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Children's competition in a natural setting: evidence for the ideal free distribution[☆]

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Abstract

Little is known of the foraging abilities of children in modern cultures, especially when children forage in groups. Here we present a test of optimal foraging theory in groups of street children working for money. The children we observed were selling bottles of water to drivers distributed in two lanes at a crossroad of Istanbul, Turkey. As predicted by the ideal free distribution (a model of optimal group foraging), the ratio of children working in the two lanes was sensitive to the ratio of cars (and therefore the ratio of potential buyers) present in each lane. Deviations from the ideal free model arose largely from numerical restrictions on the set of possible ratios compatible with a small group size. When these constraints were taken into account, optimal behavior emerged as a robust aspect of the children's group distribution. Our results extend to human children aspects of group foraging that were previously tested in human adults or other animal species.
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1. Introduction

Some of the salient characteristics of human life histories are an extended period of juvenile dependency and a delayed age of first reproduction (Gurven & Kaplan, 2006; Kramer, 2002; Sear & Mace, 2008; Walker et al., 2006). From an evolutionary perspective, an individual's most important developmental goal is to reach reproductive age in optimal conditions (Bjorklund & Pellegrini, 2000; Bjorklund & Pellegrini, 2002). Accordingly, human life histories may have evolved so that children display morphological and behavioral features that are advantageous to reproduction (Ellis, 2004; Kaplan & Gangestad, 2005; Vigil, Geary & Byrd-Craven, 2005).

Human children's extended period of dependency on adults, for example, may allow juveniles to acquire food procurement abilities that are complex and time consuming to master (Bock & Johnson, 2004; Bock & Sellen, 2002; Gurven & Kaplan, 2006; Walker, Hill, Kaplan & McMillan,

2002). The advantages derived from accessing diets that are technologically difficult to acquire but rich in energy could compensate for the costs of a delayed reproductive onset (Kramer, 2002; Lancaster, Kaplan, Hill & Hurtado, 2000). Even very young children can acquire simple foraging or food procurement techniques (Horner, Whiten, Flynn & de Waal, 2006; Rakoczy, Tomasello & Striano, 2005), however, and differences between children and adults in food gathering efficiency may depend more on children's smaller body size or slower gait than on the mastery of specific skills (Bird & Bliege Bird, 2000; Bird & Bliege Bird, 2002; Blurton Jones & Marlowe, 2002).

An extended period of juvenile dependency also has fitness costs. During this period, children may become orphans though natural disasters, wars or conflicts among groups (Hill, Hurtado & Walker, 2007; Wrangham, Wilson & Muller, 2006). The parents may also abandon their children in poverty. Another source of potential fitness costs is the presence, within the same family, of children of different ages and energetic needs (Lawson & Mace, 2009). Competition among siblings may have major effects on development through a reduced quantity and quality of parental care. Some data suggest that younger children tend to be less fed (Horton,

1988) and that child mortality increases with birth order (Modin, 2002). A child's educational level (Blake, 1989) and probability of vaccination (Lewis & Britton, 1998) may also decrease as a function of family size. Finally, family size may impact negatively on the time taken by the parents to look for assistance in situations of urgency (Schwartz, Eidelman, Zeidan, Applebaum & Raveh, 2005).

Because of these disadvantages, economic hardship can favor a child's autonomy and an active role in the economy of human societies. In cases of severe poverty, it may even become evolutionarily advantageous for children to leave their family and look for resources without the parents' assistance (Panter-Brick, 2004). Consistent with this hypothesis, in some cases better growth and health indices have been reported for children living on the streets of cities as compared to children remaining in their family (Panter-Brick, Todd & Baker, 1996; Raffaelli, 1999). In such situations, children may find it advantageous to contribute as soon as possible to their own feeding, as has been observed in some hunter–gatherer societies (Bliege Bird, Bird & Beaton, 1995; Blurton Jones, Hawkes & Draper, 1994; Blurton Jones, Hawkes & O'Connell, 1997; Tucker & Young, 2005; Winterhalder & Smith, 2000). Working on the streets may also contribute to kin strategies through which the economic resources gained by one child are redistributed to his or her younger siblings (Bock, 2002; Cain, 1977; Kramer, 2002, 2005).

To the extent that the acquisition of sparse resources affects survival, growth and reproduction (Charlesworth, 1996), some behavioral mechanisms allowing children to compete effectively with non-kin may be present early in development (Sulloway, 2001). Thus, Charlesworth and La Freniere (1983) studied groups of four children in a situation in which they were to distribute different roles among themselves. Two children were to press a button so as to allow a third child to watch a short movie, whereas the fourth child had no particular role to play. Notable disparities in the time spent on different roles were observed among children. Time of access to the movie revealed dominance hierarchies and changed with age (Liddell & McConville, 1997) as well as friendship relations (La Freniere & Charlesworth, 1987).

In an actual foraging context, as opposed to experimental simulations or role playing, studies of economic competition among children are nonexistent. In this context, competition can take different forms. Stealing and other actions that contribute directly to another child's losing resources can be classified as *competition by interference* (Pianka, 1994). Aside from interference, the mere fact that the children must share a limited pool of resources results in *competition by exploitation*. If, for example, two children visit the same patch at different times, the first child to visit the patch (and to consume some of its resources) necessarily reduces the acquisition rate of the second child. Thus, the competitive sharing of resources has important implications with respect to optimal behavior.

In optimal foraging theory (Stephens & Krebs, 1986), competition by exploitation or interference is addressed by a model known as the *ideal free distribution* (hereafter, IFD).

The IFD model (Fretwell & Lucas, 1970) makes a number of simplifying assumptions about foraging. The model assumes that all individuals have the same competitive ability, move freely between sites, are fully informed of the resource amounts and maximize their own gains. Based on these assumptions, the IFD model predicts that the foragers will distribute themselves among patches so that all sites provide the same gain per individual (Fretwell & Lucas, 1970). The IFD predictions are especially straightforward if the n_i individuals that exploit a site i share its resource amount (W_i) proportionally. In these conditions, equality of gains in sites i and j implies $W_i/n_i = W_j/n_j$, or, equivalently:

$$n_i / n_j = W_i / W_j. \tag{1}$$

According to this simple IFD model, the ratio of foragers exploiting two sites should match the ratio of resources available in these sites (Pulliam & Caraco, 1984).

Eq. (1) has been tested with human adults and in game-like situations that simulate foraging (Critchfield & Atteberry, 2003; Goldstone & Ashpole, 2004; Kraft & Baum, 2001; Kraft, Baum & Burge, 2002; Madden, Peden & Yamagushi, 2002; Sokolowski & Tonneau, 2004; Sokolowski, Tonneau & Freixa i Baqué, 1999). IFD predictions have also been assessed in natural settings (Gillis, 2003; Kennett, Anderson & Winterhalder, 2006), but none of the latter studies involved children. The aim of the present study was to evaluate how children competed for resources in a natural setting and, in particular, to assess the extent to which children's group behavior adhered to Eq. (1). In accordance with the IFD assumptions, this implied finding a situation in which the children competed for the same resource, could move from an area to another with minimal traveling costs, and in which the resource amounts in each site were clearly visible (Fretwell & Lucas, 1970).

The children who sell bottles of water on the streets of Istanbul, Turkey, face this sort of competition. Most of the children working on the streets of Istanbul come with their family from rural areas of the country (Aksit, Karanci & Gündüz-Hosgör, 2001). The majority of these children are less than 12 years old. Their tasks involve shoe-shining, garbage collection or recycling, and selling food or other products. The children often work in small groups of two to six individuals in order to play together and avoid aggressions. These children, who work "on the street," are not children "of the street" who would work and live entirely outside any home (Panter-Brick, 2002). In a 2001 ILO-IPEC survey (Aksit et al., 2001), 63% of a sample of 101 street children in Istanbul gave their daily gains (then equivalent to US$3 to US$10) to their parents, for a working schedule that ranged from 2 to 14 h/day.

2. Methods

The groups of children in our study were observed at a street intersection in the Taksim district on the 8th, 9th and

10th of July 2003 (from 11:30 a.m. to 1:00 p.m., from 11:30 a.m. to 12:00 noon and from 12:30 p.m. to 1:00 p.m., respectively). The street where the children worked had three lanes, with cars in the left and middle lanes stopping at the same traffic light. When the light turned red, children who were waiting on the pavement, near the intersection, distributed themselves among the left and middle lanes in order to sell 500-ml bottles of water to the car drivers. Thus, the children within a group competed over the same pool of clients, and children were sometimes observed to quarrel over who should sell his or her bottle to a given driver. The number of children working in the lanes varied from cycle to cycle, for example, because the children left so as to renew their stock of bottles. Red light duration was 1 min. When the light turned green, the children regrouped on the pavement.

On 66 red-light cycles, an observer counted the numbers of cars and children present in the left and middle lanes. The cars in each lane were counted, up to eight, at the end of the cycle (the children never reached any car beyond the eighth one in a lane). Buses and trucks were excluded because the children never attempted to sell water to their drivers. The children in each lane were counted cumulatively along the red-light cycle. The ratios of cars and children were computed for each trial by dividing the numbers in the left lane by the numbers in the middle lane. On 23 cycles, a child switched lanes once during the cycle. On each of these cycles, the child ratio was computed by averaging the ratios before and after the switch. For example, if a ratio of 2:4 (=0.50) was observed, followed by a ratio of 3:3 (=1), the ratio of children on this trial was taken to be 0.75. This computing procedure is consistent with that commonly used in experimental tests of the IFD model (e.g., Kraft et al., 2002; Sokolowski et al., 1999).

The data from six red-light cycles were excluded from IFD analyses because of a zero denominator in the child or car ratio. Over the 60 cycles left, 18 of them with a switch, the total number of cars present in the two lanes ranged from 4 to 16 with an average of 11.55, and the total number of children in the two lanes (hence, the size of the group of children) ranged from 3 to 6 with an average of 4.08.

3. Results

In order to evaluate the overall conformity of our data to the IFD, we averaged the child ratios obtained for each value of the car ratio and plotted the former as a function of the latter (Fig. 1). Each open square represents one data point. Error bars indicate ±1 S.D.; the squares without error bars come from single cycles and correspond to car ratios that occurred only once during the observations. The main diagonal indicates perfect adherence to the IFD model (Eq. (1)). Although the data on the left side of the graph scatter slightly above the main diagonal, as the car ratio increases, the data variance becomes larger and the child ratios eventually move below the IFD prediction (Fig. 1).
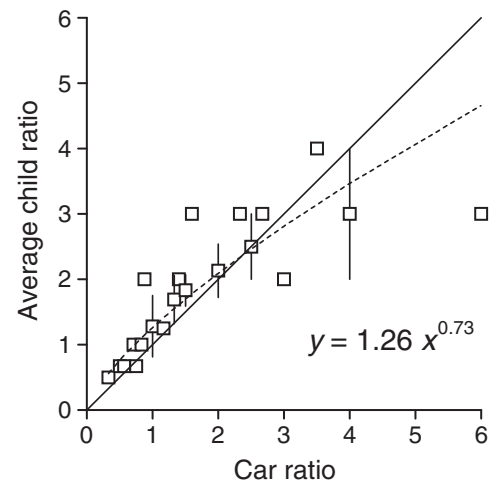

Fig. 1. Average child ratio as a function of car ratio. Unfilled squares represent the ratios of the numbers of children in the two lanes. The child ratios corresponding to a same car-ratio value were averaged; in this case, the unfilled square indicates the average and a vertical line indicates the standard deviation. Ratios were computed by dividing the numbers in the left lane by the numbers in the middle lane. The main diagonal represents the predictions of the ideal free distribution model (Eq. (1)). The dashed line and the equation shown in the graph indicate the best-fitting power function determined by linear regression on the log-transformed data.

The latter type of deviation, known as *undermatching* (Kennedy & Gray, 1993), is commonly observed in IFD studies (Kennedy & Gray, 1993; Sokolowski et al., 1999). One way to measure the extent of undermatching is to replace Eq. (1) by a power function:

$$n_i / n_j = a\left(W_i / W_j\right)^b. \tag{2}$$

Eq. (2) is often linearized by a logarithmic transformation:

$$\ln\left(n_i / n_j\right) = \ln(a) + b\ln\left(W_i / W_j\right), \tag{3}$$

which has the advantage of stabilizing data variance. The best-fitting values of a and b in Eq. (3) can then be obtained by linear regression (Fagen, 1987). Strict adherence to the IFD implies $b=1$, whereas values of b below 1 indicate deviations from optimality (Fagen, 1987; Kennedy & Gray, 1993; Sokolowski et al., 1999). The best-fitting values for our data, corresponding to the dashed curve in Fig. 1, are $a=1.26$ and $b=0.73$ (95% confidence interval for b: 0.57–0.91). The obtained value of b (<1) confirms the undermatching evident in Fig. 1.

Before concluding that the street children behaved in a suboptimal fashion, a numerical constraint on their foraging performance should be taken into account. With group sizes of three to six children, the fact that a child cannot split implies imperfect adherence to the IFD model. With a group size of three, for example, non-exclusive group ratios can only take one of two values, 1:2 and 2:1; as group size increases, finer gradations are possible and may improve the
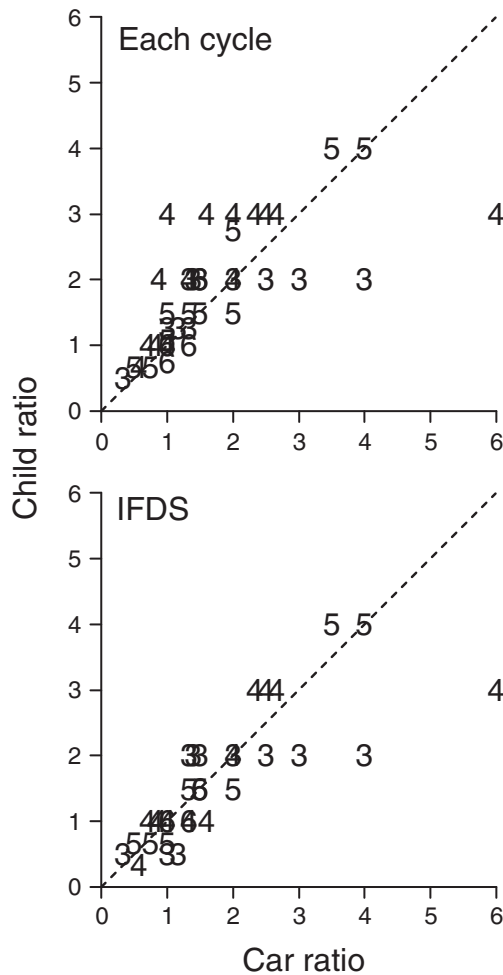
Fig. 2. Upper panel: Child ratio as a function of the car ratio on each cycle. Each data point appears as a digit from 3 to 6 that indicates group size on the corresponding red-light cycle. Lower panel: Predictions of the IFD model with group size constraints (IFDS). Same conventions as in the upper panel. See text for more details on how the predictions were computed.

children's tracking of resource ratios, hence adherence to the IFD. To evaluate whether group size affected conformity to the IFD, we reanalyzed our data in two separate batches, one for group sizes from three to four, the other for group sizes from five to six. With the move from the three–four batch to the five–six batch, the best-fitting value of b increased from 0.62 to 0.95 and r^2 increased from 0.71 to 0.97. Thus, the groups with at least five children were much closer than the groups of lesser size (≤ 4) to the IFD predictions.

The hypothesis that deviations from optimality arose from group size constraints receives further support from the data examined cycle by cycle. The upper panel of Fig. 2 shows the child ratio observed on each cycle as a function of the car ratio on this cycle. Each of the 60 data points in this panel (some of them invisible due to overlapping) consists of a digit from 3 to 6 that indicates group size on the corresponding cycle. For comparison purposes, the lower panel of Fig. 2 shows the predictions of the IFD model with group size taken into account: on each cycle we picked, among the child ratios

achievable with the current group size, the one closest to the current car ratio. This modified model (hereafter, IFDS: IFD with size constraints) reproduced the main qualitative features of the data, such as the horizontal spread of 3's and the isolated '4' on the right side of the graph.

When applied to the averaged child ratios (Fig. 3) instead of the child ratios observed on each cycle, the predictions of the IFS model (plus signs in Fig. 3) were identical to the data (unfilled circles) in 13 cases out of 21. The model explained only 69% of the overall variance, however, due largely to an outlier (z-score of the associated residual=3.67) coming from a single red-light cycle. Without this outlier, the percentage of variance accounted for increased to 89%. Most of the remaining discrepancies arose from the fact that the children could switch lanes, a factor that IFDS does not contemplate. If the averaged child ratios are recomputed by excluding the single outlier and the red-light cycles with a switch, the IFDS predictions are identical to the data in 14 cases out of 17, and IFDS explains 98% of the data variance.

Computed over the 66 cycles of the study, the proportion of red-light cycles with a switch was negatively correlated with group size (product-moment coefficient: $r=-0.91$) and positively correlated with the number of cars in the two lanes ($r=0.83$; class width for car number=3). Under standard statistical assumptions, however, the corresponding t tests were not significant ($0.05<p<.10$), and why these correlations should hold is not entirely clear. One possibility worthy of further investigation is that the children tended to switch, or were attracted by car drivers, to any area visibly empty of other vendors.

4. Discussion

The close correspondence between the average child ratios and IFDS (Fig. 3) suggests that the children in our
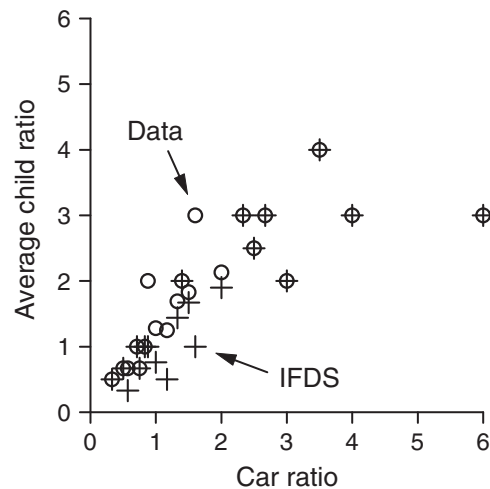

Fig. 3. Average child ratios (unfilled circles) and predictions of the IFDS model (plus signs) as a function of the car ratio. Predictions and data coincide in 13 cases out of 21.

study tracked the ratio of cars in the two lanes, as predicted by the basic IFD model. Most of the apparent deviations from ratio matching could be attributed to simple constraints on the child ratios achievable with a given group size. In this respect, our results contrast with those of animal studies in which group-size constraints are negligible and in which other mechanisms must be invoked to explain undermatching (Abrahams, 1986; Gray & Kennedy, 1994; Houston & McNamara, 1988; Sutherland, 1983).

The present result also contrasts with most of the IFD tests that have been carried out in the psychology laboratory (Sokolowski et al., 1999) and in which undermatching has been a common find, even with participant group sizes at least equal to 10. In experimental tests that employ discrete trials, undermatching may arise from the fact that the participants track resource differences instead of resource ratios (Sokolowski & Tonneau, 2004). If confirmed, this interpretation would imply that distinct strategies (e.g., difference- vs. ratio-based) can be brought to bear on IFD tasks, depending on contextual and procedural variables. Discrete-trial IFD tests, for instance, are often organized in successive phases with constant gains in each simulated site or for each type of choice. Within each phase, the participants may thus rely on visually salient cues from previous trials, such as the numbers of losers in each site, to anticipate current group outcomes (Sokolowski et al., 1999). This perceptual strategy may be less likely to occur in situations such as the present one, in which the number of cars in each lane varied unpredictably from cycle to cycle.

Aside from differences in task presentation and trial format, the participants in most experimental tests of the IFD competed for points exchangeable for money or credits, whereas the street children we observed were competing for actual money. The connection of behavioral outcomes to fitness, although not measured, was presumably tighter in our study (Aksit et al., 2001). Another difference is that, in previous experimental tests of the IFD (Critchfield & Atteberry, 2003; Goldstone & Ashpole, 2004; Goldstone et al., 2005; Kraft & Baum, 2001; Kraft et al., 2002; Madden et al., 2002; Sokolowski & Tonneau, 2004; Sokolowski et al., 1999), the participants were college students, whereas our observations involved children with an estimated age no higher than 12. That children would perform more optimally than young adults may seem surprising in this respect, but it must be recalled that the street children we studied had substantial experience within the competitive situation. Furthermore, aside from counting change, selling bottles does not require the sort of complex cognitive skills that are time consuming to acquire, which may explain the high efficiency of children in performing this task (Bliege Bird & Bird, 2002).

Even though we could account for the data without appealing to competitive differences among economic agents, it would be premature to assume that such differences were absent. The IFD assumption of equal competitive weights rarely holds (e.g., Harper, 1982; Abrahams & Healy, 1990), and personality factors, age, birth order or family size may have affected the children's strategies. There are strong strategy differences among young children who face interference competition situations with scarce resources, for example. Whereas males engage in more individualistic behaviors, females tend to form exclusionary alliances (Benenson, Antonellis, Cotton, Noddin & Campbell, 2008). It is not known whether gender also affects behavioral strategies in situations of exploitation competition (Hawkes, O'Connell & Blurton Jones, 1995). A limitation of our study is that we could neither measure competitive weights nor administer questionnaires about family structure. Clearly, these issues are worthy of further attention.

In many different communities, children contribute to the acquisition of family resources that can then be used for their own or for their sibling's consumption (Kramer, 2005). The children's decision to come to work on the streets of Istanbul (Aksit et al., 2001) would be worth examining in terms of underlying benefits within the family. Birth order as well as family size could be critical factors in this respect. In any event, our results underscore the fact that children can adapt to competition by exploitation, behaving as active economic agents (Foster, 2002; Iversen, 2002) and adjusting their group foraging so as to approximate optimality (Pulliam & Caraco, 1984). The extent to which children behave optimally in other circumstances remains to be seen.

Acknowledgments

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