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HUMAN GROUP CHOICE: DISCRETE-TRIAL AND FREE-OPERANT TESTS OF THE IDEAL FREE DISTRIBUTION

GREGORY J. MADDEN, BLAINE F. PEDEN, AND TETSUO YAMAGUCHI

UNIVERSITY OF WISCONSIN–EAU CLAIRE

Ideal free distribution theory predicts that foragers will form groups proportional in number to the resources available in alternative resource sites or patches, a phenomenon termed habitat matching. Three experiments tested this prediction with college students in discrete-trial simulations and a free-operant simulation. Sensitivity to differences in programmed reinforcement rates was quantified by using the sensitivity parameter of the generalized matching law (s). The first experiment, replicating prior published experiments, produced a greater degree of undermatching for the initial choice ($s = 0.59$) compared to final choices ($s = 0.86$). The second experiment, which extended prior findings by allowing only one choice per trial, produced comparable undermatching ($s = 0.82$). The third experiment used free-operant procedures more typical of laboratory studies of habitat matching with other species and produced the most undermatching ($s = 0.71$). The results of these experiments replicated previous results with human groups, supported predictions of the ideal free distribution, and suggested that undermatching represents a systematic deviation from the ideal free distribution. These results are consistent with a melioration account of individual behavior as the basis for group choice.

Key words: group choice, ideal free distribution, matching law, melioration, humans

Ideal free distribution theory (Fretwell & Lucas, 1970) quantitatively describes the behavior of a group of foragers in two or more resource sites or patches. In its simplest ratio form (see Baum & Kraft, 1998), the theory states that

$$\frac{N_1}{N_2} = \frac{A_1}{A_2}, \quad (1)$$

where N is the number of organisms foraging at each of the two resource sites and A is the number of resources available in these sites. Thus, if one patch contains twice as many resources as the other, Equation 1 predicts that, all else being equal, twice as many organisms will forage in that site—an outcome termed *habitat matching* (Pulliam & Caraco, 1984).

Because foragers in a resource site must share the resources available in that site, deviations from habitat matching mean that individuals in one group obtain more resources than the other. For example, if 50 units of food were available each minute in Resource Sites 1 and 2, but 40 animals were in Site 1 and 60 were in Site 2, the animals in Site 1 would obtain 1.25 units of food per minute on average, whereas those in Site 2 would obtain only 0.83 units per minute. Equation 1 implies that if such an unequal distribution of obtained resources occurred, given perfect knowledge of the number of resources available in both sites, some foragers would move to the underpopulated site until average intake levels became equal (Tregenza, 1994).

Pulliam and Caraco (1984) recognized that the ideal free distribution equation is formally similar to the simple ratio version of Herrnstein's (1961) matching law:

$$\frac{B_1}{B_2} = \frac{R_1}{R_2}, \quad (2)$$

where B_1 and B_2 are the number of responses an individual allocates toward each of two concurrently available reinforcement sources and R_1 and R_2 give the number of reinforcers obtained at each of these resource sites. Like Equation 1, the matching law holds that behavior in a choice situation is determined by the relative rate of resources obtained from the two different resource sites. Unlike Equation 1, the matching law applies to the behavior of individuals, whereas habitat matching applies to groups.

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Address correspondence and reprint requests to Gregory J. Madden, Department of Psychology, University of Wisconsin–Eau Claire, Eau Claire, Wisconsin 54702-4004 (e-mail: maddengj@uwec.edu).

Deviations from predictions of the matching law may be quantified by Baum's (1974) generalized version of the matching law:

$$\log\left(\frac{B_1}{B_2}\right) = s \log\left(\frac{R_1}{R_2}\right) + \log b, \qquad (3)$$

where s is a measure of sensitivity to changes in the relative rate of reinforcement and b is a measure of bias (a systematic preference for one resource site not accounted for by the relative rate of reinforcement). As s approaches unity, changes in the behavior ratios across the concurrent schedules are perfectly proportional to changes in the reinforcement ratios, a condition known as *ideal matching*. Values of s less than 1 indicate that changes in behavior are less extreme than changes in reinforcement, a condition of reduced sensitivity known as *undermatching*. Values of s greater than 1 indicate that changes in behavior are more extreme than changes in reinforcement; this enhanced sensitivity is called *overmatching*.

Fagan (1987) expressed a generalized version of Equation 1 to quantify deviations from the ideal free distribution by a group of laboratory pigeons (see also Kennedy & Gray, 1993):

$$\log\left(\frac{N_1}{N_2}\right) = s \log\left(\frac{R_1}{R_2}\right) + \log b. \qquad (4)$$

In this equation, s quantifies sensitivity of the group to differences in the relative rate of food obtained in the two patches and b quantifies group bias in favor of one patch over the other for reasons other than the relative availability of food (e.g., one patch may have fewer predators or less shade).

Baum and Kraft (1998) studied group foraging of 30 pigeons in the laboratory. They delivered dried peas at different rates in two resource sites and permitted the birds to forage at either site, switch between sites, or engage in other, nonforaging, activities. In those conditions in which competition between pigeons was minimized (competition reduced s), the distribution of pigeons undermatched the distribution of food obtained at the resource sites. That is, the sensitivity parameter of Equation 4 was less than 1 (M = 0.68, SD = 0.09). Undermatching was also a typical outcome in the 52 laboratory and natural habitat studies reanalyzed by Kennedy and Gray (1993) for species ranging from guppies to human sperm whalers (M = 0.70, SD = 0.43). Thus, groups tend to be less sensitive to relative resource allocations than the ideal free distribution predicts.

Although much research concerns group choice by animals, only two published studies have examined group choice by humans (Kraft & Baum, 2001; Sokolowski, Tonneau, & Freixa i Baque, 1999). Sokolowski et al. used a discrete-trial format in which a group of 15 adults chose one of two resource sites by displaying either a red or a green card to the experimenter and the other participants (cards were analogous to resource sites). Once everyone had selected a card, participants were free to switch between colors as frequently as they liked. After all participants had stopped switching, different numbers of token reinforcers were assigned to each color and participants who had chosen a particular color had an equal probability of being awarded a token (the participant who earned the most tokens was awarded a cash prize). Across five conditions, the ratio of tokens assigned to each color varied from 1:1 to 9:1. As was true of Baum and Kraft's (1998) pigeons, undermatching was obtained in this study (s = 0.67) and in replications with 10 (s = 0.70) and 20 (s = 0.62) participants.

Kraft and Baum (2001) adapted Sokolowski et al.'s (1999) discrete-trial procedure. Although the 13 college students in Kraft and Baum's first experiment also selected one of two colored cards and had the opportunity to switch cards during discrete trials, participants who chose a particular color evenly split the points assigned to that color (i.e., points were not probabilistic). Across a total of eight conditions (two conditions completed per day) the ratio of points assigned to each color was either 1:5, 5:1, 1:2, or 2:1 (e.g., in the second of these conditions 100 points were split by those choosing the red card and 20 points were split by those choosing green). The 2 participants who earned the most points received cash prizes. Once again, undermatching was obtained in this experiment (s = 0.91) and in two replications in which all conditions were conducted on the same day with 10 (s = 0.77) and 16 (s = 0.80) participants, respectively.

These two human group choice studies employed procedures atypical of previous investigations of group foraging by animals. First, Sokolowski et al. (1999) and Kraft and Baum (2001) used discrete-trial procedures in which participants selected a resource site on each trial, received some consequence, and then were given another opportunity to respond. By contrast, foraging in the wild, or in laboratory simulations of this environment, is a free-operant choice: Animals are free to choose either resource site or switch between sites at any time. Second, both human studies allowed switching between resource sites. That is, after selecting an initial resource site, participants had unlimited opportunities to simultaneously switch between sites using information about the current distribution of group members between sites to inform their selection. Although no restrictions are placed on the number of times animals foraging in the wild (or in free-operant laboratory situations) may switch between resource sites, no designated switching period precedes the delivery of any reinforcers. Third, both procedures provided participants with perfect knowledge of the rate at which reinforcers were obtained in both resource sites. Perfect knowledge of reinforcement rates is an assumption of the ideal free distribution (Fretwell & Lucas, 1970) but has not to our knowledge been provided in any prior animal experiments. Thus, to date, human group choice studies have arranged conditions that do not closely resemble either laboratory conditions arranged with animals or the natural settings in which group choice occurs.

The purpose of our experiments was to test the predictions of the ideal free distribution with groups of humans under conditions that more closely resemble those under which group choice in animals has been investigated. The first experiment systematically replicated the Kraft and Baum (2001) procedures to assess the reliability of human habitat matching in a discrete-trial choice situation in which participants were allowed to switch between resource sites before any reinforcers were delivered. The second experiment allowed participants to choose a resource site on each trial, but they were not given the opportunity to switch between sites before the consequences of that choice were administered. The third experiment introduced a free-operant procedure in which reinforcers were periodically delivered in each resource site. Participants in the resource site shared the reinforcers when they were obtained, and participants were free to switch between resource sites at any time. Data from all three experiments were analyzed with linear regression techniques using Equation 4.

EXPERIMENT 1

Method

Participants. Twelve college students attending the University of Wisconsin–Eau Claire (6 men and 6 women), ranging in age from 18 to 20 years (M = 18.4, SD = 0.39) received extra credit and $3 for their participation. In addition, $30 was awarded to the participant who earned the most points during the session, and $10 was given to the participant who earned the second most points.

Materials. Participants were seated in desks arranged in a circle (facing inward) in the center of a classroom. Each participant had two cards (10 cm by 15 cm; one red and one blue) and a score sheet on which he or she was to record choices and the number of points earned on each trial.

Procedure. Participants were first read the following instructions:

> Your task is to earn as many points as possible. The person who earns the most points today will be given a $30 bonus and the person who earns the second most points will be given a $10 bonus. You can earn points by picking either the red or the blue card. A certain number of points are allocated to each color, and you share the points with people who choose the same color. So, for example, if 100 points are allocated to red and 10 people choose red, then they each get 10 points. The number of points that I assign to each color will not change for a while. When the way points are allocated does change, I will let you know. Dishonest reporting of earned points will disqualify you from the cash prizes. If more than one person earns the most points, these people will divide the $40 cash prizes.

On each trial participants responded to the prompt ''choose now'' by simultaneously displaying a colored card and recording the color on their score sheet. In addition, an experimenter independently recorded all choices and the number of points earned by each participant on each trial. Next, participants were given the option of switching to

Table 1

Points allocated to the red and blue resource sites in each condition of Experiments 1 and 2.

Condition	Blue	Red	Ratio
1	80	40	2:1
2	20	100	1:5
3	100	20	5:1
4	40	80	1:2
5	60	60	1:1

the other color. They were free to switch an unlimited number of times and could clearly observe switching on the part of the other participants. Choices made during the switching period were not recorded. When all switching had stopped for approximately 5 s, both the participants and the experimenter recorded the final color selection. Finally, the experimenter announced the points earned by those choosing the red and blue cards and prompted participants to record these points on their score sheets. Table 1 shows the number of points allocated to the red and blue cards across the five conditions. When points were awarded, the experimenter divided the number of points allocated to each color by the number of participants choosing that color. Thus, in the first condition, if 10 participants chose the blue card, they each received 8 points (80/10). The remaining 2 participants selecting the red card would each receive 20 points (40/2). If an odd number of participants selected a card, fractions of points were awarded. The next trial began when all cards were turned face down on the desktops, the experimenter again prompted participants to ‘‘choose now,’’ and the process repeated itself.

Between conditions, the experimenter indicated that ‘‘The number of points allocated to the red and blue cards has now changed. It is up to you to determine the best way to earn points.’’ Participants were given new score sheets at the beginning of each condition and had access to drinks and snacks provided by the experimenter between conditions. These breaks lasted approximately 5 min each. Each condition was terminated after 20 trials, as in Kraft and Baum (2001). At the conclusion of the experiment, points earned were tallied from the participants' score sheets and cash prizes were awarded to the top two point earners. The entire session was completed in just under 3 hr.

Results

Interobserver agreement between participant and experimenter records was calculated for individual participants' color choices (number of color agreements divided by number of trials) and points earned. These reliabilities ranged from 0.98 to 1.0 (M = 0.99). When participant and experimenter records differed (which happened on only 11 of 1,200 opportunities), the experimenter's record was used.

Figure 1 shows the predicted and obtained number of participants who chose the red card on each trial in each condition (the remainder of the 12 participants chose blue). The left column shows participants' initial choice distributions (i.e., before they were given the opportunity to switch colors) and the right shows final choice distributions. Within 20 trials, these distributions appeared to stabilize, in that no systematic trends were observed. Initial selections were more variable from trial to trial and did not match the predicted distribution of participants as closely as the final distributions.

Figure 2 shows the logarithmic ratios of total number of participants selecting the blue and red cards in the final six trials of each condition plotted as a function of the logarithmic ratio of points allocated to the blue and red alternatives. The lines drawn through these data were fit using the method of least squares. The dashed line shows the predicted distribution of participants across the range of reinforcement ratios. Initial-selection distributions undermatched the predicted distribution (s = 0.4), and the linear function provided a poor fit of the data (r^2 = .55). Final-selection distributions more closely matched the predicted distributions (s = 0.92), and the linear function provided an excellent fit of the data (r^2 = .99). Virtually no bias was detected in either initial or final selections.

Discussion

The group's initial selections were variable and did not as closely conform to the ideal free distribution (Equation 1) as final-selection distributions. Initial-selection sensitivity to changes in the ratio of points allocated to

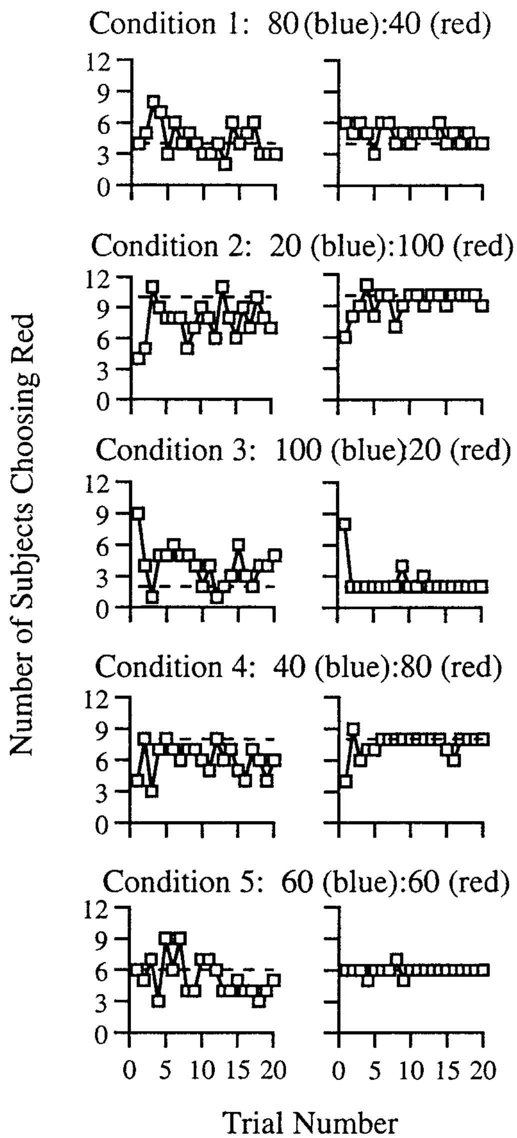

Fig. 1. Predicted and obtained number of participants selecting the red resource site on each of 20 trials in the five conditions of Experiment 1. The left column of graphs shows initial choices, and the right column shows final choices, after participants were given unlimited opportunities to switch between resource sites.

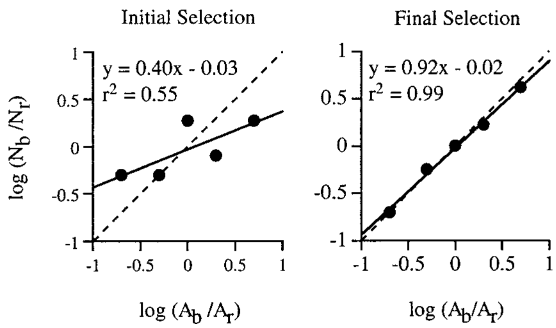

Fig. 2. Logarithmic ratios of the number of participants in the blue and red resource sites (N_b/N_r) and the average number of points obtained in these resource sites (A_b/A_r) before (left graph) and after (right graph) participants were given the opportunity to switch between resource sites. Data were taken from the final six trials from each condition. Regression lines were fitted using the method of least squares. Dashed lines indicate the prediction of the ideal free distribution.

the resource sites (*s* in Equation 4) was somewhat lower than that reported by Kraft and Baum (2001). In the two studies reported as Kraft and Baum's Experiment 2, in which similar procedures were employed, initial-selection sensitivity measures were 0.74 and 0.92, higher than our 0.40. Procedural differences separating these studies are unlikely to be responsible for our participants' lower initial-selection sensitivity. Our group size was within the range employed by Kraft and Baum, and although we did not repeat a practice condition as the final condition (as did Kraft and Baum) there was no evidence that initial-selection sensitivity improved across conditions in either our or Kraft and Baum's experiments. This suggests that initial-selection sensitivity is more variable than final-selection sensitivity, an outcome that is not surprising given that points were delivered contingent upon final rather than initial selections.

Final-selection distributions replicated the findings of Kraft and Baum (2001), in that the group was highly sensitive to changes in the number of points allocated to the resource sites. Although these data support the ideal free distribution, the behavior of our participants may not be an instance of the same group-behavioral process observed in animal studies that support the ideal free distribution (e.g., Baum & Kraft, 1998; Harper, 1982). As noted above, several procedural differences between the human and animal studies suggest that the behavioral processes responsible for these outcomes may be different. Specifically, we observed that participants frequently counted the number of others choosing the red and blue cards before revising their card selection. This suggests that participants not only had perfect knowledge of the distribution of points to the different colors (an assumption of the ideal free distribution) but also were, through verbal behavior, calculating their anticipated point earnings before switching colors so as to maximize their earnings (i.e., earn a greater number of points per trial). For example, in the third condition 100 points were split among participants choosing the blue card and 20 points were split among those choosing red. If on a particular trial 8 participants initially chose the blue card (100/8 = 12.5 points each) and 4 chose red (20/4 = 5 points each), then if one of the latter participants calculated his or her anticipated point earnings, maximizing would entail switching to blue (100/9 = 11.11, a gain of 6.11 points). If several participants employed this strategy, then the distribution of participants at the end of the switching period would necessarily be that predicted by the ideal free distribution (a distribution at which participants holding red or blue cards would earn 10 points each).

EXPERIMENT 2

Because verbal behavior (Skinner, 1957) may have played an important role in the final-selection distribution of participants in Experiment 1, the second experiment determined whether the predictions of the ideal free distribution would hold when participants had no opportunities to switch between resource sites and did not speak aloud. Experiments conducted with animal participants do not employ switching periods analogous to those used in Experiment 1, and animals are presumably incapable of precisely calculating their anticipated earnings before selecting a resource site. Thus, eliminating the switching period was designed to prevent participants from counting the number of participants displaying each colored card, calculating their anticipated point earnings, and switching cards to earn more points. They were still provided with perfect knowledge of the point distributions at the end of each trial (i.e., when points were distributed) but were not allowed to adjust the group distribution as in Experiment 1. Prohibiting talking prevented them from discussing their upcoming selections, which would have provided the information necessary to anticipate the number of points available for selecting one color over the other. Both Sokolowski et al. (1999) and Kraft and Baum (2001) barred participants from talking, but they did not restrict the delivery of points to the initial selections. Thus, no findings are currently available about selections by a group of humans when group members cannot collectively determine their anticipated earnings.

Method

Participants. Twelve college students attending the University of Wisconsin–Eau Claire (5 men and 7 women), ranging in age from 18 to 20 years (M = 18.7, SD = 0.59), voluntarily participated (none had participated in Experiment 1). Participants were recruited from a psychology course that tended to attract nonpsychology majors; thus, the probability was low that participants in this study had contact with those who had participated in Experiment 1. One participant withdrew from the study after the third condition, so the remaining two conditions were completed with 11 participants. Participants who completed the session were compensated with extra credit and $3. Cash prizes of $30 and $10 were awarded as in Experiment 1.

Materials and procedure. The physical arrangement of the room, materials, instructions, and procedures were, with three exceptions, identical to those employed in Experiment 1. First, participants were instructed not to talk during the session. They were warned that talking would result in removal from the study without receiving payment or extra credit. Participants were allowed to talk during the breaks between conditions, but were warned not to discuss the experiment. Conversations were monitored in the room during the breaks, and participants were only allowed to use the restroom individually. Second, participants were awarded points after their initial card selection and had no opportunity to switch cards. They were also instructed that it was important to show their card selection at the exact moment the experimenter said, ‘‘choose’’ (delaying would give the participant an opportunity to see the choices made by the other participants before making a decision). Third, conditions continued until the distribution of participants across trials was considered stable: when (a) at least 20 trials had been completed, (b) the mean number of

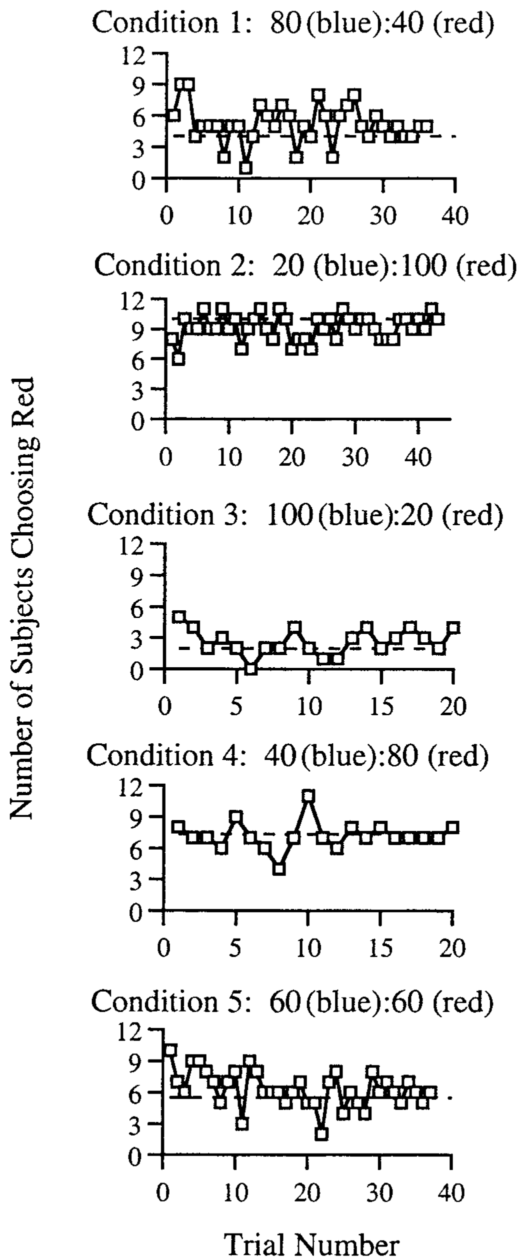

Fig. 3. Predicted and obtained number of participants selecting the red resource site on each of 20 trials in the five conditions of Experiment 2.

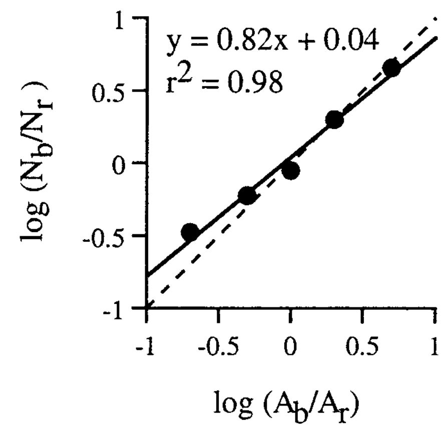

Fig. 4. Logarithmic ratios of the number of participants in the blue and red resource sites (N_b/N_r) and the average number of points obtained in these resource sites (A_b/A_r). Data were taken from the final six trials from each condition. The regression line was fitted using the method of least squares, and the dashed line indicates the prediction of the ideal free distribution.

participants choosing the preferred color on the last three trials deviated by less that 5% from the mean number of participants making this choice on the preceding three trials, and (c) no trends were visually apparent across the final 10 trials. The experiment was completed in approximately 2.5 hr.

Results

Interobserver agreement between participant and experimenter observations of color selected and points earned ranged from .97 to 1.0 (M = .99). Disagreements were resolved by using the experimenter's data.

Figure 3 shows the predicted and obtained number of participants who chose the red card on each trial in each condition (the remaining participants chose blue; note that there were 12 participants in Conditions 1 through 3 and 11 participants in Conditions 4 and 5). With the exception of the final condition, group preference stabilized more quickly after the first two conditions. By the end of each condition, the group either preferred this color or showed no preference in Condition 5 in which an equal number of points were allocated to both colors. Figure 4 shows a plot of the logarithmic ratio of the total number of participants selecting the blue and red cards (log N_b/N_r) on the final six trials in each condition as a function of the logarithmic ratio of points allocated to the blue and red alternatives (log A_b/A_r). The linear function fit to these data accounted for 98% of the behavioral variance. Group preferences were less sensitive to changes in the number of points allocated to the different colors than Equation 1 predicted (s = 0.82), and virtually no bias was detected (log $b = -0.04$).

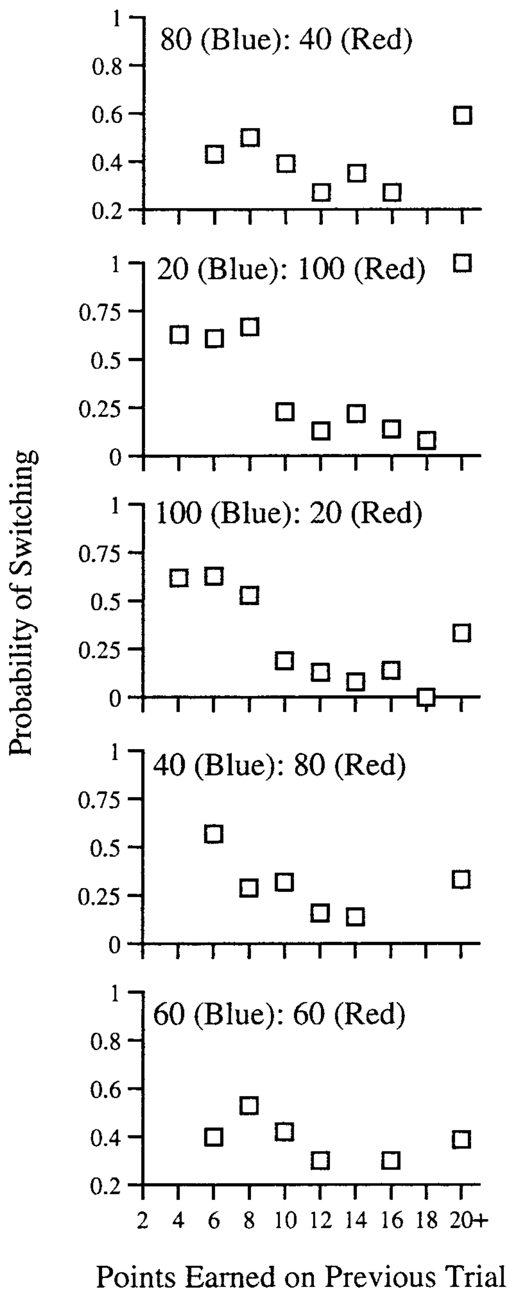

Fig. 5. The probability of switching on the upcoming trial shown as a function of the number of points earned on the preceding trial. Individual graphs are provided for the five different conditions.

An analysis of individual choices, averaged across participants, is provided in Figure 5. The figure shows the probability of switching to the other color on the next trial after having earned a range of points on the present trial. Across conditions there was a tendency to switch to the other color after earning a relatively small number of points and to stay with colors that earned more points. The exception occurred in trials after participants had earned 20 or more points; following these trials, participants were more likely to switch than if they had earned an intermediate number of points.

Discussion

This study determined if a group of college students would distribute themselves in accord with Equation 1 when they could neither talk to one another nor switch between resource sites once they had seen the site selected by the other group members. Casual observations suggested that participants complied with the instruction to refrain from talking during the session. The few vocalizations tended to occur immediately after points were distributed and tended to be emotional responses not directed at any particular member of the group. Group preference undermatched the distribution of points allocated to the two resource sites. The degree of undermatching observed was comparable to final-selection distributions observed in Experiment 1 and was in the range commonly reported in animal studies of habitat matching (see Kennedy & Gray, 1993).

The group's preference was more sensitive to changes in the number of points allocated to each resource site than were initial-selection distributions from Experiment 1. One possible explanation for this difference is that points were not contingent on initial selections in Experiment 1 but they were in Experiment 2. Thus, points were neither gained nor lost by making a random initial choice in the first experiment, but this pattern of behavior would be unlikely to earn participants many points in the second experiment. Instead, participants tended to base their choices on the relative number of points obtained on the preceding trial: If they had earned few points they were more likely to choose the opposite color next time than if they had earned relatively more points. The exception to this rule occurred on trials after participants earned 20 or more points; here switching was more likely than if an intermediate number of points had been earned. Perhaps participants were sensitive to the tendency of their fellow group members to subsequently select the color that had just paid many points and attempted to avoid selecting the color again because of the anticipated increase in the number of participants with whom they would have to share the allotted points.

This experiment supports the ideal free distribution as a model of human group choice in a discrete-trial choice situation. Because participants did not provide verbal feedback to their fellow group members and could not predict the number of points they would receive and then have the opportunity to switch resource sites to increase their earnings, the verbal behavior hypothesized to have occurred in Experiment 1 could not have played a role in the outcome of Experiment 2. As such, the present findings suggest that a similar functional relation exists between relative resources available and group choice, whether the group is composed of humans or animals. One caveat to this is that laboratory studies of habitat matching in animals have used free-operant procedures, whereas all previous human studies have employed discrete-trial procedures similar to those used in Experiments 1 and 2.

EXPERIMENT 3

The third experiment assessed habitat matching by a group of 12 participants when reinforcers were arranged according to concurrent variable-interval (VI) VI schedules of reinforcement (a free-operant procedure). Unlike discrete-trial procedures with different point amounts awarded simultaneously to both resource sites, here the consequence of selecting one resource site rather than another was a change in reinforcement rate. Sensitivity of the group to this change is quantified by s in Equation 4. In this experiment reinforcement rate had two components: (a) the average duration of the variable interreinforcement intervals and (b) the magnitude of the reinforcer obtained. The latter was dynamic because it was determined by splitting 100 points evenly among the participants who occupied the resource site at the moment when points were awarded. This increased complexity of relative reinforcement rate offers a more stringent test of the ideal free distribution than has been previously assessed with human participants.

Method

Participants. Twelve college students attending the University of Wisconsin–Eau Claire (5 men and 7 women), ranging in age from 19 to 40 years (median = 20), received extra credit and $5 for their participation. The increased hourly rate of pay was deemed necessary because the session duration was anticipated to be slightly longer than that in previous experiments. Participants earning the most and second most points received $30 and $10 bonuses, respectively.

Materials and procedure. The session was conducted in a classroom (10 m by 6 m). Figure 6 illustrates how tables (the larger shaded rectangles) were arranged so there were two areas (2 m by 6 m) in which participants could go to earn points (resource sites). Red paper was taped to the tables and walls in one area (the "red zone"), and blue paper was displayed in the "blue zone." The zones were separated by a "neutral zone" (6 m by 6 m), and participants traveled approximately 8 m through the neutral zone to switch zones. Tables served as the border of each zone. An experimenter sat at the entrance to each zone (shown as circles in the figure), and a computer was on the desk in front of each experimenter. Although chairs were unavailable to participants during the session (to increase the probability that they would travel between zones), they often sat on the floor or tables.

Each participant was assigned a number, written on two large number tags (one worn on his or her front and the other in back). The experimenters stationed at the entrance to each zone used these numbers to log participants in and out of the zones on the computer in real time. The computer recorded the number of points earned by each participant. If a participant was in the neutral zone, he or she was not logged into either zone and could not earn points. Percentage agreement between the two experimenters stationed at the computers was calculated in each condition. A third experimenter graphed the distribution of participants during each minute of the session, and these graphs were used to assess stability of the group's performance

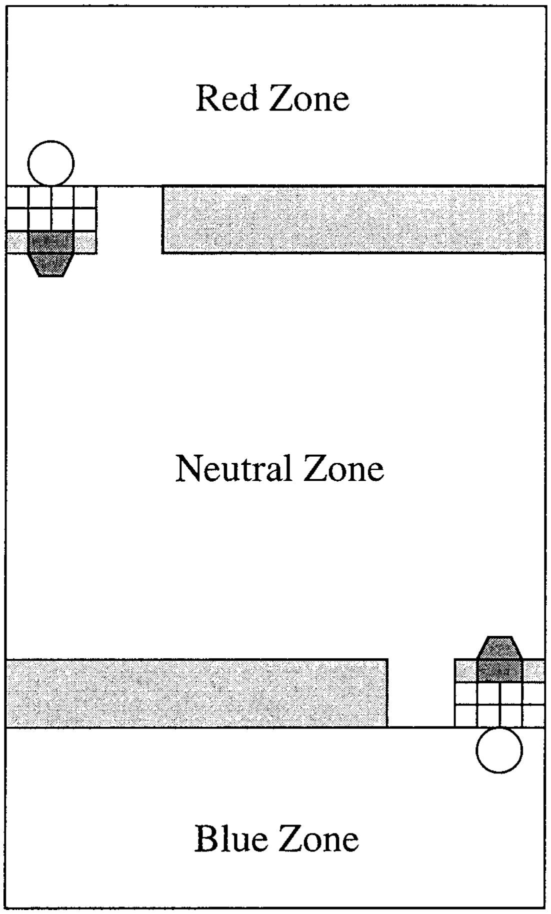

Fig. 6. Overhead diagram of the room configuration employed in Experiment 3. The red and blue resource sites (zones) were separated by tables from the neutral zone across which participants traveled to switch between resource sites. An experimenter (circles) sat at the entrance to each zone and used a computer to log people in and out of the zone.

and, therefore, the duration of each condition.

After participants provided consent and demographic information, one of the experimenters read aloud the following instructions as the participants stood in the neutral zone:

> Your task is to earn as many points as possible. You can earn points by either being in the red zone or the blue zone. Periodically, the computer in the red and blue zones will award 100 points to all of the people in the zone. So, for example, if the red computer delivered points when only one person was in the red zone, that person would get 100 points. If the red computer delivered points when 10 people were in the red zone, each of these participants would receive 10 points. Each time you earn points, you should record these points on the piece of paper we have given you. There are spaces for recording points earned in each of the different zones. It is important that you record your points accurately. Recording extra points on your record sheets will disqualify you from the cash bonuses. During the session you are free to spend as much of your time in either zone and you are free to switch between zones any time you like. You should note that if you are not within the boundary of either zone, then you are in the neutral zone and no points can be earned while you are in the neutral zone. The person who earns the most points at the end of today's session will receive a $30 cash bonus. The person who earns the second most points will get a $10 bonus. There is one important restriction on your activities during the session: you are not allowed to talk.

Participants were then prompted to move inside a zone. When all were within the boundaries of a zone, the experimenters sitting at the computers simultaneously activated the computer programs that controlled the delivery of points.

Table 2 shows the reinforcement schedules arranged in the red and blue zones in each condition. The VI schedules were generated using the method described by Fleshler and Hoffman (1962). When a VI schedule timer elapsed, the computer in that zone played a series of audible tones (50 to 200 Hz), divided 100 points by the number of participants in the zone, and displayed this amount on the screen. The experimenter at the computer immediately spoke aloud the number of points that each participant in the zone had

Table 2

Reinforcement schedules arranged in the red and blue resource sites in each condition of Experiment 3.

Condition	Blue	Red	Programmed reinforcement ratio
P1	VI 40 s	VI 20 s	1:2
P2	VI 10 s	VI 50 s	5:1
P3	VI 50 s	VI 10 s	1:5
1	VI 40 s	VI 20 s	1:2
2	VI 10 s	VI 50 s	5:1
3	VI 50 s	VI 10 s	1:5
4	VI 20 s	VI 40 s	2:1
5	VI 30 s	VI 30 s	1:1

earned, and the participants recorded this number on score sheets they carried with them; in this manner, participants in the other zone could hear how many points were being earned. The VI timer automatically resumed 1.5 s after the points were displayed on the screen.

Three practice conditions, lasting 3 min each, allowed participants to earn and record points under different concurrent schedules of reinforcement. Data from these conditions were not recorded. At the end of the third practice condition, participants were informed that only the points earned in the next five conditions would count toward winning the cash prizes. The schedules arranged in the remaining five conditions remained in effect for at least 20 min each and until the behavior of the group was judged to be stable. Stability was assessed by comparing the average number of participants in the red zone in the last 5 min with the average number in this zone from the preceding 5 min. If these averages deviated by less than one and no trends were visually apparent, the group's behavior was considered to be stable and the condition was terminated. Between conditions, participants returned to the neutral zone, submitted their record sheets and were given new sheets, were told that the computers would now use different rules for delivering points, and were provided with snacks and drinks. During these 3- to 10-min breaks, participants were prohibited from talking about the experiment. After the break, participants were prompted to select a zone. When everyone had entered a zone, the computers were activated and the sequence was repeated.

Results

Interobserver agreement between the records produced by the two computers ranged from .98 to .99. Disagreements were resolved by using the data collected by the red-zone computer.

Figure 7 shows the actual number of participants in the red zone throughout each condition and the predicted number of participants in this zone based on the programmed reinforcement rates (dashed lines). Solid lines show the number of participants in the red zone across time; open squares mark the points in time at which participants switched between zones. With the exception of Condition 2, the distribution of participants stabilized within 20 min (Condition 2 lasted 26 min). In the first four conditions, the number of participants in the richer zone increased with exposure to the schedule con-

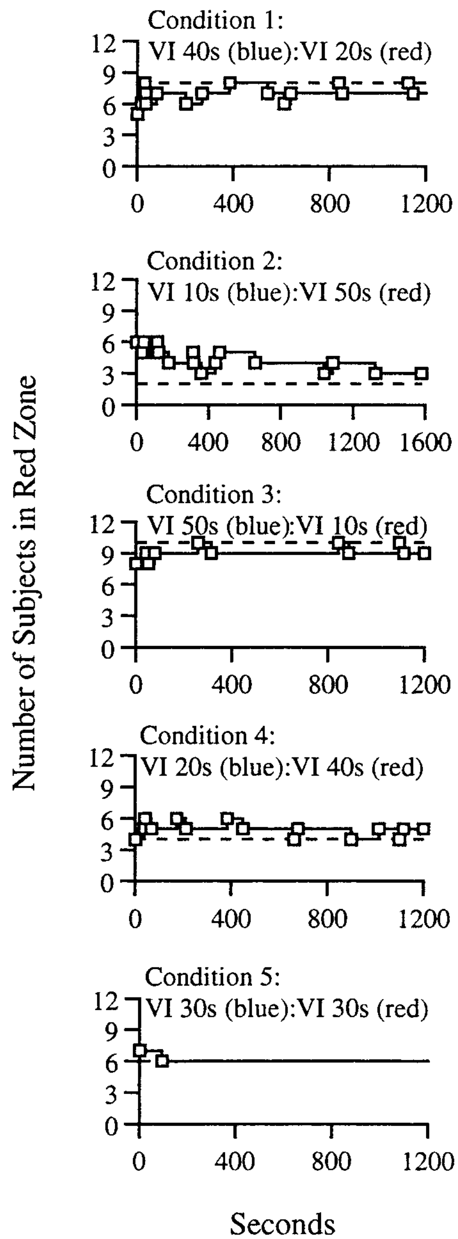

Fig. 7. Predicted and obtained number of participants in the red resource site across the five conditions of Experiment 3. Data points show times at which participants switched between resource sites, and parallel lines represent times during which no switching occurred.

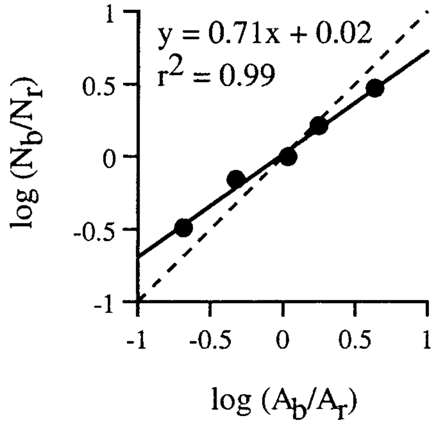

Fig. 8. Logarithmic ratios of the average number of participants in the blue and red resource sites (N_b/N_r) and the average number of points obtained in these resource sites (A_b/A_r) in the final 5 min of each condition. The regression line was fitted using the method of least squares, and the dashed line indicates the prediction of the ideal free distribution.

tingencies. In the final condition in which equivalent schedules were arranged in both zones, an equal number of participants remained in each zone throughout much of the condition.

Figure 8 shows the logarithmic ratios of the average number of participants in the red and blue zones as a function of the logarithmic ratios of the number of points delivered in these zones in the final 5 min of each condition. The average number of participants in the zones was calculated by (a) multiplying the number of participants in the zone by the amount of time that number occupied the zone in the final 5 min of the condition (e.g., 8 participants × 4.1 min, 7 participants × 0.4 min, and 9 participants × 0.5 min), (b) summing these products, and (c) dividing by 5 min. The linear function fit to these data accounted for 99% of the behavioral variance. Group preferences were less sensitive to changes in the number of points allocated to the different zones than Equation 4 predicted (s = 0.71), and virtually no bias was detected (log b = 0.02).

Discussion

Across those conditions in which points were more frequently delivered in one zone than in the other, the group was sensitive to this difference and more participants were observed in the richer resource site; Equation 4 provided an excellent fit of these data. Consistent with Experiments 1 and 2, the degree of sensitivity to the different reinforcement rates was less than predicted by Equation 1. This degree of undermatching approximated that previously reported with groups of animals under similar contingencies (e.g., Baum & Kraft, 1998) and is similar to that reported with humans using discrete-trial procedures (Kraft & Baum, 2001; Sokolowski et al., 1999).

The degree of undermatching observed in Experiment 3 (s = 0.71) was more extreme than in the prior two experiments in which discrete-trial procedures were employed (s = 0.86 and 0.82, respectively). This between-experiment variability may reflect diminished sensitivity to the available resources when free-operant procedures are employed. If this is demonstrated through replications, then one reason for this diminished sensitivity may be the increased complexity of discriminating the reinforcement rates arranged in the resource sites. In the language of the ideal free distribution literature, compared to their counterparts in Experiments 1 and 2, participants in Experiment 3 may have had less perfect knowledge of the relative resources available in the two resource sites. In the first two experiments, participants holding red and blue cards were awarded points at the end of each trial. Assessing relative reinforcement rate therefore was as easy as comparing the number of points obtained in the resource site selected to those points awarded in the one forgone. Assessing relative reinforcement rate in Experiment 3, however, required participants to discriminate the differential frequency at which points were distributed (i.e., the average interreinforcement intervals arranged by the VI schedules) *and* the differential number of points obtained in each resource site. As additional participants entered a resource site, the 100 points provided were split among more people, resulting in smaller amounts per person. In the VI 10-s (blue) VI 50-s (red) condition, for example, if participants were to distribute their numbers in accord with the ideal free distribution, the 10 participants in the blue zone would earn 10 points six times per minute (on average), whereas the 2 participants in the red zone would earn 50 points in just under 1 min, on average. With these distributions, individuals in both resource sites would earn an average of 60 points per minute. Given this complexity, undermatching may reflect an inability to discriminate small differences in reinforcement rates (i.e., imperfect knowledge of the relative resources available).

Undermatching also would result if participants were more sensitive to reinforcer magnitude than reinforcement frequency. That is, if participants were more attracted to large point deliveries (e.g., 50 points) than small but frequent point deliveries (e.g., 10 points several times per minute), then undermatching would occur when participants in the richer resource site traveled to the leaner site following large disbursements of points in the lean site. In Experiment 3, reinforcer amount was a highly salient auditory stimulus delivered at discrete points in time (the number of points earned was called out to the group at the moment the VI schedule expired). Reinforcement rate, however, was a temporally extended set of stimuli that may not have been as salient.

Contrary to this hypothesis are the results of animal studies showing greater sensitivity to reinforcer frequency than amount (e.g., Ito & Asaki, 1982; Rodriguez & Logue, 1986). Grace (1995), however, found that pigeons were more sensitive to reinforcer amount than frequency when VI schedules were arranged in the terminal links of a concurrent-chains schedule; prior researchers used fixed delays to reinforcer delivery. Whether our participants were more sensitive to reinforcer amount than delay and, if so, whether our use of VI schedules is responsible for enhanced sensitivity to amount remain speculative. Quantifying sensitivity to reinforcement amount and delay using a derivative of the concatenated matching law (e.g., Baum & Rachlin, 1969) is not possible for the present research because these factors were not independently manipulated in any condition. Sensitivity to these variables and their relation to variable interreinforcer intervals, therefore, may warrant further research.

GENERAL DISCUSSION

The results of these three experiments support the ideal free distribution as a descriptor of the functional relation between resource availability and group choice. These findings replicate and extend prior human group choice studies by Sokolowski et al. (1999) and Kraft and Baum (2001) by illustrating that human group sensitivity to differences in resources available across two resource sites is observed even when participants are prevented from switching between sites before resources are allocated (Experiment 2) and when free-operant procedures that typify the study of group choice in animals are employed (Experiment 3). The undermatching observed in each of our experiments, and all prior experiments conducted with human participants, suggests that undermatching is a systematic deviation from the ideal free distribution (Kennedy & Gray, 1993) as it is in individual choice behavior under concurrent schedules of reinforcement (e.g., Davison & McCarthy, 1988).

Baum and Kraft (1998) and Kraft and Baum (2001) examined a number of variables that may affect the behavior of individual group members that subsequently results in group conformity to the ideal free distribution. Their analyses suggested that (a) individuals do not match their time or response allocation to the distribution of reinforcers obtained by the group, (b) there are no regularities in patterns of switching across sessions, (c) there are no regularities in preference for one resource site over another across sessions (pigeons) or conditions (humans), and (d) there is no tendency for human participants to be consistently higher point earners across conditions. Each of these analyses is molar in the sense that they involved a large number of choices or the relation between individual choices and the consequences experienced across an entire condition or session. Data collected in our experiments suggest regularities at a more molecular level.

In Experiment 1 (which systematically replicated the procedures and findings of Kraft & Baum, 2001), we observed participants counting the number of individuals who had selected each resource site before switching to another resource site. We hypothesized, based on this overt counting and other verbal comments made by participants during the session, that they were calculating their anticipated earnings during the switching periods and switched to whichever resource site would yield more points under the current configuration of participants selecting the two sites. These individual choices may be analogous to the process of *melioration* in studies of individual choice under concurrent schedules of reinforcement.

Melioration (Herrnstein & Vaughan, 1980) holds that behavior under concurrent schedules of reinforcement will be increasingly directed toward the alternative with the higher local reinforcement rate until equilibrium is reached:

$$\frac{R_1}{B_1} = \frac{R_2}{B_2}, \quad (5)$$

where R is the number of reinforcers obtained from concurrent-schedule Alternatives 1 and 2, and B is the number of responses allocated to these alternatives. Participants in Experiment 1 may have used a similar equation to anticipate the points they would receive if they switched or remained in their current resource site:

$$\frac{A_1}{N_1} = \frac{A_2}{N_2}, \quad (6)$$

where A and N are defined as in Equation 1. If an individual's anticipated earnings in the current site were lower than they would be if he or she switched, switching occurred. Switching tended to continue until Equation 6 was satisfied, a configuration that satisfies the prediction of the ideal free distribution.

In Experiment 2, participants had no opportunity to calculate their anticipated earnings and so appear to have employed a different, though similar, strategy. Consistent with Equation 6, Figure 5 revealed a tendency for individual participants to switch on the upcoming trial if they earned fewer points than participants who selected the other resource site ($A_1/N_1 < A_2/N_2$). Said another way, when the local reinforcement rate (i.e., the number of points delivered) in one resource site was less than the local rate in the other, participants tended to meliorate toward the site with the higher local reinforcement rate. As noted above, the exception to this rule occurred in those trials in which the participant earned 20 or more points (earning a large number of points appears to have increased the probability of switching because so many other participants were likely to switch to that site on the next trial).

A melioration account of individual behavior also is consistent with the results of Experiment 3 (free-operant procedure). Here the A values in Equation 6 refer to the reinforcement rate obtained in the resource site currently selected (A_s) and the reinforcement rate observed in the site forgone (A_f). Local rates of reinforcement are determined by the VI values arranged and the number of individuals in each resource site who will evenly split the points (N in Equation 6). A melioration account of individual behavior in this experiment holds that participants constantly compared the rate of pay in the resource site selected (A_s/N_s) with that obtained by participants in the resource site forgone (A_f/N_f). If the current rate of pay was below that in the other site, the probability of switching is increased. Switching on the basis of this comparison would continue until the rates were judged to be equivalent. Given perfect judgment, the result of this process at the individual-participant level is the group choice predicted by the ideal free distribution.

Although the results of each of our studies are consistent with a melioration account of the individual behavior underlying group choice, none of our data definitively support this hypothesis. Future research designed in such a way that melioration and maximization (for example) accounts make different predictions may prove useful.

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