the peak shift effect across the range of 11 locations. Subjects in the peak shift group were first trained with S+ and S−, and then tested occasionally. During the test phase, all 11 locations were presented for betting. A control group was trained only with the S+ location, and tested with the same 11 locations. Points betted on unrewarded tests formed the dependent measure.

Methods

Participants

Students studying introductory psychology at the University of Alberta participated for course credit. The participants ranged from 18 to 26 years of age. Out of 28 who participated we used the data from 25 subjects (16 females and 9 males, ranging from 18 to 26 years of age) whose discrimination scores were above 0.64.

Design

The same apparatus used in Experiment 1 was used in this experiment. Participants were assigned in mixed order to one of four conditions that differed in the location of the S+ and in whether they received training trials with the S− location. Two groups received non-differential training with the S+ only. For one of these groups ($N = 6$), the S+ was at Location 5 (just left of center), and, for the other group ($N = 5$), the S+ was at Location 7 (just right of center). The data from these two groups were reported in Experiment 1 as well. Experiment 1 examined a different aspect of generalization, the shape of gradients rather than peak shift. We could find no objections to using the same data and did not run another set of subjects in the same conditions. The remaining two groups ($N = 7$ for each) received discrimination training, one with the S+ at location 5 and the S− at location 7, and the other with the S+ at location 7 and the S− at location 5. For all groups, sessions consisted of a training phase followed by a test phase.

Procedure

The procedure followed that used in Experiment 1. For participants in the two discrimination training groups, the number of training trials received by participants depended in part on discrimination accuracy: After each block of 10 training trials (5 S+ trials, 5 S− trials), a discrimination ratio was computed (points betted on S+ trials/total points betted on S+ and S− trials). Testing was initiated if the discrimination ratio was 0.8 or greater, or after a maximum of 3 blocks. Participants assigned to the non-differential training conditions received 10 training trials, all with the S+ location.

During testing, participants received 5 blocks of trials in which generalization tests were interspersed among the training trials. For participants in the discrimination training groups, each block consisted of 14 S+ training trials, 14 S− training trials and one trial at each of 11 test locations. The 11 test locations consisted of the S+ location, the S− location, one location between them and 8 locations on the outside of the range (4 on the S+ side and 4 on the S− side). For participants in the non-differential training conditions, each block during testing consisted of 14 S+ trials and one trial at each of the same 11 test locations used for participants in the discrimination training groups. All test trials (including test trials with the S+ location) functioned like S− trials in that participants lost any points bet.

We again excluded subjects with discrimination ratios below 0.64. For subjects in the discrimination training groups, these ratios were calculated by dividing bets made on test trials at the S+ location by the sum of bets made on test trials at the S+ location and the S− location. For subjects in the nondifferential training condition (who did not experience the S− location in training), we calculated similar discrimination ratios based on the hypothetical S− location (i.e., the location that would have served as the S− had they been assigned to the discrimination training condition). In Experiments 2–4, we will ignore the factor of whether the S+ location was on the right or left. We initially did statistical tests including this factor, but found only one significant interaction in four experiments, a result we attributed to type I error. Alpha level was again set at $p = .05$.

Results

Betting

The number of points betted on each location is shown in Fig. 3. The discrimination group showed an asymmetric betting pattern on the first block of trials, but thereafter, betting became roughly equal on both sides of S+. The nondifferential group showed a roughly symmetric distribution throughout.

Bets were again divided for statistical purposes into three blocks: first test, tests 2 and 3, and tests 4 and 5. Locations were coded with respect to S+ and S− for all groups; that is, for half the participants, the distribution was reflected about the middle location. A between-subjects factor was training regime (discrimination vs. nondifferential). The mixed-model analysis of variance (ANOVA) revealed significant main effects of block ($F(2,46) = 37.39$), location ($F(10,230) = 66.38$), and significant interactions of block × location ($F(20,460) = 2.30$), and training regime × block × location ($F(20,460) = 1.84$). The block main effect indicates that betting levels dropped after the first test. The block by location interaction indicates that the betting did not drop for S+. The triple interaction reflects the fact that the differences in the spatial distribution of betting between the two groups were greatest in the first block. For the discrimination group, we examined symmetry of betting on the two sides of S+ by running an ANOVA on the discrimination group only and contrasting (a priori) the four locations on either side of S+. Betting was significantly higher on the S+ side ($F(1,130) = 30.76$).

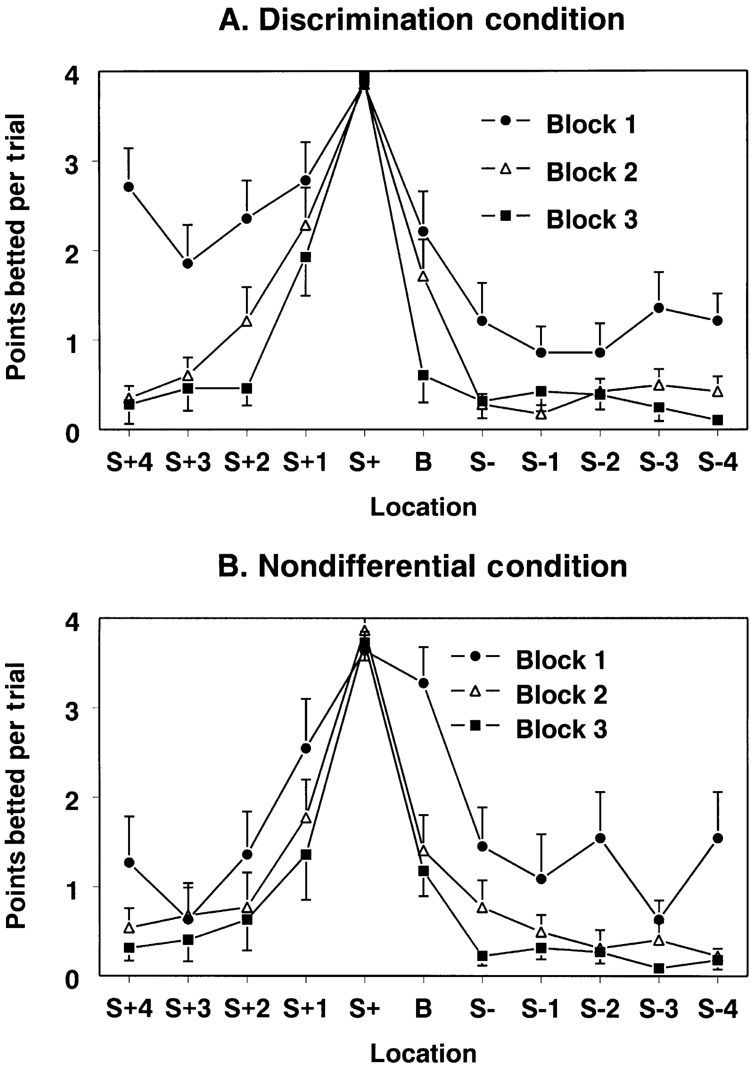

Fig. 3. Pointed betted (±*SEM*) in Experiment 2 for subjects in (A) the discrimination condition, and (B) the nondifferential condition. Block 1 was test 1, block 2 was tests 2 and 3, and block 3 was tests 4 and 5.

Discussion

In this experiment, spatial area shift was found. Participants trained with a peak shift regime (i.e., discrimination training) betted more on the side of S+ away from S−. The effect was transient. It was found mainly on the first bets at new locations. By the final block of betting, the pattern had become close to symmetrical. The results parallel those of pigeons tested on a similar task but with wider interstimulus spacing, with food as reward rather than points (Cheng et al., 1997). For pigeons as well, the spatial area shift disappeared quickly with repeated tests: after 6 tests, the distribution of responses became symmetric about S+.

Experiment 3

Experiment 3 repeated the discrimination training conditions of Experiment 2, but tested each subject on only a subset of the positions used in Experiment 2. The locations tested ranged from one end to either the S+ or the S− location, whichever was farther. Cheng et al. (1997) carried out the same experiment on pigeons. Testing over a restricted range tests for range effects or different patterns of generalization depending on the range used in testing. With the method of using only occasional tests, Cheng et al. (1997) found no range effects in experiments on peak shift with pigeons. This experiment also provided a further test of the area shift found in Experiment 2. Subjects tested on the S+ side should bet more (on the S+ side) than subjects tested on the S− side (betting on the S− side).

We added a check on subjects' ability to discriminate stimulus locations. After all betting trials, we added 15 trials in which subjects were asked to identify whether a location was S+ or not. The S+ location and its two neighbors were presented, and the subjects were asked if each location was the one at which they won the most points. This check on discrimination helped us interpret the data from Experiment 2. In particular, it allowed us to test the hypothesis that betting at locations next to S+ arises in part because of a failure to discriminate S+ from its neighbors, or a confusion in memory as to which location was S+. An alternative is that memory for locations was perfect, and the asymmetry in betting was caused solely by the propensity to bet differently on the S+ and S− sides. If discrimination and memory for the S+ location are both good, then S+ should be identified as the location winning the subjects' most points. A confusion about the location of S+, however, would mean that $S + 1$, the location adjacent to S+ on the S+ side, would be identified as the winning location as much or more so than S+.

Methods

Subjects

Students studying introductory psychology at Macquarie University participated for course credit. Out of 35 who participated, we used the data from 24 subjects (9 males, 15 females, ranging from 17 to 24 years in age) whose discrimination scores were above 0.64. Subjects were assigned at random to one of four conditions to provide six subjects with acceptable data in each condition.

Materials

Stimulus materials were presented on a 386 PC. The light grey background, measuring approximately 24.3 cm wide by 18 cm high, was bordered by a black frame. The stimulus location was marked by a dark blue square (approximately 1.1 cm on each side). The 11 locations used were determined in the same way as in Experiment 1. On the last 15 trials of the experiment, three lines of words consisting of a question and instructions for responding appeared below the stimulus. The distance between the top of the words and the bottom of the square measured approximately 1.6 cm. The left side of the words (left-justified) lined up with the left side of the middle location (thus they were just to the left of center).

Procedure

Subjects were given instructions much like those given in Experiment 2. The instructions included mention that the last 15 trials consisted of questions. Each subject was given 175 trials. Training and test trials were presented as in Experiment 1, except that tests were done only over a restricted range of seven locations.

On the last 15 trials, subjects were presented with one of three locations: the S+ location, or the locations immediately next to S+ on either side, five times at each location arranged at random. The instructions were: Is this the location at which you won the most points? Type y for yes, or n for no. No feedback was given.

Design

The four conditions differed by S+ location (right or left of center) and range tested (right side or left side). Rather than right and left, we recoded the sides as S+ or S−. The S+ side ran from S− to the four locations beyond S+, and the S− side ran from S+ to the four locations beyond S−. Statistical tests were considered significant at an alpha level of .05.

Results

Betting

Consistent with the results of Experiment 2, subjects betted more on the S+ side than on the S− side (Fig. 4). The points betted were analyzed with a mixed-model ANOVA, with side (S+ or S−) as a between-subjects factor, and test number (1 to 5) and location (5 levels) as within-subjects factors. For locations, we used only five in each condition. S+ was included for all subjects. For subjects tested on the S+ side, the four locations on the S+ side next to S+ were also included, while for subjects tested on the S−

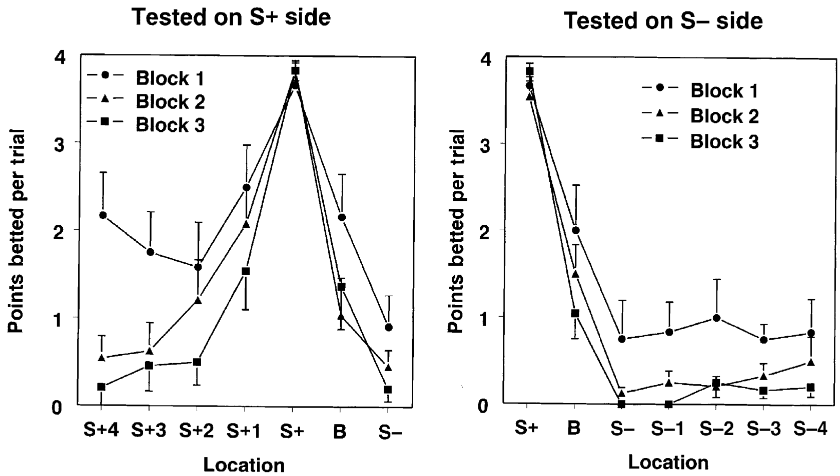

Fig. 4. Points betted (±*SEM*) in Experiment 3 for subjects trained and tested on the S+ side (left) and subjects trained and tested on the S– side (right).

side, the four locations on the S– side next to S+ were also included. The ANOVA revealed that betting was significantly higher on the S+ side than on the S– side ($F(1,22) = 6.23$), indicative of area shift. It also revealed significant effects of location ($F(4,88) = 125.66$), test ($F(4,88) = 9.81$), and test × location ($F(16,352) = 1.77$). These effects indicate, respectively, that subjects betted most on the S+ location, that subjects betted most on the first test, and that the drop in betting over tests was found only for locations other than S+.

Questions

Fig. 5 shows the proportion answering "yes, this was the location that won me the most points" to different locations presented. The results showed that which side the subject had previously been tested on made an enormous difference to the outcome. Subjects previously tested on the S+ side, for whom the tested range included both neighbors of S+, were on the whole accurate: They chose S+ most often as the winning location. Subjects previously tested on the S– side, for whom the tested range was entirely on one side of S+, showed a peak shift. They did not choose S+ most often as the winning location, but the location that they had never before encountered, the neighbor of S+ on the side away from S–. Formal statistics confirms these impressions. The proportions of "yes" answers were subjected to a mixed-model ANOVA with side of previous testing (S+ or S–) as a between-subjects factor, and location (neighbor on S+ side, S+, neighbor on S– side) as a within-subjects factor. A significant main effect of location was obtained ($F(2,44) = 13.69$), as was a significant interaction between location and side of previous testing ($F(2,44) = 9.35$).

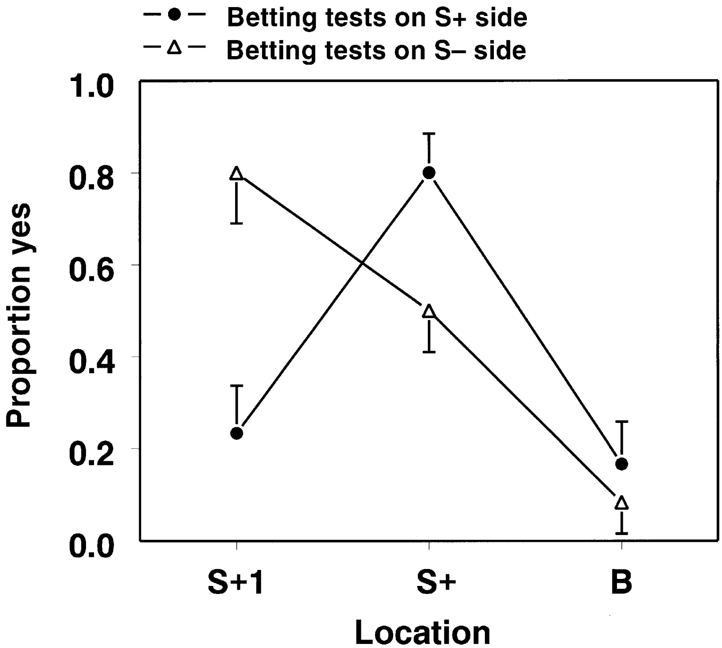

Fig. 5. Proportion of "yes" answers to the question "is this the location at which you won the most points?" (±*SEM*) in Experiment 3.

Comments

Of interest were comments from two subjects with the S+ on the right side and tested with the left side of the range. These subjects never encountered locations to the right of S+ during testing; they were presented one location to the right of S+ only in the yes/no questions at the end. Both commented that *two* positions to the right of center won points (our emphasis)! These comments corroborate the peak shift found in the questions on the location of the winning spot.

Discussion

The results of Experiment 3 replicated those of Experiment 2, and those of pigeons (Cheng et al., 1997). In betting, the spatial area shift was still found, across subjects, when only a subset of the entire range was presented on tests. Subjects tested on the S+ side betted more than subjects tested on the S– side.

One interpretation of the area shift is that it all arises from the propensity to bet more on one side. That is, participants discriminated all locations, and remembered which location won points. They betted differently on the two sides, not because they systematically misremembered the S+ location, but because the S− training induced a propensity to bet more on the S+ side. The results of questions on the winning location cast doubt on this betting-propensity-only interpretation. This test did not involve betting and yet subjects who had received betting tests on the S− side picked a location other than S+ most as the winning location.

Exposure to locations on the S+ side during betting tests appeared to abolish the peak shift on location questions. This exposure presumably alerted subjects to the fact that locations on the S+ side as well as those on the S− side did not pay off as well as S+. We expect that in general, this peak shift on yes/no questions will disappear whenever both sides of S+ are presented for betting.

Response range effect is one possible interpretation of this misremembrance of the S+ location. It is also possible that subjects actually misremembered the S+ location when all S− training and testing was on one side of S+. It is very unlikely that such an effect was artifactually caused by the words appearing on the discrimination trials. The words appeared in the same place on the screen for all subjects, but the systematic error depended on the nature of the previous betting experience and not on the S+ location. The systematic error indicates peak shift to us.

Experiments 4a and 4b

Experiments 4a and 4b were an attempt to confirm the interpretation that the peak shift found on questions about the S+ location stems in part from misremembrance of S+ location, and that the opportunity to bet on both sides of S+ prior to the location questions should abolish this peak shift. The experiments also tested explicitly for range effects on the question dependent measure. Asking subjects whether a stimulus is S+, without feedback, is the classic way of testing for generalization and peak shift in humans. Thomas (1993) reviewed many experiments using this method that found response range effects. We therefore varied the range of locations presented during the yes/no questions to determine whether different patterns of peak shift are attributable to different ranges being presented during the questions about S+ location.

Subjects in Experiment 4a served as controls. Like subjects in Experiment 2, they went through some initial discrimination training, and then were presented with a range of locations for betting; the range ran from $S+2$ to $S-2$, and hence included locations on either side of S+. After the betting, they were presented questions about the S+ location, in the same manner as in Experiment 3. We manipulated the location range of the questions between subjects: Some subjects had the range $S+3$ to B (the location between the S+ and S−), while others had the range $S+1$ to $S-1$. Thus, the locations $S+1$, S+, and B were included in both groups and allowed us to test for range effects. Subjects in Experiment 4a were not expected to show a peak shift or area shift effect on the questions.

Subjects in Experiment 4b underwent the same conditions as those in Experiment 4a, with an additional component designed to generate peak shift or area shift on the questions on S+ location. After the initial discrimination training, we presented the subjects with questions about the S+ location, again with two ranges across subjects. On these questions we expected peak shift or area shift in this group. After this question phase, the subjects went through betting and another round of questions about S+ location, parallelling the subjects in Experiment 4a. This allowed us to test whether the rounds of betting eliminated the peak shift or area shift on the questions about S+ location. The area shift effect is a contrast between the $S+1$ and B positions (part of a location main effect), while a range effect is shown by a range $\times$ location interaction. Thus the two effects are orthogonal, and our design allowed us to find both if they existed.

Methods

Subjects

Participants again came from the pool of introductory psychology students at Macquarie University. Of 52 subjects who participated, we used the data from 42 (15 males, 27 females, ranging from 18 to 35 in age) whose discrimination scores were above 0.64. Subjects were randomly assigned to one of eight conditions to provide at least 5 subjects per condition.

Materials and procedure

The materials were the same as those used in Experiment 3. The procedure also followed that of Experiment 3 in general, with a few changes in design. Subjects were given the first phase of discrimination training as in Experiment 3. Subjects in Experiment 4b, but not those in Experiment 4a, were then asked five questions on five locations about whether it was the winning location; this was done in the same manner as in Experiment 3. All subjects then were presented with opportunities for betting, on locations ranging from $S+2$ to $S-2$. Thus, they betted on seven locations, with five bets on each location. S+ locations won points, and all other locations lost points. Another phase of questions on S+ location then followed, again with five questions on each of five locations.

Design

Subjects were assigned to eight groups in a $2 \times 2 \times 2$ fashion. They were either in Experiment 4a or 4b. The two experiments differed in the question phase after initial discrimination training. The S+ location was either on the right or on the left, as in Experiment 3. One of two ranges of locations was presented in the question phases (the same range in both question phases in

Experiment 4b), either from S+ 3 to B or from $S+1$ to $S-1$. Location was a within-subjects factor. For data on betting, the alpha level was set at .05. But because we used the data on questions in several analyses, the alpha level was set more conservatively at .01 for data on questions.

Results

Betting

The pattern of betting (Fig. 6) was similar in the two experiments and replicates the findings of Experiments 2 and 3. An area shift was found on the first block of betting, and this effect diminished over repeated betting. Statistical analyses were performed separately for the two experiments. Each ANOVA had a between-subjects factor of question range ($S+3$ to B or $S+1$ to $S-3$), and within-subjects factors of test number (5) and location (7). For Experiment 4a, the ANOVA revealed significant main effects of test ($F(4,76)=21.86$) and location ($F(6,114)=52.80$) and significant interactions of test $\times$ location ($F(24,456)=2.86$) and test by range ($F(4,76)=2.74$). For Experiment 4b, the ANOVA revealed significant main effects of test ($F(4,76)=10.13$) and location ($F(6,114)=52.55$) and a significant interaction of text $\times$ location ($F(24,456)=2.08$). The test $\times$ location interaction reflects the fact that the area shift diminished over testing. To examine symmetry in betting, we contrasted (a priori) the two locations nearest S+ on the S+ side vs. the S− side. Subjects betted more on the S+ side in Experiment 4a ($F(1,114)=16.53$) and in Experiment 4b ($F(1,114)=41.26$).

Questions

Answers to the questions on S+ location are shown in Fig. 7. An area shift effect is evident in that subjects were more likely to answer "yes" when presented with locations on the S+ side. This asymmetry was found in both experiments, although it was especially strong in the first phase of Experiment 4b. Statistical analyses confirm these impressions.

ANOVAs were conducted only on the locations $S+1$, S+, and B, the three common to both ranges. We first analyzed each experiment separately. A between-subjects factor was range, and within-subjects factors were location for Experiment 4a and location and phase (before betting tests or after betting tests) for Experiment 4b. For Experiment 4a, the ANOVA revealed only a main effect of location ($F(2,38)=33.68$), although the location $\times$ range interaction was significant at the .05 level. For Experiment 4b, the ANOVA revealed only a main effect of location ($F(2,38)=35.46$), with no other effects close to significance. Two orthogonal a priori contrasts were performed on the location factor. Contrasting the S+ location vs. the other two locations revealed a significant effect in Experiment 4a ($F(1,38)=56.28$) and Experiment 4b ($F(1,38)=38.29$). Contrasting the

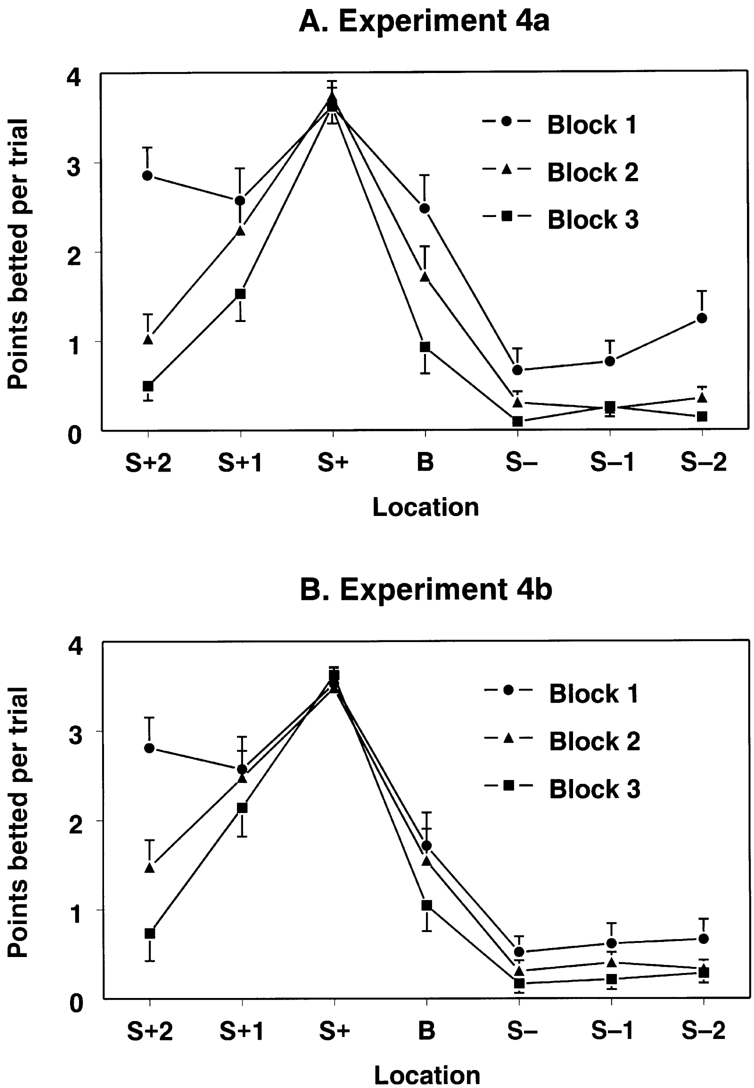

Fig. 6. Points betted (±*SEM*) in Experiment 4. Block 1 was test 1, block 2 was tests 2 and 3, and block 3 was tests 4 and 5.

S + 1 location against B also revealed a significant effect both in Experiment 4a ($F(1, 38) = 11.08$) and in Experiment 4b ($F(1, 38) = 32.63$). Thus, despite our attempt to use Experiment 4a as a control condition, area shift was found in both experiments.

Next, we included results from both experiments in ANOVAs, one using the first phase of questions (before betting tests) from Experiment 4b, and one using the second phase (after betting tests). Each analysis had experi-

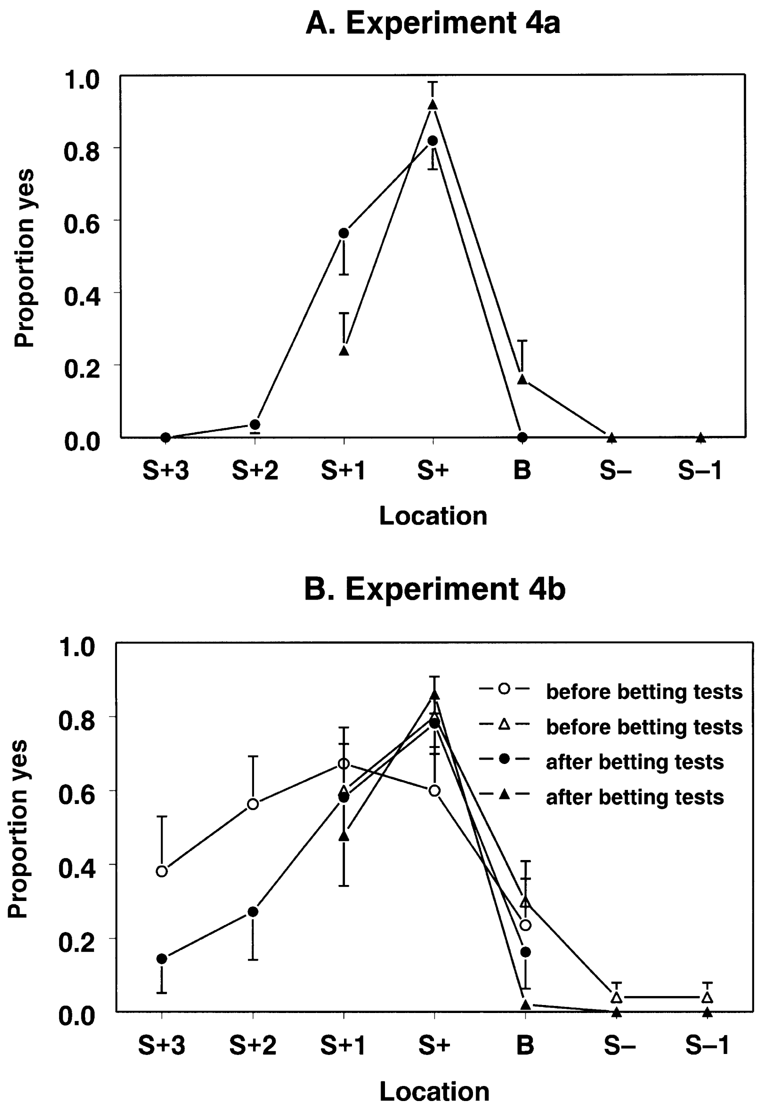

Fig. 7. Proportion of "yes" answers to the question "is this the location at which you won the most points?" (±*SEM*) in Experiment 4. In Experiment 4b, subjects were asked the questions both after initial training but before betting tests, and after betting tests across the range S + 2 to S − 2.

ment and range as between-subjects factors and location as a within-subjects factor. Comparing Experiment 4a with the first phase of questions in Experiment 4b, the ANOVA revealed a main effect of location ($F(2,76) = 37.93$) and an interaction of location × experiment ($F(2,76) = 4.94$). Comparing

Experiment 4a with the second phase of questions in Experiment 4b, the ANOVA revealed only a main effect of location ($F(2, 76) = 57.97$).

The analyses thus show that the proportion of "yes" answers across locations differed between Experiment 4a and the first phase of questions in Experiment 4b, confirming that the area shift was stronger in the first phase of Experiment 4b. The difference between experiments had disappeared by the second phase of questions in Experiment 4b. Range effects, as represented by location × range interactions, were marginal at best and inconsistent.

Comments

One subject in Experiment 4b mentioned in a written comment "a couple of positions to the right of center that would win . . ." indicating a belief that more than one location on the S+ side were winning locations.

Discussion

This experiment has demonstrated area shift in two different ways. The pattern of betting found in Experiments 2 and 3 was replicated. Subjects betted more on the S+ side than on the S− side, reflecting an area shift, with the effect diminishing over bets. Area shift also was found on questions about whether a location was the S+. This was found with both response ranges and in all conditions, and the effect was orthogonal to any range effects, which were marginal and inconsistent in the experiment. The results on yes/no questions suggest that the area shift found in betting arises from more than a propensity to bet on the S+ side.

It surprises us not to find robust range effects, as Thomas (1993) reviewed many experiments showing range effects. We even tried 'fishing' for the effect where it was most likely to be found: in the first block of questions in Experiment 4b. It was not there; the location × range interaction had $F < 1$. Two characteristics of our experiments come to mind as factors mitigating against range effects. One possible factor is some aspect of testing procedure. Typically, wider response ranges and more tests are used (e.g., Thomas et al., 1991). We only examined three locations in looking for range effects, and with fewer degrees of freedom, our statistical tests may not have had enough power to detect range effects. A possible factor is the second dimension of experience in question; we used spatial position and Thomas typically used brightness and line tilt (e.g., Thomas et al., 1991). Only further research can settle this issue.

Experiment 5

In the final experiment, we tested for peak/area shift while controlling for range effects in another way. The innovation here is to add another dependent measure that is not subject to range effects. After peak-shift inducing manipulations, we asked subjects to point to S+ (the "winning location") in the absence of a location stimulus. We dispensed with measures of betting in this experiment, but kept the yes/no questions. Two conditions were run. A Horizontal Training condition used manipulations designed to produce peak/area shift along the horizontal axis, while a Vertical Training condition served as a control, using manipulations that should produce peak/area shift along the vertical but not the horizontal axis. With the pointing measure, range effects are conceptually impossible. The test does not present a range of locations for judgement; in fact, no location stimulus is presented on the screen during the test. Should peak/area shift be found on this measure, we can conclude that it is not due to an effect of response range.

Method

Participants

Students studying introductory psychology at the University of Alberta participated for course credit. Out of 57 who participated, we used the data from 32 subjects (27 females and 5 males, ranging from 18 to 44 years of age) whose discrimination scores met our accuracy criterion of 0.64.

Materials

Materials from Experiment 1 were used, with an infrared touch frame (Carroll Touch, 1492 Smart Frame) attached to the monitor to record touches. The x and y locations of touch responses were recorded with the touch screen.

Design

Sixteen participants were assigned to the Horizontal Training condition and sixteen were assigned to the Vertical Training (control) condition. Within each condition, participants were assigned to one of two versions ($N = 8$ per condition) that differed in the location of the S+ and S− stimuli. Of significance is that in the course of piloting, we changed the possible S+ locations vertically to just above center. Horizontally, the S+ locations remained on each side of center. The diagrams in the left column of Fig. 8 show the location of the S+ and S− stimuli during training (betting trials) and the right columns show the locations of the stimulus during the yes/no questions for each condition and version. The S+ location is shaded for illustrative purposes only. As in the previous studies, only a single location was presented on any given trial, and the location was always marked with a dark blue square. Within each version, half of the participants ($N = 4$) were tested with the yes/no questions first and half were tested with the touchscreen questions first.

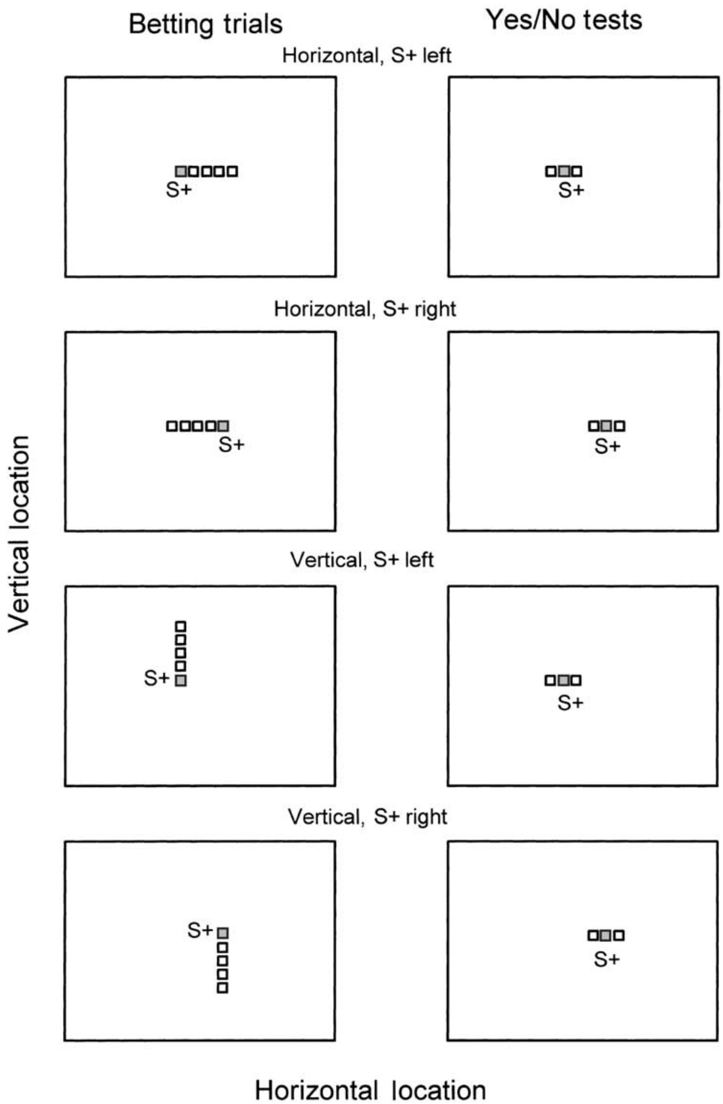

Fig. 8. Diagram (drawn to scale) showing the stimulus locations on the monitor screen during betting trials (left) and yes/no questions (right) for each of the four conditions of Experiment 5. Only a single location was presented on each trial and it was always marked with a dark blue square. The S+ location is shaded in the diagram for illustrative purposes only.

Procedure

To the usual set of five instructions, we added: (6) "Part way through the experiment you will receive some trials on which you will be asked to either touch the screen or answer yes or no. Use the eraser end of the pencil to touch the screen, taking care to hold the pencil straight. To answer yes or no, touch the y or n keys. Try to be as accurate as possible on these questions."

Participants received three blocks of 8 training trials. Each block contained 4 S+ trials and one trial at each S− location, presented in random order. Participants then received a block of test trials. For participants tested in conditions with pointing tests first, testing began with a pointing test trial on which the screen display was blank except for the following message: "Touch the location on the screen at which you won the most points." This message was centered horizontally at the bottom of the screen. The display remained on until the participant touched the screen. Three touch pointing test trials were presented, each followed by a block of 8 training trials. Next, the participant received three sets of yes/no tests, separated by a block of 8 training trials. Each set of yes/no tests consisted of 3 consecutive trials on which the blue square was presented on the screen accompanied by the message "Is this the location at which you won the most points? (y or n)." Within each set of yes/no tests, one trial presented the square at the S+ location, one at the location adjacent to the S+ horizontally on the S− side (S − 1H) and one at the location adjacent to the S+ horizontally on the S+ side (S + 1H). Order of trials was randomly determined within each set. For participants tested with yes/no questions first, the procedure was identical except that the order of the touch pointing and yes/no tests was reversed.

The discrimination ratio was determined by dividing the points betted on S+ trials by the sum of points betted on S+ and all S− trials. Data from participants whose discrimination ratios were below .64 during initial training or either of the test phases were again excluded.

Results

On tests, subjects in the Horizontal Training group showed systematic errors consistent with peak shift in both dependent measures. In the yes/no questions (Fig. 9), response patterns differed for subjects in the Horizontal Training and Vertical Training conditions. Under Horizontal Training conditions, a high proportion of "yes" answers were given to the S+ and S + 1H locations, while few "yes" answers were given to the S − 1H location. Under Vertical Training (control) conditions, "yes" responses were lower overall, but they peaked at the S+ location, and were similar for S + 1H and S − 1H. In pointing, the Horizontal Training subjects erred more than the Vertical Training subjects in the predicted peak-shift direction along the horizontal axis (Fig. 10). Fig. 10 also shows that a systematic error along the horizontal axis was apparent even in the Vertical Training group, at least for the first two tests. Along the vertical axis, the Vertical Training group showed more peak shift than the Horizontal Training group only for one S+ location (right), for which the induced peak-shift direction was up (Fig. 11).

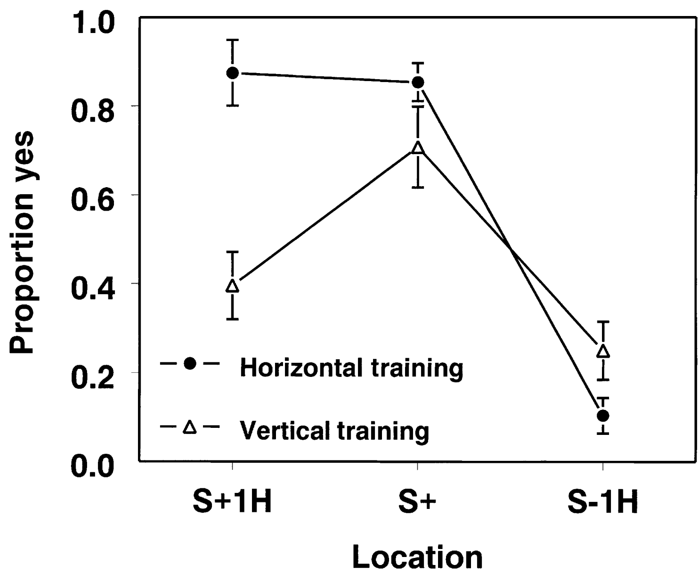

Fig. 9. Proportion of "yes" answers to the question "is this the location at which you won the most points?" (±*SEM*) in Experiment 5.

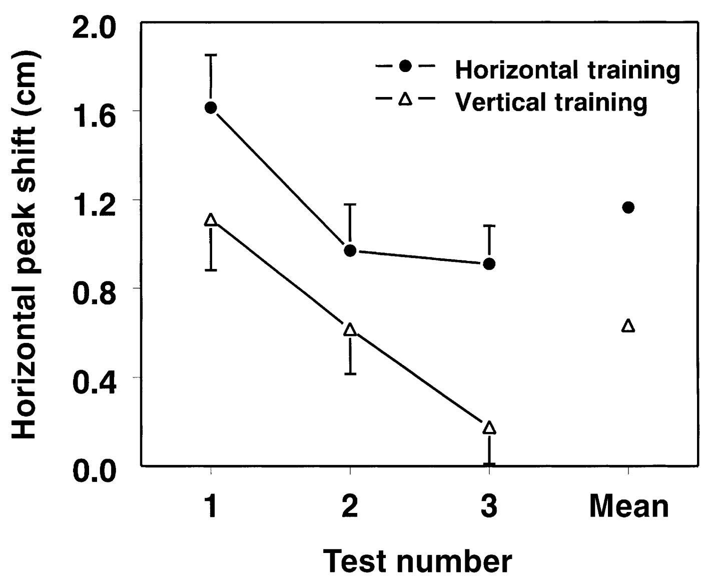

Fig. 10. Horizontal error in pointing in the peak-shift direction (±*SEM*) in Experiment 5.

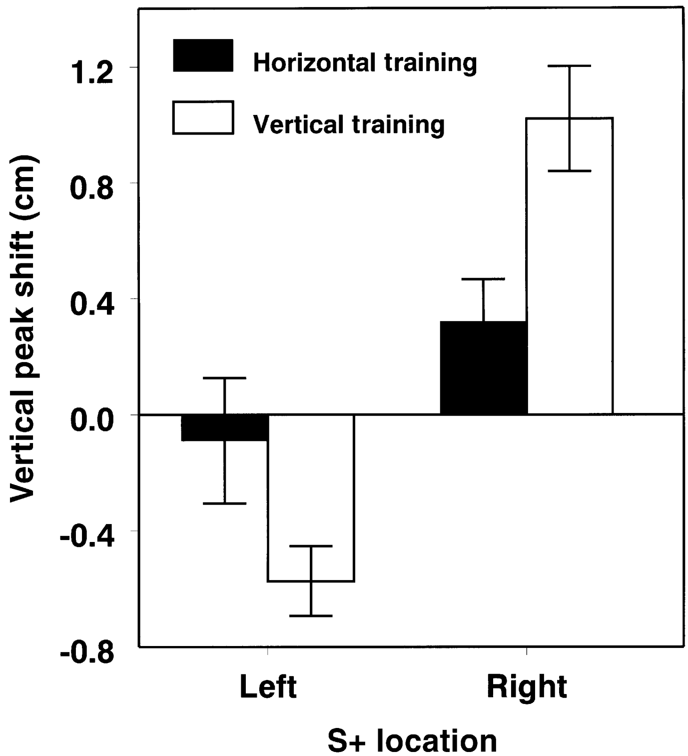

Fig. 11. Vertical error in pointing in the peak-shift direction (±*SEM*) in Experiment 5.

For statistical analyses, a mixed-model ANOVA was conducted on each dependent variable. Between-subjects factors were condition (Horizontal Training vs. Vertical Training), order of testing (2), and S+ location (2). The within-subject factor was location for yes/no questions (3), and test number for pointing (3). On the question data, the ANOVA revealed a main effect of condition ($F(1,24) = 9.28$), a main effect of location ($F(2,48) = 47.40$), and an interaction of condition and location ($F(2,48) = 11.66$). We then ran ANOVAs on each condition separately to conduct a priori comparisons of the S + 1H and S − 1H locations. For the Horizontal Training condition, this contrast was significant ($F(1,24) = 79.06$), indicating a significant area shift. For the Vertical Training condition, the contrast was not significant, suggesting similar levels of responding on the S+ and S− sides.

On the horizontal dimension of the pointing data, the ANOVA showed a main effect of condition ($F(1,24) = 4.99$), and a main effect of test number ($F(2,48) = 20.97$). A significant three-way interaction, with no ready explanation, of test number × order of testing × S+ location was also found ($F(2,48) = 5.01$).

Along the vertical axis of the pointing data, one subject made an error of 6.9 cm on one test. We discarded all the data of this subject on this dependent variable, although her data on the horizontal dimension of pointing and on questions were kept. (The pattern of data and inferential statistics on the horizontal dimension and on questions remain the same without this subject.) The ANOVA revealed a main effect of S+ location ($F(1,23) = 20.14$), and interactions of S+ location with condition ($F(1,23) = 7.02$), S+ location with order of testing ($F(1,23) = 5.15$), and S+ location with test number ($F(2,46) = 7.03$). The S+ location $\times$ condition interaction is shown in Fig. 11. For the right S+ location, the Vertical Training group showed more peak shift. The reverse is true for the left S+ location.

Discussion

This experiment replicates Experiments 3 and 4 in finding an area shift in the yes/no questions. A new finding in this experiment is that systematic errors were also made in pointing to the S+ location, in the predicted peak-shift direction. Along the horizontal axis, this was especially clear. Although both groups showed systematic errors in the peak shift direction, or away from the center, the group undergoing peak-shift induction in the horizontal dimension showed a significantly greater error. Along the vertical dimension, no main effect of peak shift was found, but indications of peak shift were found for one of the S+ locations. We provide an explanation of this below. Overall, the peak shift effect in pointing, which is not subject to response range effects, adds confidence to the results. The different expressions of peak shift (verbal answers and pointing) suggest an error in the memory of the S+ location.

Why were the pointing results ambiguous along the vertical dimension, with peak shift for one S+ location but not for the other? In this experiment, S+ location was confounded with the direction of peak shift induction. We suspect that the difference is attributable to the direction of peak shift induction rather than the S+ location. Both S+ locations used were slightly above the center on the vertical axis. For S+ at the left, the induction was in the downward direction, or toward the center, while for S+ at the right, the induction was in the upward direction, or away from the center. Note also that along the horizontal axis, peak shift induction was in the outward direction, away from the center, for both S+ locations. With locations near the center of either axis, peak shift may be easier to induce in the direction away from the center than in the direction toward the center.

Human spatial judgements often exhibit systematic errors attributable to boundaries (e.g., Tversky, 1981). Huttenlocher, Hedges, and Duncan (1991) have found that humans spontaneously impose boundaries on a circle, dividing it vertically and horizontally at the center (and hence into four quadrants). Judgements often err in a direction away from these subjective boundaries, toward the center of a categorical region. It is reasonable to suppose that our subjects would also impose similar subjective boundaries at the vertical and horizontal center of the monitor. Data in Figs. 10 and 11 give strong hints of systematic errors away from the center horizontally and vertically. We suppose that it is easier to induce peak shift away from a subjective boundary than toward it. The data are consistent with this idea, but of course, complete parametric experiments free of confounding are necessary to test the hypothesis rigorously. The relation between boundaries, subjective and objective, and peak shift needs more research.

General discussion

In these experiments, subjects betted points in a computer game, with payoffs varying according to the location shown on a computer monitor. The S+, a winning location, was near the center of the computer monitor. In Experiment 1, subjects were trained only with the S+ location and then tested for generalization to a range of locations including S+. Generalization gradients were exponential in shape, supporting Shepard's (1987) law. In Experiments 2–5, various S− (losing) locations were presented. Training consisted of S+ and S− trials mixed at random. Area shift and peak shift were demonstrated in three different ways. (1) After the initial training, the university students betted more points on the S+ side than on the S− side, showing area shift. (2) After the initial training, single locations were presented, and subjects were asked if each was the winning location. When S − s were all on the same side of S+, the proportion of "yes" answers was higher on the S+ side than on the S− side (Experiments 3–5), showing area shift or peak shift. (3) After initial training, subjects were asked to point to the winning location. They made systematic errors in pointing consistent with peak shift (Experiment 5).

Spatial generalization

Spatial generalization has now been tested on three species, the pigeon (Cheng et al., 1997), the honeybee (Cheng, 1999, 2000, 2002), and humans (present experiments). The species differ a great deal. The testing methods used differed. But all the results except one data point support Shepard's (1987) law. The data on spatial generalization give some confidence to the universality of the law.

Area shift and peak shift

This is the second vertebrate species in which we have found area shift and peak shift in the spatial domain. The pigeon also shows spatial area shift in the same paradigm (Cheng et al., 1997), with a wider spacing between locations than the humans had in the current study. The pattern of data resembles what we have found here on betting. In both cases, (1) the asymmetry was an area shift, with the most responding occurring at S+, (2) the effect dissipated quickly over repeated tests, and (3) no response range effects were found. In addition, when the pigeons were tested with the spacing we used in these human experiments, they showed peak shift. Although our human subjects did not show a peak shift in betting, they did show a peak shift on yes/no questions and on pointing under some circumstances.

The peak shift found in our experiments cannot be attributed to processes associated with adaptation level theory. This is because we designed the experiments to minimise the role of such processes. We kept the adaptation level constant by giving subjects mostly training trials throughout, with only occasional tests in the test phase. We also checked for range effects, and found no evidence of them. Again, the results do not rule against adaptation level theory, which we consider to have plenty of evidence in its support. Rather, what we have shown conclusively is that other processes can cause peak shift in humans as well. In particular, the results from the questions and the pointing suggest that one mechanism for spatial peak shift is a misperception or misremembrance of the absolute location of S+. Peak shift in nonhuman animals has often been accounted for by interacting gradients of excitation and inhibition, stemming from Spence's (1937) influential ideas. It remains to be seen whether the systematic errors found in these experiments can be explained in this fashion.

Recently, peak shift in the temporal domain has also been tested in pigeons (Spetch & Cheng, 1998). In these experiments, the temporal duration of a stimulus was the dimension varied. S+ was one duration, and S− was another. After peak-shift training, a step function was obtained as a generalization gradient. Durations on the S+ side elicited high pecking rates, while durations on the S− side elicited low pecking rates. The intermediate duration (analogous to B here in Experiments 2–4) elicited an intermediate rate.

Conclusions

These experiments, conducted on humans on a touch-screen task, supported Shepard's (1987) law on generalization, and demonstrated peak and area shifts in the spatial domain. The results in general parallel those found with pigeons (Cheng et al., 1997). Area shift was demonstrated in the willingness of subjects to bet at different locations. Peak shift and area shift were found in the answers that subjects gave as to whether location was the winning location (S+) and in pointing to the S+ location from memory.

Acknowledgments

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