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Euclidean distances discriminatively predict short-term and long-term attraction to potential mates

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ABSTRACT

We tested the ability of a Euclidean algorithm to predict attraction to potential mates—a relatively upstream domain in the temporal sequence of the mating process. Participants in two studies reported their ideal mate preferences using a 23-item preference instrument. Separately, they rated their attraction to profiles of potential mates that varied on those 23 dimensions. Study 1 ($N = 522$) found that Euclidean distances predicted attraction to potential mates both in terms of (1) overall mate value and (2) unique mate value. Study 2 ($N = 411$) replicated these effects and further found that Euclidean mate values discriminatively predict between short- and long-term attraction. Across both studies, a Euclidean model outperformed a variety of alternative models for predicting attraction to potential mates. These results suggest that a Euclidean algorithm is a good model for how multiple preferences are integrated in mate choice.

1. Introduction

Mate selection poses both a critical adaptive problem and a formidable computational challenge. Choosing one mate from a larger pool of potentials has large and direct effects on individual reproduction, the driving engine of evolution. But successfully selecting a mate requires comparing a set of mate preferences to an array of potential mates who vary somewhat independently across multiple dimensions in a way that reliably identifies those mates that are overall fitness-beneficial and those mates that are fitness-costly. One hypothesis suggests that human mate selection psychology solves this computational problem by integrating information on multiple mate preference dimensions according to a Euclidean algorithm that represents ideal preferences and potential mates as points within a common multidimensional space (Conroy-Beam & Buss, 2016; Conroy-Beam, Goetz, & Buss, 2016). Here we test this hypothesis by examining whether Euclidean integration of mate preferences can predict attraction to potential mates.

Mate selection would have had large and direct impacts on fitness throughout human evolutionary history. For ancestral humans, chosen mates could have represented reproduction partners, cooperation partners, and parenting partners. Which mates an ancestral individual selected would have affected their reproduction, the care their offspring received, the strength of their social alliances, and the traits their offspring inherited. For these reasons, selection would have strongly favored the evolution of mating psychologies capable of guiding ancestral individuals toward fitness beneficial mates and away from cost-inflicting mates.

Prior mate preference research supports this fundamental idea. People across cultures express desires for many qualities that would have yielded fitness benefits to human ancestors, including kindness, intelligence, dependability, emotional stability, and healthiness (Buss, 1989; Botwin, Buss, & Shackelford, 1997; DeBruine, Jones, Crawford, Welling, & Little, 2010). Moreover, men, more than women, desire partners who are physically attractive and youthful, embodying cues to reproductive potential. Women, more than men, desire partners who are slightly older than they are and who have social status and good financial prospects—cues to provisioning ability (Buss, 1989; Kenrick & Keefe, 1992; Li, Bailey, Kenrick, & Linsenmeier, 2002).

These many mate preferences are hypothesized to function to guide mate selection in fitness-beneficial directions, but their multiplicity introduces a computational challenge to mate selection. The fitness benefits a potential mate offers can vary at least somewhat independently across a large number of dimensions. A kind cooperator, for example, may or may not be intelligent or healthy. An emotionally stable individual may or may not be high in social status. Crucially, these individual dimensions could also interact in complex ways: a mate whose beauty would otherwise signal fertility could only offer few benefits if they are also cruel, selfish, or extremely ill. Each potential mate represents a constellation of qualities that must be compared against a constellation of preferences. How does a mate who is intelligent, considerate, and ill compare to one who is dull, selfish, and healthy? To make these decisions, ancestral humans would have needed some computational machinery capable of integrating information from many

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different preference dimensions into useful summary variables that track overall value as a mate.

There are a variety of algorithms human psychology could use to integrate mate preferences. One class of preference integration algorithms are satisficing algorithms that involve using few, highly informative criteria to search for mates only until a mate who fulfills some aspiration is found (e.g. Miller & Todd, 1998). Such satisficing algorithms do not search for the best mates, but rather accept the first mate who meets some acceptable threshold. These algorithms work well for decision problems such as the "secretary problem" wherein alternatives are encountered sequentially—that is, one must decide upon one alternative before evaluating another—and problems wherein the space of alternatives is too large or too costly to search exhaustively (Todd & Miller, 1999). The conditions under which satisficing algorithms perform well appear to be good descriptions of mate search in large modern populations, and could serve as a good description of the problems faced in mate choice for species such as guppies that must forage their environment for mates, risking predation in the process (Godin & Briggs, 1996).

However, it is less clear that sequential, costly mate search would have characterized the mating markets of the ancestral environments that forged human mating psychology. For most of our evolutionary history, humans lived in small social groups (Dunbar, 1992; Marlowe, 2005) that would have been easier to search relatively exhaustively. Whereas modern humans can measure their space of potential mates in the millions, ancestral humans would likely have measured this space in at most the hundreds. Humans are additionally adept at extracting information from others relatively quickly based on brief exposure (e.g. Naumann, Vazire, Rentfrow, & Gosling, 2009) and at leveraging information from third-parties (e.g. Rodeheffer, Leyva, & Hill, 2016), so ancestral humans could have extracted much information from each of their potential mates at low cost. Finally, our small-group living ancestors could have evaluated mates relatively simultaneously. One potential mate does not need to be rejected before another can be considered. Moreover, mates rejected at one time could become potentials again when circumstances change. Given these circumstances, and particularly given the large impact of mate choice on reproductive success, sequential and information-frugal satisficing algorithms may have been less efficient solutions to the problem of selecting fitness-beneficial partners than algorithms that utilize more information and allow identification of the best available mates, rather than merely sufficient mates.

One such algorithm is a linear combination algorithm where mate preferences act like slopes in a linear regression (Eastwick, Luchies, Finkel, & Hunt, 2014; Miller & Todd, 1998). A psychology that used such an algorithm could guide individuals to fitness beneficial partners because it would estimate high mate value partners as being those who possess more of preferred features. By using preferences as weights, a psychology with a linear combination algorithm would allow stronger preferences to contribute more strongly to mate value estimates overall.

Nonetheless, such linear combination algorithms have some shortcomings. For example, a regression-like combination must consider each preference dimension independently and simply aggregate information across dimensions after the fact. This linear combination algorithm cannot consider interactions between preference dimensions without the addition of potentially intractable numbers of interaction parameters. Because of this, a mate who is brilliant but extremely cruel could be considered equal in value to a mate who is moderately kind and intelligent.

In contrast to satisficing or linear combination algorithms, emerging evidence suggests that human mate selection psychology employs an alternative algorithm, a Euclidean algorithm, that is able to integrate a variety of preferences in a holistic fashion (Conroy-Beam & Buss, 2016; Conroy-Beam et al., 2016). A Euclidean algorithm represents ideal preferences and potential mates as points within a multidimensional preference space. Consider a simplified scenario in which humans have just three preferences—for kindness, dependability, and intelligence. These three preferences could be used to form a three-dimensional preference space with one preference representing each of the X, Y, and Z axes (Fig. 1). Any point within this 3D space represents a possible set of mate preferences as well as a possible set of traits. A Euclidean preference integration algorithm places ideal preferences and the traits of potential mates at their appropriate locations within this preference space and calculates mate value as proportional to the distance between these points.

This algorithm has several features that make it useful for integrating preferences in mate choice. First, just as with a linear combination algorithm, the Euclidean algorithm can integrate any number of preferences into a single decision variable reflecting the extent to which a mate embodies a given set of mate preferences. These values can be compared continuously among an array of potential mates to identify which mates best fulfill mate preferences overall. Second, the nature of the Euclidean algorithm directly reflects the computational challenge human ancestors would have faced in mate selection. Each potential mate encountered represents a unique collection of qualities—a single point at the intersection of multiple mate preference dimensions. It is this point that must be accepted or rejected as a whole: one cannot accept a potential mate's beauty without also accepting their cruelty, ill-health, and so on. The Euclidean algorithm, unlike satisficing or linear combination algorithms, represents potential mates in exactly this way: as points within an *n*-dimensional preference space that must be evaluated as a whole.

Finally, because the Euclidean algorithm evaluates potential mates simultaneously across all dimensions, it naturally incorporates interactions between preference dimensions that historically could have led to more fitness-beneficial mate choices. Due to the nature of the Euclidean distance, but not other distance metrics such as the Manhattan distance, deviation from preferences on any one dimension decrease the extent to which other dimensions can contribute to mate value. A mate's beauty or intelligence counts less in determining their mate value if they are also cruel or infectious. A Euclidean algorithm therefore captures threshold effects documented in prior mate preference research (Li et al., 2002). Under a Euclidean algorithm, a potential mate increases in mate value to the extent that they fulfill preferences across all dimensions; mates who are exemplary on some dimensions but deficient on others do not suffice.

Because of these features, the Euclidean algorithm proves to be a highly evolvable means of integrating mate preferences. In agent-based models where agents compete to identify and select the most fitness beneficial mates among mates who vary on multiple dimensions,

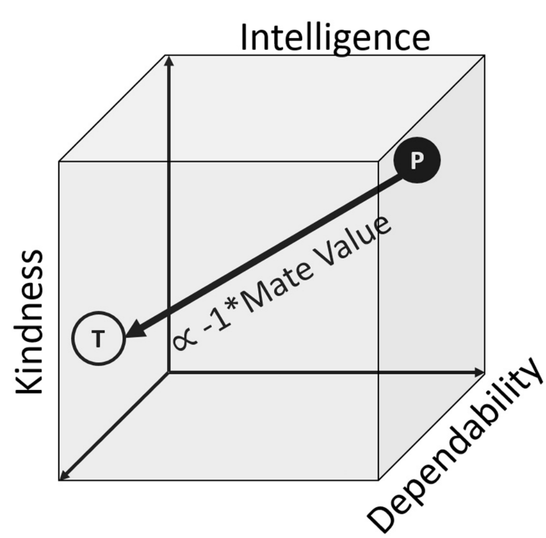

Fig. 1. Graphical depiction of preference integration according to a Euclidean algorithm. Mate value is calculated as proportional to the distance between ideal preferences (P) and potential mate traits (T) through the multidimensional preference space.

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agents employing a Euclidean algorithm outperform competitors employing alternative algorithms, including linear, polynomial, and threshold algorithms, under a variety of conditions (Conroy-Beam & Buss, 2016).

And the merits of the Euclidean algorithm are not just theoretical. Actual relationships show evidence of being formed based on Euclidean mate preference integration. People's actual long-term mates tend to fall short distances from their preferences through the multidimensional preference space, consistent with these mates being chosen according to Euclidean integration of preferences. Importantly, mate value increases preference fulfillment: the distance between preferences and chosen partners tends to be shorter for people who are higher in mate value according to Euclidean calculations (Conroy-Beam & Buss, 2016). Finally, discrepancies in mate value according to Euclidean calculations have downstream consequences: people are satisfied with partners who are higher in mate value than themselves or than their alternatives when mate value is calculated as the Euclidean distance between a person and the preferences of their potential mates (Conroy-Beam et al., 2016).

Overall, this collection of findings from studies of ongoing romantic relationships is consistent with the hypothesis that mate preferences are integrated in mate choice according to a Euclidean algorithm. Here we test a novel prediction of this hypothesis at a relatively upstream stage of mate choice: if human mate selection psychology integrates mate preferences according to a Euclidean algorithm, Euclidean distances should have power in predicting attraction to potential mates. In Study 1 we explore the ability of the Euclidean algorithm to predict attraction to potential mates in terms of two key indices of desirability as a potential mate: (1) *unique mate values*, or the extent to which a person fulfills the mate preferences of a specific potential mate, and (2) *overall mate value*, or the extent to which a person fulfills the consensually-defined mate preferences of their potential mates in general. Study 2 tests the ability of the Euclidean algorithm to discriminatively predict attraction to short- and long-term mates. In both studies, we compare the predictive power of the Euclidean algorithm to multiple alternative models for predicting human attraction.

2. Study 1: predicting attraction from Euclidean estimates of unique mate value and overall mate value

In Study 1, we presented participants profiles of potential mates who varied on an array of traits. If mate preferences are actually integrated according to a Euclidean algorithm, Euclidean distances should be able to predict attraction to these potential mate profiles at the levels of both unique and overall mate value.

2.1. Method

2.1.1. Participants

Participants were $n = 522$ heterosexual people ($n = 226$ males) recruited using Amazon's Mechanical Turk. Participant recruitment was targeted at a sample size of $n = 400$; this sample size was chosen to be comparable to but larger than sample sizes that have found significant effects of Euclidean distances in prior studies (e.g. Conroy-Beam & Buss, 2016). We over-recruited because of variability in recruitment rates, but retained participants recruited after the target sample size was met. Results did not qualitatively differ in any of 1000 random subsamples of $n = 400$. Participants were $M = 36.13$ ($SD = 12.36$) years old on average.

2.1.2. Materials

All participants completed a 23-item mate preference instrument. This instrument was a modified version of one used in Buss (1989) and requested participants rate their ideal partner on 23 trait dimensions such as “good cook”, “ambitious”, and “intelligent.” Each preference variable was rated on a 7-point bipolar adjective scale with each pole representing extreme levels of the relevant trait, for instance “very unkind” to “very kind.” Participants rated their ideal desired location for each trait in a long-term mate, described as a committed, romantic relationship.

Each participant separately viewed a set of nine potential mate profiles. Profiles were described to participants as profiles of ratings from the same mate preference instrument the participants completed, with each profile representing a different person. Profiles showed participants each of the 23 trait dimensions, along with a rating on the same 7-point scale the participants previously used. Participants rated how attractive they would find the person in the profile as a long-term mate on a 7-point scale ranging from “not at all attractive” to “very attractive”.

Profiles were generated in a two-step process. We first used data from a prior study (Conroy-Beam et al., 2016; Study 1) to estimate the average male and female preferences across the 23 trait dimensions. To generate each profile, we created an R script which added random uniform noise to these average preference values to create unique, random profiles. The amount of random noise added was manipulated in order to yield profiles with specific overall Euclidean mate values where overall Euclidean mate value is proportional to the Euclidean distance between a profile's traits and the average preferences of the opposite-sex. Three profiles were constructed to be of overall Euclidean mate value approximately equal to the highest Euclidean mate value observed in Conroy-Beam et al. (2016); three profiles were generated to have mate values approximately equal to the median observed mate value; and three profiles were generated to have mate values approximately equal to the lowest observed mate value. Separate profile sets were generated for male participants and for female participants because the sexes have distinct patterns of mate preferences in multidimensional terms (Conroy-Beam, Buss, Pham, & Shackelford, 2015). Fig. 2 shows an example profile, generated to be high in overall Euclidean mate value to females.

2.1.3. Procedure and data analysis

Participants first rated their ideal mate preferences using the ideal preferences questionnaire. Participants later rated the 9 profiles for their sex in randomized order.

We calculated the unique mate value of each profile as the Euclidean distance between each participant's ideal mate preferences and the traits of the profile. This distance was the square root of the sum of the squared differences between the participant's ideal preference for each dimension and the profile's corresponding trait value. For ease of interpretation, we transformed these Euclidean distances by multiplying them by negative one and adding to them a constant equal to the maximum possible Euclidean distance plus one: 29.77. Mate value was thus calculated as: mate value $= -1^{*}\sqrt{\sum_{1}^{n}(p_n - t_n)^2} + 29.77$. This transformation yielded mate values that were positively keyed, easy to interpret, and directly proportional to the untransformed Euclidean distances. This differs from the inverse transformation used in prior research (e.g. Conroy-Beam & Buss, 2016; Conroy-Beam et al., 2016). The new transformation used here is superior to the inverse transformation because inverted distances have a non-linear relationship with untransformed distances and therefore require more complicated non-linear models to fully observe their effects. We calculated the overall Euclidean mate value of each profile as the transformed Euclidean distance between each profile's traits and the average preferences of all opposite-sex participants—that is, consensually desired preferences.

We analyzed the effects of Euclidean distances on attraction using linear mixed modeling. The first set of models predicted participant attraction to the potential mate profiles from the interaction of participant sex and the overall Euclidean mate value of the profiles, with profiles nested within participants. The second set of models predicted participant attraction from the unique mate value of each profile to each

Good cook	Pleasant personality	Sociable	Refined	Good financial prospects	Muscular
4	7	5	5	6	4

Dependable	Emotionally stable	Desires home and children	Good social status	Good looking	Religious
6	6	6	5	5	4

Ambitious	Kind	Healthy	Educated	Dominant	Confident
6	6	6	6	5	7

Intelligent	Masculine	Feminine	Loving	Elderly
7	6	3	6	3

Fig. 2. An example potential mate profile. This profile was generated to be high in overall Euclidean mate value to females.

participant. All models incorporated relevant random slope and intercept effects. All predictor and outcome variables were standardized before analysis for all models.

Finally, we compared the predictive power of Euclidean distances to that of five other methods for predicting attraction to the potential mate profiles. The alternative models attempted to predict attraction using (1) a traditional regression model including the interaction between each ideal mate preference dimension and potential mate profile, (2) the Manhattan distance, or the absolute deviation between participant preferences and the traits of each profile, (3) the Chebyshev distance, or the maximum deviation between participant preferences and the traits of each profile across all dimensions, (4) profile correlations, or the correlation between each participant's preferences and the traits of each profile (e.g. Fletcher, Simpson, & Thomas, 2000), and (5) profile valence, or the sum of each profile's traits when all trait dimensions were re-coded such that higher values corresponded to more "positively" valenced values. Profile valance models did not incorporate information about participant preferences.

We compared the predictive power of the six models using the Bayesian information criterion (BIC). Because BIC comparisons would be largely influenced by the number of parameters used across models, we also compared models using the root-mean squared error (RMSE) from a leave-one-out cross validation. To conduct this cross-validation, from each participant we randomly set aside one of that participant's ratings into a test set and set the participant's remaining ratings into a training set. We trained each model on the training set and then used the resulting models to predict the test set. Finally, we calculated and saved for each model the square root of the mean squared errors between each test value and the value predicted by each model. This process was iterated until each of the participant's ratings had been used in the test set at least once; we report the average RMSE across these 9 iterations.

2.2. Results

2.2.1. Overall mate value

Results from the linear mixed model predicting attraction to profiles from their overall mate values are shown in Table 1. Because males and females viewed different profiles, we included sex as in interaction term to assess whether overall mate value affected both male and female attraction ratings.

Table 1
Results of the linear mixed model predicting profile attractiveness from profile euclidean mate value and participant sex.

	Effect	β	SE
Fixed effects	Overall Euclidean mate value	0.42***	0.04
	Participant sex	10	0.06
	Overall Euclidean mate value × participant sex	−0.14***	0.03
Random effects	Intercept	0.33	
	Overall Euclidean mate value	0.06	

*** $p < 0.001$.

An unpredicted interaction emerged between profile mate value and participant sex (Fig. 3). Overall Euclidean mate value increased the attractiveness of the potential mate profiles for both males and females, but did so more for female participants than for male participants. This effect suggests that both males and females were attracted to profiles high in overall mate value, but female participants were more selective in their attraction than were male participants.

2.2.2. Unique mate value

Table 2 presents the results of the linear mixed model predicting participant attraction to potential mate profiles from the unique mate value of each profile to the participants. Unique Euclidean mate values were a significant predictor of participant attraction: participants reported being more attracted to profiles that were a shorter Euclidean distance from their unique mate preferences. This effect is presented in Fig. 4.

Additionally, unique mate value predicted attraction ratings above and beyond overall mate value. A model that included both unique and overall mate values found that unique mate values predicted participant attraction, $\beta = 0.41$, $p < 0.001$, but overall mate value did not, $\beta = -0.005$, $p = 0.91$. Finally, unique mate value additionally interacted with sex in the same manner as overall mate value, $\beta = -0.11$, $p < 0.001$. Unique mate value increased attraction for both males and females, but did so more positively for females than for males.

2.2.3. Comparing Euclidean and alternative models of attraction

We finally compared the model predicting attraction to profiles from unique Euclidean mate values to models using traditional regression,

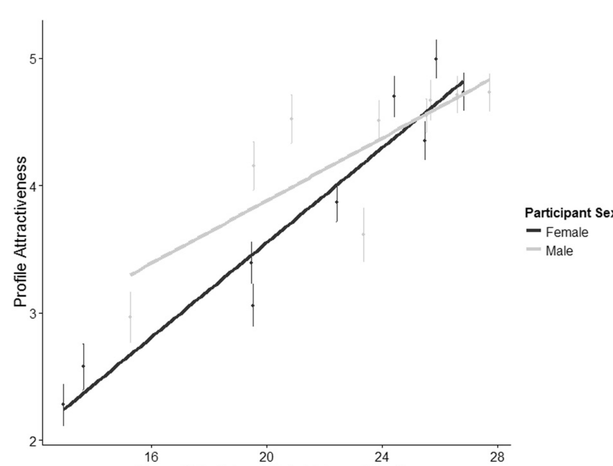

Fig. 3. Attractiveness of potential mate profiles as a function of the profiles' overall Euclidean mate values. Mate value predicted attraction to profiles with a stronger slope for women than for men. Error bars represent 95% confidence intervals.

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Table 2
Results of the linear mixed model predicting participant attraction to profiles from unique mate value.

	Effect	β	SE
Fixed effects	Unique mate value	0.40***	0.02
Random effects	Intercept	0.34	
	Unique mate value	0.07	

*** $p < 0.001$.

Table 3
Comparing models of attraction with the BIC and RMSE.

Model	BIC	RMSE
Euclidean	10,296.71	0.722
Manhattan	10,340.96	0.726
Chebyshev	10,394.87	0.738
Profile Correlations	10,448.11	0.754
Profile Valence	10,524.61	0.742
Traditional Regression	11,622.97	0.746

the Manhattan distance, the Chebyshev distance, profile correlations, and profile valence. If mate preferences are integrated into feelings of attraction according to a Euclidean algorithm, models using Euclidean mate values should emerge as superior in predicting attraction relative to models using other predictors. Table 3 presents the Bayesian information criterion and RMSE values for each of the six models; lower values of both metrics indicate better predictive power from that model. By both metrics, the Euclidean algorithm was favored as a model for predicting attraction over all other models.

2.3. Discussion

Euclidean distances predict attraction as a function of both unique and overall mate value. People find profiles that embody consensually-defined mate preferences in multidimensional terms to be more attractive overall. Participants furthermore specifically expressed attraction to those profiles that embodied their unique mate preferences. Importantly, this Euclidean model of attraction also outperforms several other possible models for how mate preferences are translated into feelings of attraction. Altogether, these results suggest that a Euclidean algorithm is a good description of how human mate preferences are integrated into overall assessments of potential mates.

One limitation of Study 1, however, was that we focused exclusively on long-term attraction to potential mates. Humans engage in long-term, committed mating as well as short-term casual mateships (Buss & Schmitt, 1993). If a Euclidean algorithm underlies the integration of preferences into feelings of attraction, Euclidean distances should be able to predict short-term and long-term attraction to potential mates. We therefore conducted Study 2 to both replicate the results of Study 1 as well as test the ability of Euclidean distances to discriminatively predict short- and long-term attraction.

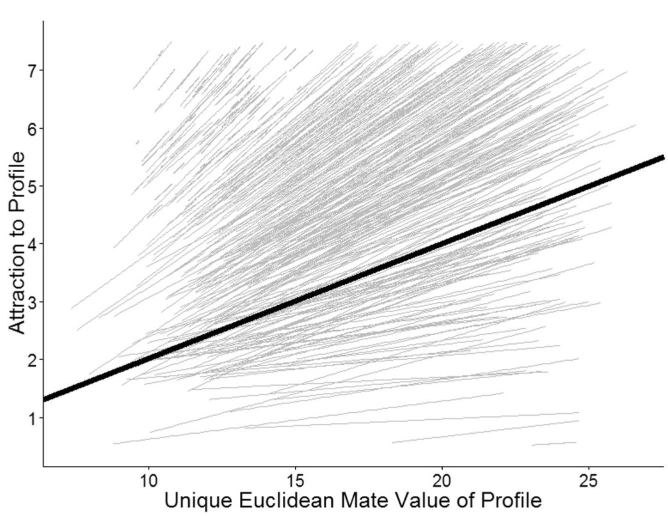

Fig. 4. Attraction to profiles as a function of the unique mate value of each profile to participants. Each grey line represents the predicted trend line for a single participant; the black line represents the trend line for participants overall.

3. Study 2: using Euclidean distances to discriminatively predict short- and long-term attraction

Study 2 had two goals: to replicate the findings of Study 1 and to determine whether Euclidean distances can discriminatively predict short-term and long-term attraction. That is, does distance from short-term preferences predict short-term attraction better than distance from long-term preferences and does distance from long-term preferences predict long-term attraction better than distance from short-term preferences?

3.1. Method

3.1.1. Participants

Participants were 411 heterosexual people ($n = 208$ male) recruited using Amazon's Mechanical Turk. Participants were $M = 33.72$ years old on average ($SD = 10.70$). Recruitment was again targeted at a sample size of $n = 400$.

3.1.2. Materials

Participants completed the same 23-item mate preference instrument from Study 1. Participants separately rated what they ideally desired for each trait in a long-term mate, described as a committed, romantic relationship as well as in a short-term mate, described as a one-night stand or uncommitted, sexual relationship.

All participants additionally viewed a set of 12 potential mate profiles. Six of these profiles were taken from the set of profiles rated in Study 1—two each of high, medium, and low long-term mate value profiles. Six new profiles were generated using the same R script to be roughly low, medium, and high in short-term mate value. Participants rated how attractive they would find the person in the profile as a long-term mate and as a short-term mate on 7-point scales ranging from "not at all attractive" to "very attractive." Male and female participants again viewed different sets of profiles.

3.1.3. Procedure and data analysis

Participants reported their ideal long-term preferences, their ideal short-term preferences, and rated the potential mate profiles in counterbalanced order. As in Study 1, we calculated the unique long-term mate value of each profile as the transformed Euclidean distance between the traits of the profile and each participant's long-term mate preferences. We calculated the unique short-term mate value of each profile as the transformed Euclidean distance between the profile's traits and the participant's short-term preferences. Overall short- and long-term mate values were calculated for each profile as the transformed Euclidean distance between the profile's traits and the average short- and long-term mate preferences of all opposite-sex participants respectively.

We analyzed the effects of Euclidean distances on attraction using linear mixed modeling. First we replicated the analyses of Study 1 with both short- and long-term mate values, predicting long-term attraction using Euclidean distances from long-term preferences and short-term attraction using Euclidean distances from short-term preferences. We additionally compared the predictive power of these Euclidean models to the same set of alternative models as in Study 1. All predictor and outcome variables were again standardized before

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analysis for all models. Second, we explored the discriminative predictive power of short- and long-term Euclidean mate values. For these analyses, we entered short- and long-term Euclidean mate values as predictors of both short- and long-term attraction.

3.2. Results

3.2.1. Separately predicting long- and short-term attraction

We first attempted to replicate the results of Study 1 and extend these effects to short-term attraction. Overall Euclidean mate value again interacted with sex to predict long-term attraction to potential mates (Table 4). Profiles that were closer to participants' consensual long-term mate preferences through the multidimensional preference space were more attractive to participants overall as long-term mates. This effect was stronger for female participants than for male participants as in Study 1. Table 4 also shows that again unique Euclidean mate value predicted attraction to the potential mate profiles; participants were more attracted to potential mate profiles that were closer to their specific preferences through the multidimensional preference space. As in Study 1, this effect also emerged over and above overall mate value: in a model predicting long-term attraction from both overall and unique mate value, unique long-term mate value ($\beta = 0.45$, $p < 0.001$) predicted attraction but overall long-term mate value did not ($\beta = -0.07$, $p = 0.10$). Finally, unique long-term mate value interacted with sex in the same way as overall long-term mate value: $\beta = -0.08$, $p = 0.02$. Unique long-term mate value predicted long-term attraction for both males and females, but did so with a stronger positive slope for females than for males.

These effects also extended to short-term attraction. Just as for long-term attraction, sex and overall short-term mate value interacted to predict short-term attraction to the potential mate profiles (Fig. 5A). Increasing short-term overall mate value increased the attractiveness of the profiles to participants for both males and females, but more for female participants than for males. Unique short-term mate values additionally predicted short-term attraction to potential mates; profiles that were closer to participants' unique short-term preferences through the multidimensional preference space were more attractive to the participants as short-term mates (Fig. 5B).

As for long-term mate values, unique short-term mate value predicted short-term attraction over and above overall short-term mate value ($\beta = 0.31$, $p < 0.001$); overall short-term mate value did not predict attraction when controlling for unique short-term mate value ($\beta = 0.00$, $p = 0.94$). Finally, sex and short-term unique mate value interacted to predict short-term attraction: $\beta = -0.10$, $p = 0.007$. Unique mate value predicted short-term attraction for both males and females, but did so with a more positive slope for females than for males.

We next compared the Euclidean models of attraction to the same alternative models as in Study 1 using the Bayesian information criterion and the RMSE. Table 5 presents the results. Again the Euclidean model emerged as the best model for predicting long-term attraction. However, although Euclidean mate values significantly predicted short-term attraction, the Euclidean model did not emerge as the best model for predicting short-term attraction in this sample. The Euclidean model was superior to the traditional regression and profile correlation models, but worse than the Manhattan distance and profile valence models according to the Bayesian information criterion and RMSE. The Manhattan distance model was overall the best model for predicting short-term attraction.

Participant mating strategies might provide one explanation for the poorer performance of the Euclidean model in predicting short-term attraction. Many of our participants were involved in committed, long-term relationships: 66% of participants reported being married, engaged, or involved in exclusive, committed relationships. People in committed, long-term relationships are known to have lower overall desire for short-term relationships (Penke & Asendorpf, 2008). Short-term attractiveness ratings from mated participants may therefore include additional noise because these participants are less interested in short-term mating on average. This noise may decrease the differences between the models in their predictive power. Relationship status indeed moderated the effect of unique short-term mate values on short-term attraction, *est.* $= -0.06$, $t(387.30) = -3.27$, $p = 0.001$. Unique short-term mate values predicted short-term attraction for both single and mated participants, but mate values were a stronger predictor for single participants. When we repeated the model comparison procedure for single participants alone, the Euclidean algorithm emerged as the best model for predicting both short- and long-term attraction to potential mates (Table 6).

3.2.2. Discriminatively predicting short- and long-term attraction

We next tested whether Euclidean mate values discriminatively predicted long- and short-term attraction. Overall Euclidean mate values showed discriminative power in predicting long-term attraction when controlling for short-term attraction. Both overall long-term ($\beta = 0.22$, $p < 0.001$) and overall short-term ($\beta = 0.20$, $p < 0.001$) mate value predicted long-term attraction when considered in separate models. However, in a model that included overall long- and short-term mate values simultaneously, overall long-term mate value remained a significant predictor of long-term attraction ($\beta = 0.44$, $t(400) = 8.79$, $p < 0.001$) whereas overall short-term mate value negatively predicted long-term attraction to the potential mate profiles ($\beta = -0.22$, $t(403) = -0.46$, $p < 0.001$). Proximity to participants' consensual long-term preferences increased the long-term attractiveness of profiles whereas, when controlling for long-term mate value, proximity to consensual short-term preferences decreased long-term attractiveness

The effects were similar for unique Euclidean mate value. Long-term ($\beta = 0.24$, $p < 0.001$) and short-term ($\beta = 0.20$, $p < 0.001$) unique mate values both emerged as significant predictors of long-term attraction in separate models. Yet in a model including short- and long-term unique mate values, long-term unique mate values positively predicted long-term attraction ($\beta = 0.35$, $t(249) = 11.57$, $p < 0.001$) whereas short-term unique mate values negatively predicted long-term attraction ($\beta = -0.13$, $t(294) = -4.25$, $p < 0.001$). Proximity to participants' unique long-term preferences increased participants' long-term attraction to the profiles whereas proximity to participants' short-term preferences decreased participants' attraction to the profiles as long-term mates.

Finally, Euclidean mate values discriminatively predicted short-term attraction as well. Both short-term ($\beta = 0.12$, $p < 0.001$) and long-term ($\beta = 0.11$, $p < 0.001$) overall mate value predicted short-term attraction when entered in separate models. In a model with both overall short- and long-term mate value as predictors, overall short-term mate value positively predicted short-term attraction, $\beta = 0.18$, $t(404) = 4.34$, $p < 0.001$; overall long-term mate value did not significantly predict short-term attraction, $\beta = -0.07$, $t(426) = -1.54$, $p = 0.12$. Both unique short- and long-term mate value predicted short-term attraction in separate models: $\beta = 0.14$, $p < 0.001$, and $\beta = 0.12$, $p < 0.001$, respectively. However, in models with short- and long-term mate value as

Table 4
Linear mixed models separately predicting long- and short-term attraction from overall and unique mate value.

Outcome	Predictors	β
Long-term attraction	Overall long-term mate value	0.39***
	Sex	0.27***
	Overall long-term mate value * Sex	−0.08*
Long-term attraction	Unique long-term mate value	0.37***
Short-term attraction	Overall short-term mate value	0.33***
	Sex	0.35***
	Overall short-term mate value * sex	−0.11**
Short-term attraction	Unique short-term mate value	0.31***

* $p < 0.05$.
** $p < .01$.
*** $p < 0.001$.

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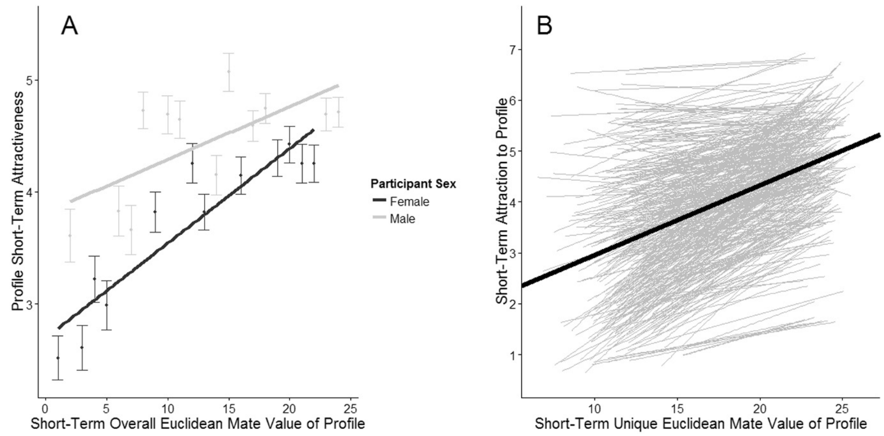

Fig. 5. Short-term attraction to profiles as a function of (A) the overall mate value of each profile to participants and (B) the unique mate value of each profile to participants. Euclidean mate values predicted short-term attraction as a function of both overall and unique short-term mate value.

simultaneous predictors, unique short-term mate value positively predicted short-term attraction, $\beta = 0.20$, $t(340) = 6.39$, $p < 0.001$, whereas unique long-term mate value marginally negatively predicted short-term attraction, $\beta = -0.06$, $t(315) = -0.190$, $p = 0.06$. For both unique and overall mate value, an increase in short-term mate value increased the short-term attractiveness of the profiles to participants whereas increasing long-term mate value did not significantly affect short-term attraction.

3.3. Discussion

The results of Study 2 replicate and extend those of Study 1 in several ways. Euclidean distances predicted long-term attraction in terms of overall and unique mate value and emerged as the best predictor of long-term attraction relative to several other models. Euclidean overall and unique mate value also emerged as good predictors of short-term attraction; the Euclidean algorithm was the best predictor of short-term attraction for unmated participants, though predicting short-term attraction appears to be more complicated for mated people. Importantly, short- and long-term mate values discriminatively predicted short- and long-term attraction: long-term attractiveness increased as a function of long-term mate value, but not short-term mate value; short-term attractiveness increased as a function of short-term mate value, but not long-term mate value. Altogether, Study 2 demonstrates that Euclidean distances have replicable and theoretically consistent roles in predicting attraction to potential short- and long-term mates.

4. General discussion

Selecting a mate from a larger pool of potentials represents both a key adaptive problem and a difficult computational challenge. Human mating research has generated a large and growing body of knowledge centered on the mate preferences evolved to solve the adaptive problem of selecting fitness-beneficial mates (e.g. Buss, 1989; Kenrick, Sadalla, Groth, & Trost, 1990; Lewis, Russell, Al-Shawaf, & Buss, 2015). Here we provide novel evidence concerning how these many preferences are integrated computationally to make mating decisions. Across two studies, we show that Euclidean distances discriminatively predict long-term and short-term attraction to potential mates both in terms of overall and unique mate value. These findings support the novel hypothesis that human mate selection psychology integrates mate preferences according to a Euclidean algorithm which represents preferences and potential mates as points within a common multidimensional preference space.

The ability of the Euclidean algorithm to predict attraction to potential mates represents an important extension of this algorithm within the mating domain. Mating behavior requires computations at several stages throughout a broad sequence of events. These include evaluating potential mates, selecting mates, evaluating and regulating ongoing relationships, and dissolving extant mateships. Euclidean distances have established power to connect ideal mate preferences to relatively downstream stages of mating including actual mate selections (Conroy-Beam & Buss, 2016) and evaluations of and satisfaction with ongoing relationships (Conroy-Beam et al., 2016). The findings of our two new studies push the Euclidean algorithm to a relatively upstream stage of mating: attraction to mates prior to mate selection.

4.1. Limitations and future directions

The results of our two studies also point to important new directions for future research. For instance, the current studies were limited in that participants responded to static stimuli representing hypothetical mates rather than actual potential mates in vivo. Our profile method affords substantial experimental control in that we were able to precisely manipulate the mate value of the potential mate profiles to participants. These profiles also allow researchers to explore attraction based on more holistic stimuli; this person-centered affords the opportunity to more easily explore the effects of patterns of multiple traits on

Table 5
Comparing models of attraction in Study 2 with the BIC and the RMSE.

	Long-term attraction		Short-term attraction	
Model	BIC	RMSE	BIC	RMSE
Euclidean	11,352.23	0.720	11,665.92	0.748
Manhattan	11,407.57	0.723	11,653.08	0.746
Chebyshev	11,622.48	0.747	12,078.33	0.787
Profile correlations	11,638.59	0.775	11,843.47	0.788
Profile valence	11,426.77	0.726	11,654.70	0.747
Traditional regression	13,452.25	0.769	13,715.91	0.790

Table 6
Comparing models of attraction among unmated participants in Study 2 with the BIC and RMSE.

	Long-term attraction		Short-term attraction	
Model	BIC	RMSE	BIC	RMSE
Euclidean	3174.84	0.770	3178.52	0.766
Manhattan	3199.74	0.778	3181.19	0.767
Chebyshev	3245.20	0.794	3311.30	0.817
Profile correlations	3252.14	0.819	3223.62	0.806
Profile valence	3222.40	0.783	3222.69	0.784
Traditional regression	4861.56	0.922	4846.33	0.911

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attraction, rather than merely considering the impact of single variables (Asendorpf, 2015). For that reason, the profiles we developed here could be of great utility to researchers studying attraction in the future. But this experimental control trades off against ecological validity relative to methods incorporating more naturalistic stimuli. Crucial future tests of the Euclidean algorithm's ability to predict attraction will come from studies that include more dynamic stimuli, such as videos of mates who vary on multiple dimensions, and in vivo mate selection in speed dating or laboratory-based experimental designs.

The Euclidean algorithm performs well as a model for how mate preferences are integrated in mate selection, but this algorithm could itself be further refined. For instance, at present, the Euclidean algorithm weights deviations on each preference dimension equally—effectively assuming that all preferences have equivalent impact on attraction and mate selection. This assumption is unlikely to be true, given that people across cultures express variability in the importance of various mate preferences (Buss, 1989). A better model could allow preferences to contribute differently to attraction by weighting deviations along each dimension proportionally to their importance, making more important dimensions longer through the multidimensional space. Future research could use the profiles we developed here to empirically compare these weighted and unweighted versions of the Euclidean distance: if mate preferences do have weighted contributions to estimations of mate value, a weighted Euclidean distance should have more power in predicting attraction to potential mates than an unweighted distance and this greater predictive power should outweigh the costs of greater model complexity.

Additionally, the Euclidean algorithm generally compared well to the alternative algorithms we considered here but there are still other algorithms against which the Euclidean algorithm could be compared. These could include more sophisticated linear combinations incorporating interactions and non-linear effects, more fast-and-frugal algorithms such as those that use aspiration levels (e.g. Miller & Todd, 1998), or strategies such as simply avoiding mates with undesirable qualities rather than pursuing mates with desirable qualities (e.g. Grammer, Fink, Juette, Ronzal, & Thornhill, 2001; Long & Campbell, 2015). The Euclidean, Manhattan, and Chebyshev distances are also just three members of a larger family of distance metrics: the Minkowski distance. While the Euclidean, Manhattan, and Chebyshev distances are the most natural and commonly applied distance metrics, the mind could integrate preferences according to any of the infinite Minkowski distances. Future research should continue to compare distance metric algorithms against alternative algorithms the mind could use to integrate mate preferences as well as compare alternative distance metrics to one another in order to better approximate the algorithms the mind uses in mate choice.

Alternative mate preference integration algorithms also must be compared against one another in terms of their ability to predict mating phenomena across the stages of the mate choice process. For instance, here we found the Euclidean algorithm has absolute and relative power to predict feelings of attraction toward profiles. However, we did not give participants the opportunity to select among the profiles. Future research could assess the ability of the Euclidean algorithm and other algorithms to predict both participants' continuous feelings toward potential mates as well as their categorical selections among them. Even further in the stream of mate selection decisions, relatively little research attempts to bridge the gap between the decision to pursue a mate and the actual initiation of a relationship with that mate (Campbell & Stanton, 2014). This stage of mate selection, along with attraction and within-relationship decisions, may serve as a critical arena for comparing alternative models of human mate preference integration.

Further, the Euclidean algorithm would not necessarily have been efficient for human ancestors to apply at all stages of the mate selection process. Some stages of mate choice likely would have involved sequential and costly searches. For these decision problems, selection should be expected to have favored satisficing psychologies over Euclidean psychologies. For instance, traveling between social groups in search of more favorable mating markets requires sequential and costly search (e.g. Miner, Gurven, Kaplan, & Gaulin, 2014). When traveling between groups, an individual must decide to stay with or leave one group before moving on to evaluate another; traveling between groups can also impose substantial costs in terms of time and energy spent as well as risk of injury or predation. For this reason, selection may have favored the evolution of satisficing psychologies for selecting among different mating markets but Euclidean psychologies for selecting among mates within mating markets. Future research should explore the selectivity of the Euclidean algorithm's application: The Euclidean algorithm should perform better than satisficing algorithms for those stages of mate choice where alternatives would historically have presented simultaneously and search was cheap but worse for those stages of mate choice where alternatives presented sequentially and search was costly.

Finally, the Euclidean algorithm need not be limited to mating decisions. Humans engage in a wide array of functionally distinct social relationships including friendships and coalitions. Just as in mating, these social relationships require, at some stage, partner selection. Any given person will have at any time more potential friends, coalition partners, and leaders than they can realistically accommodate given time constraints, energetic constraints, and tradeoffs with other adaptive problems that require effort. Ancestral humans would thus have been posed with the problem of sifting through these potential social relationships and selecting just those few friends, allies, and leaders who best served their fitness interests. These social demands also pose largely the same computational challenge: ideals and social partners represent multidimensional objects that must be compared to make partner selection decisions. Preference integration psychologies in these domains could therefore use very similar algorithms to the Euclidean algorithm explored here. Researchers could use Euclidean tools to compute friend values, coalition values, leadership values, and even kin values and explore the ability of these internal regulatory variables to explore interest in and formation of friendships, alliances, leadership relationships, and kin relationships.

4.2. Conclusions

A large literature establishes that humans have ideal mate preferences that vary predictably across gender, context, culture, and ecology (Buss, 1989; Botwin et al., 1997; DeBruine et al., 2010; Kenrick & Keefe, 1992; Gangestad, Haselton, & Buss, 2006; Gildersleeve, Haselton, & Fales, 2014). But psychologists have lacked an understanding of precisely how, computationally, these many preferences are compared against potential mates, who themselves vary on multiple dimensions, in order to make real mating decisions. A growing body of evidence, of which the current two studies are a part, suggests mate preferences are integrated according to a Euclidean algorithm that represents preferences and potential mates as points within a shared multidimensional space and calculates attraction as proportional to the distance between these points (Conroy-Beam & Buss, 2016; Conroy-Beam et al., 2016). This study provides critical novel evidence bearing on that hypothesis, demonstrating that Euclidean distances discriminatively predict both short-term and long-term attraction as a function of both overall mate value and unique mate value. These findings provide new insight into the design of human attraction psychology at the computational level and validate novel Euclidean tools for understanding the links between mate preferences and mating outcomes.

Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.evolhumbehav.2017.04.004.

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