Adaptive Behavior

Partner Search Heuristics in the Lab: Stability of Matchings Under Various Preference Structures

Kimmo Eriksson[1], Pontus Strimling[2]
[1] *Mälardalen University, School of Education, Culture and Communication*
[2] *Stockholm University, Centre for the Study of Cultural Evolution*

When agents search for partners, the outcome is a matching. K. Eriksson and O. Häggström (2008) defined a measure of instability of matchings and proved that under a certain partner search heuristic, outcomes are likely to have low instability. They also showed that with regards to stability, the preference structure known as common preferences lie somewhere in between the extreme cases of homotypic and antithetical preferences. Following up on this theoretical work, we let human subjects search for a good partner in a computer game where preferences were set to be either common, homotypic, or antithetical. We find that total search effort and instability of the outcome vary in the predicted ways with the preference structure and the number of agents. A set of simulations show that these results are consistent with a model where agents use a simple search heuristic with a slight possibility of error.

Keywords stable matching · mate search · preference structures · simple heuristics · mate choice · simulation · experimental economics

1 Introduction

Mate search is a classic case of adaptive behavior (see Simao & Todd, 2002). In this article we will broaden the scope to include a search for non-romantic partners as well. Following recent theoretical work on partner search by Eriksson and Häggström (2008), we will empirically address three issues that are more tightly interwoven than they may seem: (a) Are people using some simple heuristic when they search for a partner? (b) What relevance does stable matching theory have for partner search? (c) How does the collective structure of agents' preferences affect the process and outcome of partner search? We start by giving some necessary background to these three questions.

1.1 Mate Search Heuristics

As most people have experienced, the problem of mate choice may be dauntingly complex. There is a very large set of potential mates about whom you initially know next to nothing. When you find someone you think you like, there is both the risk that someone you like even more could be found later, and the risk that the person you like may not like you. Instead of optimizing, one may use satisficing: accept if mate quality is above a certain threshold. The threshold level may be set in different ways; Todd (1997) discusses the "next best" rule, where you first observe mate qualities for a certain time, and then look for someone better than all you have seen so far. Thresholds can also be lowered over time; this is called the "prettier-at-

Correspondence to: Kimmo Eriksson, Mälardalen University, School of Education, Culture and Communication, Box 883, SE-721 23 Västerås, Sweden. *E-mail*: kimmo.eriksson@mdh.se. *Tel.*: +4621101533, *Fax*: +4621101330

(2009), Vol 17(6): 524–536.
DOI: 10.1177/1059712309341220

closing-time" effect (Pennebaker et al., 1979). A probabilistic rule of the latter type was used in the first simulation models (Kalick & Hamilton, 1986). Since then a number of agent-based models have used various more or less simple rules for mate choice (Billari, 2000; Fawcett & Bleay, 2009; Hills & Todd, 2008; Johnstone, 1997; Todd & Miller, 1999; Simão & Todd, 2002, 2003; Todd, Billari, & Simão, 2005).

Eriksson and Häggström (2008) observed that if all agents use a heuristic with a gradually lowered threshold starting from a sufficiently high level, and the market is sufficiently small, then the search process is equivalent to *maximin* matching: Among all possible pairs of agents, pick the one where the least satisfied agent is most satisfied; let this pair mate and leave the game, and repeat the process. The simplification introduced by this equivalence made possible a mathematical analysis of the stability of the outcome of such a heuristic, see below.

1.2 Stable Matching Theory

Stable matching theory is a body of work in economics that deals with the problem of finding good matchings of agents whose preferences are known. A matching is simply a partitioning of a set of agents into couples and, possibly, singles. A matching can be stable or unstable. It is unstable if there exist two agents who are not a couple but prefer each other to their current partners. Such a pair of agents constitute a *blocking pair*. If there are no blocking pairs, the matching is *stable*. The standard reference is Roth and Sotomayor (1990).

Stable matching theory has proved very useful in a number of practical applications, such as the famous study by Roth (1991) of the British labor market of medical interns. In order to match interns with hospitals, various centralized matching mechanisms (taking preferences of hospitals and interns as input) were introduced, with varying degrees of success. The most successful mechanism turned out to be a version of the "deferred acceptance procedure" of Gale and Shapley (1962), which has the desirable property that the outcome is always a stable matching; for all details, see Roth and Sotomayor (1990).

In the case of interns and hospitals, agents on both sides were able to state their preferences over all agents of the other side. In contrast, when animals search for a mate, or people search for a partner of any kind, they usually do not know their preferences from the beginning. The main reason is that in order to form preferences for potential partners you need to have some experience of them, and such experience can often be gained only by meeting one potential partner at a time. It has been suggested that stable matching and partner search models could somehow be profitably combined (Bergstrom & Real, 2000; Roth & Sotomayor, 1990, p. 247; Todd, 1997). Little progress in this direction seems to have been made, though, and doubts have been expressed about the usefulness to mate search of stable matching theory since its emphasis on "full knowledge and stability only diverts attention from other issues of greater empirical relevance" (Simão & Todd, 2002, p. 116).

It is true that perfect stability is not a typical outcome of human mate search, but neither is there any rampant instability; long-lasting relationships are common in love and business alike. Indeed, even in the absence of full knowledge, a partner search process may result in an outcome that is close to stable. In order to approach this issue, Eriksson and Häggström (2008) defined a measure of the *instability* of a matching as the proportion of blocking pairs. They then found that, assuming agents' preferences to be random and independent, the instability of the maximin matching tends to zero as the number of agents grows (Eriksson & Häggström, 2008, Theorems 3 and 4). In other words, in this model the outcome of partner search is typically pretty close to stable.

1.3 Different Preference Structures

The above-mentioned theorems of Eriksson and Häggström assume agents' preferences to be *independent* of each other (see also Eriksson, Sjöstrand, & Strimling, 2008). In this article we instead consider models where agents' preferences are not independent but are related to each other in various ways. For instance, scholars have considered preferences that are *homotypic*, meaning that agents prefer mates of similar quality to themselves, or *common*, meaning that all agents prefer mates of highest possible quality (Kalick & Hamilton, 1986; see Alpern & Reyniers, 1999, 2005, for mathematical analysis of mate search when preferences are homotypic or common, respectively).

Although homotypic and common preferences seem on the whole more realistic, mathematical considerations of stability suggest studying yet another preference structure: *antithetical* preferences, where agents' preferences over each other are negatively correlated, so that the higher agent A is on B's preference list, the lower B is on A's list. Thus, antithetical preferences constitute the antithesis to homotypic preferences. Homotypic and antithetical preferences are fundamental structures in the following mathematical sense: they attain, respectively, the minimal and maximal expected instability among all possible preference structures (Eriksson & Häggström, 2008, Theorem 1). Hence, if one wants to study questions about stability for outcomes of partner search conducted under various preference structures, then there are reasons to believe that the results for any other preference structure will fall somewhere in between the results for homotypic and antithetical preferences.

Psychology offers some data on real human preferences for both romantic and non-romantic partners. For instance, there is definitely a homotypic element in non-romantic contexts: people tend to like those who like them in return (Kenny, 1994). However, in a recent popular description of pick-up artistry, it is repeatedly stressed that a man who wants to pick up a woman ought to pointedly signal *lack of interest* in her, and instead give attention to other individuals in her group. This seems to suggest the possibility of an antithetical element of dating preferences. A new methodology, speed-dating experiments, make possible controlled studies of dating preferences (Finkel, Eastwick, & Matthews, 2007). One recent study found that compared with more discriminating persons, individuals who generally liked many others were generally less liked by their dates (Eastwick, Finkel, Mochon, & Ariely, 2007).

1.4 Research Questions and Article Outline

In Section 2 we review the definitions and results of Eriksson and Häggström, and discuss how they apply to the non-romantic partner search context that is the focus of our study. This leads to a number of specific hypotheses related to our three research questions. The remainder of the article is devoted to testing these hypotheses. The research questions and how we deal with them can be summarized as follows.

What type of heuristic do people use when they search for a partner? We have seen that various heuristics are assumed in many models, but it is difficult to make direct tests of the validity of these assumptions. An indirect type of test can be made by comparing demographic data about, say, marriage with results of agent-based simulations where some heuristic is used (see Todd et al., 2005, and references therein). A complication with this type of evidence is that the uncertainty of the accuracy of models is not limited to the search heuristic, but extends also to how individuals form their preferences. In order to obtain a complementary type of evidence, we will use methods from experimental economics (Section 3), whereby the preference structure and the number of agents can be controlled. We will then compare data from experiments (Section 4) with simulations of an agent-based model following a heuristic of the type discussed by Eriksson and Häggström (Section 5).

The experimental data will also be used to answer our second question about the relevance of stable matching to partner search: **When people search for partners, do they end up with a matching that is close to stable?** This is what we predict if the assumptions of the theoretical result of Eriksson and Häggström are reasonably accurate.

Finally, in order to assess the robustness of the answers to the first two questions we conduct the partner search experiment in all three of the preference structures; homotypic, common, and antithetical. As a consequence, we obtain an answer to the third question following naturally from the work of Eriksson and Häggström: **How are the process and outcome of partner search affected by the preference structure and the number of agents?**

Section 6 concludes with a discussion of our findings in relation to previous studies as well as potential applications.

2 Applicability of the Theory of Eriksson and Häggström to Non-Romantic Matching

Most of stable matching theory deals with bipartite matching, which means that agents are naturally divided into two categories—for example males and females—such that all matched pairs consist of one agent of each category. However, the fundamental concepts of blocking pairs and stability apply just as well to matching where all agents belong to a single category. Clearly, this is a more general class of matching problem with bipartite matching as a special case. The single-category matching problem is often referred to as the *roommate problem* (Gale & Shapley, 1962; Roth & Sotomayor, 1990, p. 23). Following Eastwick et al. (2007), we will sometimes use the term *non-romantic* matching as opposed to the (strictly heterosexual) romantic matching usually considered in mate search theory.

The fundamental result of stable matching theory is that in bipartite matching, whatever the preference structure, it is always possible to find a stable outcome. This result does not generalize to non-romantic matching, which is the reason for the theory's emphasis on the bipartite case. However, as we will see below, non-romantic matching situations always allow a stable outcome when the preference structure is homotypic, common, or antithetical.

The theory of Eriksson and Häggström deals with the bipartite case. In this section we will discuss its wider applicability to non-romantic matching.

2.1 Fundamental Preference Structures

We will here define the non-romantic versions of the three fundamental preference structures (Eriksson & Häggström, 2008). Following common practice in game theory, preferences are assumed to be transitive so that they can be modeled by assigning utility values to options; an option with higher utility is more preferred.

Let u_{ij} denote the utility for agent i of being matched with agent j. With n agents, the utilities form an $n \times n$ matrix $U = (u_{ij})$. The diagonal elements indicate the utility of being single; we will assume these to be always zero. We will further assume preferences to be strict, that is, $u_{ij} \neq u_{ik}$ for $j \neq k$.

2.1.1 Homotypic Preferences: "I like you as much as you like me" Homotypic preferences can be generated from a universal notion of attractiveness by having each agent rank other agents according to how close their attractiveness is to her own (Alpern & Reyniers, 1999). Assuming ranks can be converted to utilities, this means that the utility matrix will be symmetric. For example, with $n = 4$ we may have the matrix

$$U^{\text{hom}} = \begin{pmatrix} 0 & 1 & 2 & 3 \\ 1 & 0 & 3 & 2 \\ 2 & 3 & 0 & 1 \\ 3 & 2 & 1 & 0 \end{pmatrix}$$

Under our assumption of strict preferences it is easy to see that there is a unique stable matching under homotypic preferences: Every agent must be matched with her unique most preferred partner (because otherwise they constitute a blocking pair). In the example, the stable matching pairs the first agent with the fourth one, and the second agent with the third one. (From this it is also clear that homotypic strict preferences are only possible for even n.)

2.1.2 Common Preferences: "I like you as much as everyone else likes you" Common preferences mean that, for any agent i, all other agents experience the same utility of being matched with i. For example, with $n = 4$ we may have the matrix

$$U^{\text{com}} = \begin{pmatrix} 0 & 2 & 3 & 4 \\ 1 & 0 & 3 & 4 \\ 1 & 2 & 0 & 4 \\ 1 & 2 & 3 & 0 \end{pmatrix}$$

Again, under our assumption of strict preferences there can only be a unique stable matching under common preferences: The highest ranked agent must be matched with the second highest ranking agent (otherwise they would be a blocking pair); similarly, the third ranked must be matched with the fourth ranked, and so forth.

2.1.3 Antithetical Preferences: "The more I like you, the less you like me" As discussed in the introduction, antithetical preferences are the antitheses to homotypic preferences. In terms of utilities they can be implemented by the rule that the sum of utilities in a pair, $u_{ij} + u_{ji}$, is the same for all pairs i, j. A simple way of constructing such a matrix is to shift the first row by one step for each new row. For four agents, the utility matrix can look like this:

$$U^{\text{ant}} = \begin{pmatrix} 0 & 1 & 2 & 3 \\ 3 & 0 & 1 & 2 \\ 2 & 3 & 0 & 1 \\ 1 & 2 & 3 & 0 \end{pmatrix}$$

Although there may be a multitude of stable matchings under other realizations of antithetical preferences, this shifted construction allows only a unique stable matching for even n: Every agent must be matched with the agent she ranks in the middle. To see that no other matching can be stable, assume that i is matched to j who is worse than mid-ranked by i. Then there are at least $n/2$ agents that i prefers to j, and by the pigeonhole principle at least two of these agents, say k and ℓ, must be matched with each other. By the shifted construction, one of these, say k, must prefer i. Thus i and k are a blocking pair.

2.2 Definitions of Instability Measures

Recall that the definition of a blocking pair in a given matching is two agents who both prefer each other to the agents they are matched with. Eriksson and Häggström define the instability of a matching as the proportion of blocking pairs, that is, the number of blocking pairs divided by the total number of possible pairs of agents. If there are m males and f females, the total number of possible pairs is $m \cdot f$.

For non-romantic matching, the size of the problem is defined by a single parameter n, the number of agents. The definition of instability applies immediately to non-romantic matching, with the exception that there are now $n(n - 1)/2$ possible pairs.

For comparisons across preference structures, Eriksson and Häggström found the instability measure to be biased: If agents are matched at random, the expected instability differs by a factor of two between a market with homotypic preferences and one with antithetical preferences (the two extreme cases). For this reason another measure was defined. The *relative instability* of a matching is the probability that a randomly drawn complete matching would be less unstable. (A matching is complete if all agents are matched with someone.)

For a non-romantic matching market of even size n, there are $(n - 1)!! = (n - 1)(n - 3)(n - 5) \ldots 1$ possible complete matchings of n agents. Hence the relative instability of a matching μ is

$$\frac{\#\{\mu' : \text{instability}(\mu') \leq \text{instability}(\mu)\}}{(n-1)!!}.$$

When n is sufficiently small, this relative instability measure can be exactly calculated by a computer through complete enumeration of all possible matchings. For larger markets, relative instability of matchings can be estimated through Monte Carlo methods.

2.3 Application of the Maximin Matching Mechanism to Non-Romantic Markets

Given a utility matrix U, the maximin matching mechanism can be expressed as follows: Let i, j be the pair of agents maximizing $\min\{u_{ij}, u_{ji}\}$. (In case there are several such pairs, choose the pair that maximizes $\max\{u_{ij}, u_{ji}\}$; if there are several such pairs, use any tie-breaking rule.) Match i with j and repeat the procedure with the remaining agents until none is left.

As an illustration, let us run the maximin matching mechanism for the matrix U^{ant} from the above example of antithetical preferences. All pairs have either utilities 3,1 or 2,2; the latter are the maximin pairs. Pick any of these pairs, for example, the first and third agents. This leaves the second and fourth agents to be paired in the next step. Thus, every agent is matched to the agent she ranks in the middle, so we obtained the unique stable matching. Similarly, the outcomes of maximin matching on U^{hom} and U^{com} are also the unique stable matchings in these markets.

For bipartite matching markets, Eriksson and Häggström (2008) proved a number of results about the outcome of the maximin matching mechanism:

- It is approximately what would be implemented by agents who independently search for a partner following a heuristic of the type “accept your current date if above a certain threshold; lower the threshold as search proceeds” (p. 416).
- For each of the three fundamental preference structures, it always yields a stable outcome (Theorem 2, p. 416).
- If preferences are drawn at random, then the expected instability of the outcome of maximin matching tends to zero as the size n of the market tends to infinity (Theorem 3, p. 417).
- This holds even if every agent only evaluates a random subset of partners, as long as the expected number of partners that an agent evaluates grows with n (Theorem 4, p. 419).

If one analyzes the proofs of these results it turns out that they apply to non-romantic matching as well. The only difference is that in non-romantic matching all utilities are collected in the same matrix, whereas in bipartite matching Eriksson and Häggström let the two categories each have their own smaller utility matrix. This only affects the proof of their Lemma 4 (p. 417), where the size of the utility matrix must be doubled, but this does not change the result.

To summarize these results: The question of whether stability is a relevant concept for outcomes of partner search may have an affirmative answer. Assuming only that people use a search algorithm of a type that approximately implements maximin matching, and that they increase their search effort when the number of agents increases, we can expect the instability of the outcome to be very small for large markets.

2.4 Hypotheses About Human Non-Romantic Matching

We have described the theory of Eriksson and Häggström and its applicability to non-romantic matching. As all mathematical models, it relies on idealized assumptions that may or may not be close to actual human partner search. Based on the theory and its assumptions we make the following predictions, to be experimentally tested in the coming sections.

Hypothesis 1. *Search behavior is consistent with a model where agents follow a simple heuristic of the type "accept a partner if above a certain threshold; lower the threshold as search proceeds" (with some small probability of error in execution of the heuristic).* Aspiration-dropping heuristics are common in the literature (see Simão & Todd, 2002). It is also the overarching assumption behind the maximin matching approach of Eriksson and Häggström. In order to test it, we will compare experimental data with results from agent-based simulations in Section 5. Humans cannot be expected to behave with perfect consistency, which in the model would be reflected as errors in the execution of the heuristic rule.

Hypothesis 2. *The average search effort increases with the size of the market.* Theorem 4 of Eriksson and Häggström depends on this premise, which therefore must be tested. It seems reasonable that people actually search a bit more when the range of possibilities is greater. In studies of search effort among consumers, the number of alternatives on the market has been found to be a positive determinant (Beatty & Smith, 1987). In the context of partner search, there are some studies of the effects of the number of options but they seem not to have been concerned with search effort (Lenton, Fasolo, & Todd, 2008, 2009). We discuss how to operationalize search effort in Section 3.

Hypothesis 3. *The instability of the final matching decreases with the size of the market.* If hypothesis 1 is correct, then the theory of Eriksson and Häggström predicts that instability will decrease when the number of agents grow. In order to be able to aggregate data from different preference structures we will use the relative instability measure, as discussed above.

Hypothesis 4. *Better alignment of agents' interests decreases the average search effort.* Under homotypic preferences, agents have perfectly aligned interests. The opposite holds for antithetical preferences, with common preferences in-between. In other words, we predict the average search effort to be smallest under homotypic preferences and greatest under antithetical preferences. We derive this hypothesis from the hypothesized simple heuristic. Under homotypic preferences, agents would only need to search until they find a date above the threshold, for by definition of homotypic preferences the date would accept to mate. Under common preferences, this would only apply to high-ranked agents; however, as high-ranked couples mate and leave the game the search becomes ever easier for the low-ranked couples (as their thresholds become ever lower). Under antithetical preferences, no one would be able to mate until the threshold has been lowered down to average utility, so everyone would have to make a large search effort.

Hypothesis 5. *Better alignment of agents' interests decreases the instability of the outcome of partner search.* Given the previous hypothesis, we expect necessity of searching more when agents' interests are misaligned. Assuming that agents sometimes make errors in their partner search, we expect the total number of errors to be larger when agents must search more. Given that perfectly executed partner search is assumed to lead to very low instability, more errors will usually lead to higher instability.

3 The Cocktail Game

Using the paradigm of experimental economics, we can control subjects' preferences by assigning different monetary rewards to different matches. A few economic experiments on decentralized matching have been carried out, but they are substantially different to ours in aim and procedure (Niederle & Roth, 2004; Ünver, 2005). For instance, our experiment seems to be the first where participants search for a partner in real time instead of a small number of fixed stages.

Our computer program *Cocktail* implements the following game: n players arrive at a "cocktail party" that is spatially divided into n locations. Players can experience the utility of each other's company and chat if they are at the same location. At most two players can simultaneously occupy the same location. (The number of players that can simultaneously occupy the same location is a parameter that can be set by the experimenter; in this study only the value 2 was used. Software is available on request from the authors.)

3.1 Rules of Payoff in the Cocktail Game

The preference structure is determined by a utility matrix, which is set by the experimenter. Entry u_{ij} of the utility matrix is the utility to player i of being with player j, on a scale from 0 to 10. The range of this scale is known to the players, but the actual entries of the utility matrix are unknown to the players from the start. When player i meets player j, she can see how good it is for her to be with j, but not how good it is for j to be with her. (For convenience, we use female pronouns for all players.) In other words, u_{ij} is revealed to i, but u_{ji} is not.

Player i earns u_{ij} points for every second that she is in the same location as player j. Each participant receives a cash payoff proportional to the number of points they have collected during the game.

3.2 Rules of Movement in the Cocktail Game

The players all start at different locations. By clicking at a new location the player moves there (unless it is already occupied by two players). The game lasts for 5 min, during which time each player is free to move around unless she makes an agreement to stay together with another player for the remainder of the game. Offering and acceptance of such an agreement is make by the click of a button. As soon as both parties have agreed, their ability to move to another room is switched off.

3.3 The Cocktail Game Screen

Figure 1 shows how the computer screen can look for a player of the Cocktail game. Every player is represented graphically by an avatar (designed before the game by the participant). The location of all players is common knowledge, shown in the left half of the screen. The right half shows larger pictures of the player's avatar and the player's current partner. A scale—updated whenever the player or partner moves—shows which utility the current partner gives to the player.

The "Status" field shows the remaining time of the game, the utility of the current partner (again), and the accumulated points. Underneath the status field is a button for proposing and accepting agreements to stay in this pair, and a "Chat" field (discussed below).

3.4 The Chat Feature

A potential problem in repetitious laboratory experiments is that participants may eventually become bored, and therefore behave in ways that are not representative. One of the functions of monetary incentives, as used in experimental economics, is to counter boredom (Smith, 2000, p. 18). However, money is not everything—not even to college students. We were concerned that boredom may arise in the Cocktail game when players have settled into pairs that they intend to stay in. Conceivably, players who have become bored may in the next round purposefully continue to move around instead of settling down, in order to postpone the boring stage. To avoid this effect, and make the cocktail party framing more salient, the Cocktail game includes a chat function (the communication field in the game screen). Players can chat with each other when they occupy the same location. All chats are logged.

The chat feature obviously comes at a price: Chatting may be so engaging that people do it instead of moving around. Also, chatting allows communication of strategic information. In order to assess these effects we studied the chat logs. First, almost without exception people did not start chatting until they had stopped moving, so the interference with the search process seems to be very small. Second, the vast majority of the conversations were not related to the game. Chats could be about anything from what players study to how much they drink; the most common topic was the looks of the avatars. Questions like "How much am I worth to you?" were asked very seldom, on average

Figure 1 The *Cocktail* game screen, as shown to player 1 whose current partner is player 4. The line indicates the last move of player 1. The text, in Swedish, translates to: "Status: Game time. Experienced fun right now. Accumulated fun. Agreement: Sign your part of an agreement to lock the group. Communication."

only once by one player per entire game. Probably the reason for this lack of curiosity is that the answer does not matter much—either the other person stays with you or she leaves you. Players never revealed their identities during chat, so no transfer of payoff between players was possible.

4 An Experimental Study With the Cocktail Game

4.1 Procedures

Experiments were conducted with the Cocktail game software in a computer lab for game experiments at a Swedish university. A total of 96 participants were recruited from a pool of volunteering college students of miscellaneous fields of study.

Group sizes varied from 6 to 14. Each group initially played two practice games, where preferences were random. They were followed by three games with homotypic, common, and antithetical preferences, in random order. Many groups (but not all, because of time constraints) also played an extra game with a different set of common preferences.

Sessions began with orally presented general instructions about behavior in the lab. Then each participant was escorted to one of the private cubicles with a desk and a computer. Thus, participants were separated from each other for the duration of the experiment. After filling out on-screen participation forms, participants followed on-screen instructions for the experimental procedure.

After about 1 hr, participants were paid, debriefed, and dismissed. Participants received an average payoff of about 100 SEK (about 15 US dollars at the time), with actual payoffs ranging from about 50 SEK to 150 SEK. In addition, every participant was given a cinema ticket for showing up.

4.2 Data

Games vary in two independent variables: group size and preference structure. For each game a large amount of data is collected, including all movements, all agreements, and logs of all chats. We extracted two dependent variables:

- *Search effort* per player—operationalized as the total number of movements divided by the number of players in the group.
- *Instability* of the outcome of the partner search process—operationalized as the relative instability of the matching of players at the end of the game.

4.3 Results: Tests of Hypotheses 2, 3, 4, and 5

Tables 1 and 2 show descriptive statistics of search effort and relative instability, respectively, by game type (group size and preference structure).

Two groups had size 7, which is an odd number and hence some player must necessarily be left without a partner. The data in Table 1 clearly show that players took note of this and adapted their behavior by matching up earlier. The size 7 groups are henceforth left out of the analysis.

The hypotheses were tested by a sequence of ANOVAs, using a dummy variable for the preference structure reflecting the misalignment of agents' interests (homotypic = 0, common = 1, antithetical = 2).

Controlling for preference structure, greater group size predicts greater search effort ($p < 0.01$) but smaller relative instability ($p < 0.001$), supporting Hypotheses 2 and 3.

Controlling for group size, greater misalignment of interests predicts greater search effort ($p < 0.001$) as well as greater relative instability ($p < 0.001$). This supports Hypotheses 4 and 5.

Table 1 Search effort in terms of average number of moves per player, by game characteristics. Standard deviations within parentheses. N is the number of data points (individuals) in the cell.

Group size	Preference structure		
	Homotypic	Common	Antithetical
6	2.8 (1.9)	9.5 (12.9)	23.8 (16.2)
	N = 18	N = 36	N = 18
7	3.6 (3.0)	3.4 (3.3)	4.1 (3.0)
	N = 14	N = 28	N = 14
10	2.0 (1.9)	26.9 (21.7)	29.0 (18.1)
	N = 10	N = 20	N = 10
12	1.3 (1.4)	8.2 (7.5)	11.4 (8.6)
	N = 12	N = 12	N = 12
14	3.9 (4.9)	20.7 (16.2)	31.6 (18.4)
	N = 42	N = 42	N = 42

Table 2 Average relative instability of final matchings. Standard deviations within parentheses. N is the number of data points (groups) in the cell.

Group size	Preference structure		
	Homotypic	Common	Antithetical
6	0.07 (0.00)	0.20 (0.16)	0.75 (0.30)
	N = 3	N = 6	N = 3
10	0.05 (–)	0.09 (0.12)	0.21 (–)
	N = 1	N = 2	N = 1
12	0.06 (–)	0.69 (–)	0.48 (–)
	N = 1	N = 1	N = 1
14	0.01 (0.01)	0.05 (0.06)	0.12 (0.13)
	N = 3	N = 3	N = 3

4.4 Discussion

In our experiments there were two variables that we did not control for in the above analysis: avatars and chatting. Although it is difficult to see how these variables could interact with group size, it is conceivable that they could perturb preferences. However, such perturbations would only work against our hypotheses, since any changes of the extreme preference structures (antithetical and homotypic) would make them more similar to each other.

We are of course aware that the game is not equivalent to a real-life cocktail party, where one can get cues about how much fun another person is in ways other than direct interaction with the person, and where preferences may be very volatile.

5 A Simulation Study: Test of Hypothesis 1

Our fundamental hypothesis says that *search behavior is consistent with a model where agents follow a simple heuristic of the type "accept a partner if above a certain threshold; lower the threshold as search proceeds,"* with some small probability of error in execution of the heuristic (Hypothesis 1).

In this section we shall investigate how well such a model, in a simulation of the Cocktail game, can be fitted to our experimental results. All possible strategic options open for an agent in the Cocktail game (who has not yet made a binding agreement) can be categorized as follows:

1. Proposing/accepting a binding agreement to stay (if she is with someone at the moment).
2. Moving to a currently single agent she already knows.
3. Moving to a currently single agent she does not know.
4. Moving to become single.
5. Doing nothing.

The fundamental part of the heuristic is an acceptance threshold $A(t)$, linearly decreasing with time t, such that agents propose/accept if the utility of being with the current partner is above this threshold. We tested both a deterministic and a probabilistic model, by simulating 300 rounds (one per second) in each of which every agent makes one decision.

5.1 A Simulation Model

We let the threshold $A(t)$ be a linear function (same for all agents), starting at some set proportion $A(0)$ of the maximal utility and ending at $A(300) = 0$. We simulated a model where every agent applied the following deterministic rule in each round: *Propose/accept if current partner is above the threshold; if not, and you see some currently single agent who you know to be above your threshold, you move to her; if not, and you see a currently single agent you do not know, you move to her; if not, you go single/stay single.*

To this rule we added a probabilistic component, to reflect that people do not consistently make a new decision every second, that they tend to avoid other agents who have already rejected them, and that they sometimes make errors. We added three corresponding parameters: a large probability p_{nothing} of doing nothing in this round, a large probability p_{sore} of refraining to move to an agent if she has rejected you before, and a small probability p_{error} of making an error in a decision when following the rule, for example, because of imperfect recall of previous events.

We searched the parameter space by varying, independently of each other, $A(0)$ in steps of 0.05 between 0.5 and 1, p_{nothing} and p_{sore} in steps of 0.1 between 0 and 1, and p_{error} in steps of 0.01 between 0 and 0.1. We obtained the best fit to the experimental data for parameter values in the following ranges: $A(0)$ between 0.65 and 0.85, p_{nothing} between 0.3 and 0.7, p_{sore} between 0.3 and 0.7, and p_{error} between 0.01 and 0.05. In these ranges, the results are quite robust. Table 3 shows the results when the parameters take values at the midpoints of these intervals.

The fit to the experimental data can be quantified as follows: Qualitatively, the two datasets agree on how search effort and instability vary with preference structure and group size (Hypotheses 2 through 5). Quantitatively, the average simulation results are generally within one standard deviation of average experimental results.

We conclude that the experimental results are consistent with a model where agents use a heuristic based on a dropping threshold, thus supporting Hypothesis 1.

6 Discussion and Conclusion

In this article we have tried to test the theory proposed by Eriksson and Häggström (2008) to reconcile two

Table 3 Results of 10,000 simulations of the probabilistic model: average number of moves per player (first row) and average relative instability of the final matching (second row). Standard deviations within parentheses. Parameter values used: $A(0) = 0.75$, $p_{nothing} = 0.5$, $p_{sore} = 0.5$ and $p_{error} = 0.03$.

Group size	Preference structure		
	Homotypic	Common	Antithetical
6	1.4 (0.6)	14.9 (4.4)	26.5 (9.3)
	0.07 (0.02)	0.22 (0.23)	0.71 (0.33)
10	3.0 (1.1)	16.6 (3.5)	31.0 (8.7)
	0.01 (0.01)	0.11 (0.17)	0.44 (0.29)
12	2.9 (0.9)	17.2 (4.0)	31.5 (8.1)
	0.00 (0.00)	0.08 (0.13)	0.32 (0.25)
14	2.5 (0.8)	16.6 (2.9)	32.8 (7.7)
	0.00 (0.00)	0.05 (0.11)	0.30 (0.25)

views on matchings: the theory of stable matchings and the theory of mate search. In an experimental situation emulating non-romantic partner search, we found that people seemed to search in a way consistent with their using a heuristic based on an acceptance threshold dropping over time, the "prettier-at-closing-time" effect (Pennebaker et al., 1979). Results also confirmed that players made a higher search effort in larger groups, as well as the important theoretical prediction that the outcomes of partner search tends to be closer to stable in larger groups. The effects of varying the preference structure—a unique feature of the experimental method we used—were also as predicted, with partner search being easier the more aligned agents' interests are. In particular, for partner search under homotypic preferences the outcomes were often perfectly stable.

6.1 Previous Studies With Varying Preference Structures

We know of only one previous study that has investigated the effects of varying the preference structure. Roth and Xing (1997) simulated the American entry-level market for clinical psychologists with agents following the rules of APPIC (Association of Psychology Postdoctoral and Internship Centers), the organization that administers the market. Under these rules, which are much more restrictive than the Cocktail game rules, simulations showed that common preferences of firms caused more congestion than random preferences of firms. Congestion led to more inefficient matching, resulting in greater instability. This result is not directly comparable to ours, as we have not used random preferences in our study.

6.2 Non-Romantic Partner Search Versus Mate Search

In this study we have used a non-romantic setting for partner search, which may be cognitively different to mate search. Previous research on non-romantic partner preferences includes a study by Chapdelaine, Kenny, and LaFontana (1994), where reciprocity of liking developed quickly when people interacted. These results suggest that in non-romantic settings we might expect preferences to have a homotypic element. As pointed out by Eastwick et al. (2007), the picture may be more complex in romantic settings.

On the theoretical side, we have shown that the work of Eriksson and Häggström, which was originally framed in terms of mate search, can be adapted to non-romantic contexts. It is an open question whether the converse holds on the empirical side, that is, whether the empirical results we obtained in this study also hold for mate search.

6.3 Applications to Real-Life Matching

An interesting and largely unexplored issue is which preference structures resemble which real-life matching situations. Here we connect preference structure to search effort and stability. It would be interesting to see how these findings hold up in the real world. For instance are partner matchings in cultures where there are common preferences (such as where wealth is the most important thing) less stable then partner matchings in cultures with more homotypic preferences (such as where compatibility of mates is highly valued)? The question is relevant for both romantic and non-romantic situations.

In this study we found empirical support for the outcome of partner search to be more stable (or, more precisely, to have less relative instability) when groups increased in size, as predicted by the theory of

Eriksson and Häggström. As pointed out by an anonymous reviewer, this raises the question why modern marriages in the Western world actually turn out to be increasingly unstable (Goode, 1993), while the divorce rate is declining elsewhere (Heaton, Cammack, & Young, 2003). There are, of course, some obvious limitations to the stable matching model as a representation of life-long romantic relationships because of volatility in real-life romantic preferences, cultural norms, and so forth. Still, it may be worthwhile to investigate the role played by cultural differences in the partner search process per se (see Hills & Todd, 2008).

Unrelated to our hypotheses, our data also showed a very reasonable correlation between search effort and stability of outcome: When comparing different groups in the same preference structures, we find that groups who exerted greater search effort tended to end up in less unstable matchings ($p < 0.01$). If we think of stability as a collective good, this finding points to a social dilemma here: The collective benefits from individuals searching for as long as possible—but individuals want to continue searching only if other people can be trusted not to take tempting early opportunities to match. This was exactly the dilemma of the British market for medical interns before centralization (Roth, 1991). Social dilemmas usually lead to the creation of institutions, such as official central agencies or less official social contracts, to regulate behavior (Ostrom, 1990). It would be interesting to chart what different kinds of institutions regulate partner search.

Acknowledgments

This work was partially supported by grants from the Knut & Alice Wallenberg Foundation, the Swedish Research Council, and the CULTAPTATION project (European Commission contract FP6-2004-NESTPATH-043434). The computer program *Cocktail* was developed for this project by Jonathan Johnson, Carl Licke, and Mattias Albinsson.

References

Alpern, S., & Reyniers, D. (1999). Strategic mating with homotypic preferences. *Journal of Theoretical Biology*, *198*, 71–88.

Alpern, S., & Reyniers, D. (2005). Strategic mating with common preferences. *Journal of Theoretical Biology*, *237*, 337–354.

Beatty, S. E., & Smith, S. M. (1987). External search effort: An investigation across several product categories. *Journal of Consumer Research*, *14*, 83–95.

Bergstrom, C. T., & Real, L. A. (2000). Towards a theory of mutual mate choice: Lessons from two-sided matching. *Evolutionary Ecology Research*, *2*, 493–508.

Billari, F. C. (2000). Searching for mates using "fast and frugal" heuristics: A demographic perspective. In G. Ballot & G. Weisbuch (Eds.), *Applications of simulation to social sciences*(pp. 53–65). Oxford: Hermes Science.

Chapdelaine, A., Kenny, D. A., & LaFontana, K. M. (1994). Matchmaker, matchmaker, can you make me a match? Predicting liking between two unacquainted persons. *Journal of Personality and Social Psychology*, *67*, 83–91.

Eastwick, P. W., Finkel, E. J., Mochon, D., & Ariely, D. (2007). Selective versus unselective romantic desire: Not all reciprocity is created equal. *Psychological Science*, *18*, 317–319.

Eriksson, K., & Häggström, O. (2008). Instability of matchings in decentralized markets with various preference structures. *International Journal of Game Theory*, *36*, 409–420.

Eriksson, K., Sjöstrand, J., & Strimling, P. (2008). Asymmetric equilibria in dynamic two-sided matching markets with independent preferences. *International Journal of Game Theory*, *36*, 421–440.

Fawcett, T. W., & Bleay, C. (2009). Previous experiences shape adaptive mate preferences. *Behavioral Ecology*, *20*, 68–78.

Finkel, E. J., Eastwick, P. W., & Matthews, J. (2007). Speed-dating as an invaluable tool for studying romantic attraction: A methodological primer. *Personal Relationships*, *14*, 149–166.

Gale, D., & Shapley, L. (1962). College admissions and the stability of marriage. *American Mathematical Monthly*, *69*, 9–15.

Goode, W. J. (1993). *World changes in divorce patterns*. New Haven: Yale University Press.

Heaton, T. B., Cammack, M., & Young, L. (2003). Why is the divorce rate declining in Indonesia? *Journal of Marriage and Family*, *63*, 480–490.

Hills, T. T., & Todd, P. M. (2008). Population heterogeneity and individual differences in an assortative agent-based marriage and divorce model (MADAM) with relaxing expectations. *Journal of Artificial Societies and Social Simulation*, *11*, 5.

Johnstone, R. A. (1997). The tactics of mutual mate choice and competitive search. *Behavioral Ecology and Sociobiology*, *40*, 51–59.

Kalick, S. M., & Hamilton, T. E. (1986). The matching hypothesis reexamined. *Journal of Personality and Social Psychology*, *51*(4), 673–682.

Kenny, D. A. (1994). *Interpersonal perception: A social relations analysis*. New York: Guilford.

Lenton, A.P., Fasolo, B., & Todd, P.M. (2008). `Shopping' for a mate: Expected versus experienced preferences in online mate choice. *IEEE Transactions on Professional Communication*, *51*, 169–182.

Lenton, A.P., Fasolo, B., & Todd, P.M. (2009). The relationship between number of potential mates and mating skew in humans. *Animal Behaviour*, *77*, 55–60.

Niederle, M., & Roth, A. E. (2004). Market culture: How norms governing exploding offers affect market performance. *NBER Working Paper* No. W10256, National Bureau of Economic Research (Cambridge, MA, USA).

Ostrom, E. (1990). *Governing the commons: The evolution of institutions for collective action*. New York: Cambridge University Press.

Pennebaker, J. W., Dyer, M. A., Caulkins, R. S., Litowitz, D. L., Ackreman, P. L., Anderson, D. B., & McGraw, K. M. (1979). Don't the girls get prettier at closing time: A country and western application to psychology. *Personality and Social Psychology Bulletin*, *5*, 122–125.

Roth, A. E. (1991). A natural experiment in the organization of entry-level labor markets: Regional markets for new physicians and surgeons in the United Kingdom. *American Economic Review*, *81*, 415–440.

Roth, A. E., & Sotomayor, M. A. O. (1990). *Two-sided matching*. New York: Cambridge University Press.

Roth, A. E., & Xing, X. (1997). Turnaround time and bottlenecks in market clearing: Decentralized matching in the market for clinical psychologists. *Journal of Political Economy*, *105*, 284–329.

Simão, J., & Todd, P. M. (2002). Modeling mate choice in monogamous mating systems with courtship. *Adaptive Behavior*, *10*, 113–136.

Simão, J., & Todd, P. M. (2003). Emergent patterns of mate choice in human populations. *Artificial Life*, *9*, 403–417.

Smith, V. L. (2000). *Bargaining and market behavior: Essays in experimental economics*. New York: Cambridge University Press

Todd, P. M. (1997). Searching for the next best mate. In R. Conte, R. Hegselmann, & P. Terna (Eds.), *Simulating social phenomena* (pp. 419–436). Berlin, Springer-Verlag.

Todd, P. M., & Miller, G. F. (1999). From pride and prejudice to persuasion: Satisficing in mate search. In G. Gigerenzer & P. M. Todd (Eds.), *Simple heuristics that make us smart* (pp. 287–308). Oxford University Press.

Todd, P. M., Billari, F. C., & Simão, J. (2005). Aggregate age-at-marriage patterns from individual mate-search heuristics. *Demography*, *42*, 559–574.

Ünver, M. U. (2005). On the survival of some unstable two-sided matching mechanisms. *International Journal of Game Theory*, *33*, 239–254.

About the Authors

Kimmo Eriksson received a Ph.D. in mathematics from the Royal Institute of Technology in Stockholm, Sweden, in 1993. He is a professor of applied mathematics at Mälardalen University in Sweden, and a member of the Centre for the Study of Cultural Evolution at Stockholm University. His research interests include mathematical modeling and behavioral experiments.

Pontus Strimling received a Ph.D. in mathematics from Mälardalen University, Sweden, in 2008. He is currently a postdoctoral researcher at the University of St. Andrews. In his research he uses mathematical modeling and behavioral experiments to better our understanding of human social behavior. *Address*: Centre for the Study of Cultural Evolution, Stockholm University, SE-106 91 Stockholm, Sweden.
E-mail: pontusstrimling@gmail.com