Facial attractiveness choices predicted by divisive normalization

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Abstract

Do people appear more or less attractive depending on the company they keep? I employed normalization models to predict context dependence of facial attractiveness preferences. Divisive normalization – where representation of stimulus intensity is normalized (divided) by concurrent stimulus intensities – predicts that choice preferences between options increase with the range of option values. I manipulated attractiveness range trial-by-trial by varying the attractiveness of undesirable distractor faces, presented simultaneously with two attractive targets. The more unattractive the distractor, the more one of the targets was preferred, suggesting that divisive normalization (a potential canonical computation in the brain) influences social evaluations. We obtained the same result when participants chose the most "average" face, suggesting that divisive normalization is not restricted to value-based decisions (e.g., attractiveness). This new application to social evaluation of a classic theory opens possibilities for predicting social decisions in naturalistic contexts such as advertising or dating.

Keywords: attractiveness, physical appearance, divisive normalization, decision making, social perception, face perception, sensory adaptation, facial distinctiveness

Introduction

It is sometimes assumed that a face appears more attractive than another because of its physical attributes, not because of when, where or with whom it is seen. Indeed, classical decision-making theories assume rational agents who assign values to decision options (Luce, 1959) and that these values are fixed, regardless of what other alternatives are encountered (i.e., context). These assumptions may contribute to the dearth of theory predicting context effects on facial evaluations (e.g., facial attractiveness). One candidate theory for predicting context effects – normalization – draws support from decision making studies showing context effects (Rangel & Clithero, 2012). For decisions between multiple options, divisive normalized representations of option values can be obtained by dividing each option's value (assessed without context) by all available option values (Louie, Khaw & Glimcher, 2013; Louie & Glimcher, 2012). For example, when an option value of 3 is presented together with option values 2 and 1, divisive normalization yields 3/(3+2+1) = ½.

Normalization may mediate context effects on attractiveness decisions. It typifies neural responses throughout the brain and amounts to a putative canonical neural computation (Carandini & Heeger, 2012). Normalization proliferates in the brain because it ensures that neural firing rates optimally span prevailing stimulus ranges. Divisive normalization is well-studied for vision and explains non-linear neural responses including photoreceptor normalization to light intensity (Boynton & Whitten, 1970), contrast normalization and saturation effects (Bonin, Mante & Carandini, 2005), cross-orientation suppression (Carandini Heeger & Movshon, 1997), and neural responses to motion (Simoncelli & Heeger, 1998) and multiple objects (Zoccolan, Cox & DiCarlo , 2005). Normalization outside vision includes non-linear neural responses to auditory contrast (Rabinowitz, Willmore, Schnupp & King, 2011) and cross-modality normalization in multisensory integration (Ohshiro et al., 2002).

Reward value representations are also normalized. Brain responses encoding choice option values adapt to ranges of option values (Cox & Kable, 2014; Padoa-Schioppa, 2009; Rangel & Clithero, 2012). This normalization affects human choice behavior too. Undesirable options modulate choices between two other options (Soltani, De Martino & Camerer, 2012), including in contexts where monkeys choose between juice rewards and humans choose between snack foods (Louie et al., 2013). In Louie et al. (2013), lower-value distractor items (i.e., a wider range of option values) increased preference for the better of two desirable options, a finding predicted by computer simulations of divisive normalization. This divisive normalization effectively expands or contracts the dynamic range of value representations to span the range of option values.

Normalization could mediate similar context effects in the social domain too, and theory to predict context effects for social evaluations is lacking. I tested whether normalization predicts facial attractiveness (Attraction Experiment). Participants evaluated facial attractiveness without context in a first phase and then, in a second phase, a trinary choice task assessed attractiveness preferences. When two highly attractive targets and a low-attractiveness distractor are choice options, participants' choice should become more sensitive to differences in attractiveness of the two targets. In a control experiment, we tested for the same effects using a task where participants chose the most "average" appearing face (Averageness Experiment). These averageness choices may share some perceptual bases with attractiveness choices (Langlois & Roggman, 1990), but have no overt value-based connotation. This control task can therefore show whether normalization is restricted to value-based judgments like attractiveness, or whether it affects high-level facial judgments more generally.

Method

Participants

We enrolled two samples of 40, equivalent to that reported in Louie et al. (2013). For the Attractiveness Experiment, all 40 (ages 18-23, 25 females) contributed data for analysis. For the Averageness experiment (ages approximately 18-55, 28 females), one participant was removed from data analysis, as responses suggested that instructions were not followed. Participants were Royal Holloway, University of London students or staff and had normal or corrected to normal vision.

For the Attractiveness Experiment, participants were entered into a drawing for one £25 Amazon voucher. For the Averageness Experiment, participants were compensated £8 for participation. The Attractiveness Experiment was approved by the Psychology Department Ethics Committee and the Averageness Experiment was approved by the College Ethics Committee, both committees at Royal Holloway, University of London.

Procedures

Procedures were identitical for both experiments, aside from the choice under study (attractiveness or averageness). Stimuli included 15 male and 15 female color photographs of neutral faces sampled from the Karolinska Directed Emotional Faces (KDEF) face set (Lundqvist, Flykt & Ohman, 1998). In Phase 1 (Fig. 1a, left), participants rated either the attractiveness or averageness of the 30 faces, two times each, sequentially and in a pseudo-random order. On each trial, participants saw a horizontal line below a face, representing a continuum of values (between 0 and 1), and used the mouse to click the point on that line indicating the chosen value. The trial advanced to the next at the mouse click. These Phase 1 ratings were taken as estimates of each participant's judgment (attractiveness or averageness) assessed without context or normalization. The two ratings recorded for each face during Phase 1 were averaged. Based on a sorting of these averages, the lowest rated (least attractive or average) 10 males and 10 females were selected as distractors and the highest rated five males and five females were selected as target faces for Phase 2 (Fig. 1b and 1c). For each participant, 200 trials were constructed for Phase 2, formed from the 10 possible pairs of the five targets for each sex, matched to each of the 10 same-sex distractors. Trials were presented to each participant in a pseudorandom sequence, with each of the three images randomly placed in the center, right and left of the computer monitor (Fig, 1a, right). Each trial advanced to the next one when the participant indicated the screen position of the most attractive or average image by button press. We measured which target was chosen on each trial and whether the chosen target was the more attractive (or average) target (as rated during Phase 1).

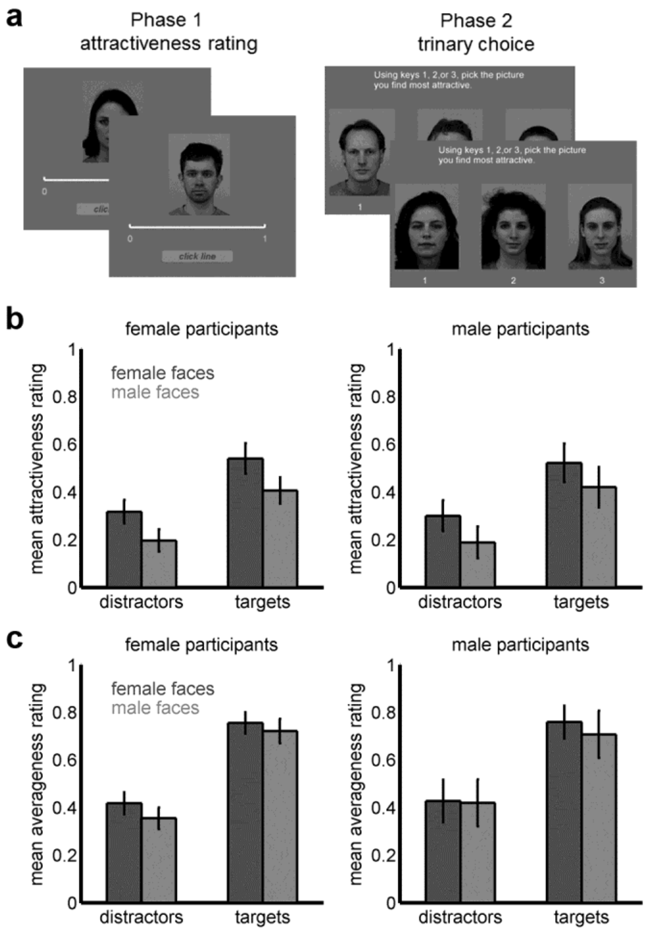

Fig. 1. (a) Sample trials for the two phases of the Attractiveness Experiment. In Phase 1 (left), attractiveness was measured without context. Phase 2 (right) was a trinary choice task. Participants chose the most attractive of three faces (target 1, target 2 and distractor). Faces were presented in color. (b) Attractiveness ratings in Phase 1 where used to divide faces into distractors (10 males and females with lowest ranking attractiveness ratings) and targets (top ranked five male and female faces). Error bars show 95% confidence intervals. (c) Averageness ratings in Phase 1.

Results

In Phase 1, attractiveness ratings (Fig. 1b) were significantly greater for targets compared to distractors $F(1,38) = 320.06$, $p < .001$, $\eta_p^2 = .89$ and for female faces compared to male faces $F(1,38) = 40.52$, $p < .001$, $\eta_p^2 = .52$, although there were no effects of participant sex or any interactions among the three factors. Averageness ratings (Fig. 1c) were also significantly greater for targets compared to distractors $F(1,37) = 349.78$, $p < .001$, $\eta_p^2 = .90$. Neither face sex *(p* = 0.08) nor any other effects reached significance for averageness ratings. Because the distractors were always low rated, compared to the targets, distractors were rarely chosen in Phase 2.

For Phase 2 data, divisive normalization predicts that distractor faces that receive lower Phase 1 ratings should be associated with greater choice differences between the two target faces. Because each participant provided their own ratings, Fig. 2a (Attractiveness Experiment) and Fig. 2b (Averageness Experiment) standardizes ratings across participants by showing ranks, where the lowest rated distractor of each face sex had the lowest rank (i.e., a 1). Visual inspection of these results reveals that distractors with a lower rank were associated with more choices of the more attractive target (Fig. 2a) and the same was true for choice of the most average target (Fig. 2b). For the Attractiveness Experiment, an unexpected result showed that male participants were more likely to choose the more attractive target face when it was male than when it was female, while female participants showed this pattern to a lesser degree (Fig. 2b). Several analyses, focusing on our hypothesized effects of distractor rating, confirmed these patterns. For the Attractiveness Experiment, an ANOVA that predicted the proportion of choices of the more attractive target using the factors distractor rank, face sex and participant sex showed a significant main effect of distractor rank $F(9,342) = 3.79$, $p < .001$, $\eta_p^2 = .09$, main effect of face sex $F(1,38) = 15.03$, $p < .001$, $\eta_p^2 = .28$ and interaction between face sex and subject sex $F(1,38) = 4.22$, $p = .047$, $\eta_p^2 = .10$. The Averageness Experiment replicated the significant main effect of distractor rank $F(9,333) = 4.27$, $p < .001$ with a similar effect size $\eta_p^2 = .10$, although there were no other significant effects for this ANOVA. The distractor rank effects for both Attractiveness and Averageness experiments were confirmed by a second analysis. This analysis used multiple linear regression to quantitatively test for the predicted negative direction of the effect of distractor rank on choice behavior. In regressions fit separately to each participant's data, the predictors distractor rank, face sex and their interaction predicted proportion choices of the higher-rated (more attractive or average) target. The resulting participant-specific beta values were tested for significance across the sample in the "second level" of a hierarchical analysis, treating participant as a random effect. For the Attractiveness Experiment, a negative relationship between distractor rank and proportion choices of the more attractive target was confirmed by a significant left-sided t-test on the participants' beta-values, mean β = -.006, confidence bound = -.003, $t(39) = -4.02$, $p < .001$. The same analysis replicated this effect for the Averageness Experiment mean β = -.01, confidence bound = -.007, $t(39) = -5.30$, $p < .001$. This shift in proportion higher target choices was associated with an effect size conventionally regarded as large (Attractiveness Cohen's d = 1.29 and Averageness Cohen's d = 1.72) and the shift in relative choice as a function of distractor value is within the range of previous reports of other decision making paradigms. See Trueblood, Brown, Heathcote and Busemeyer (2013) for an example that also investigates the attraction effect for visual stimulus dimensions.

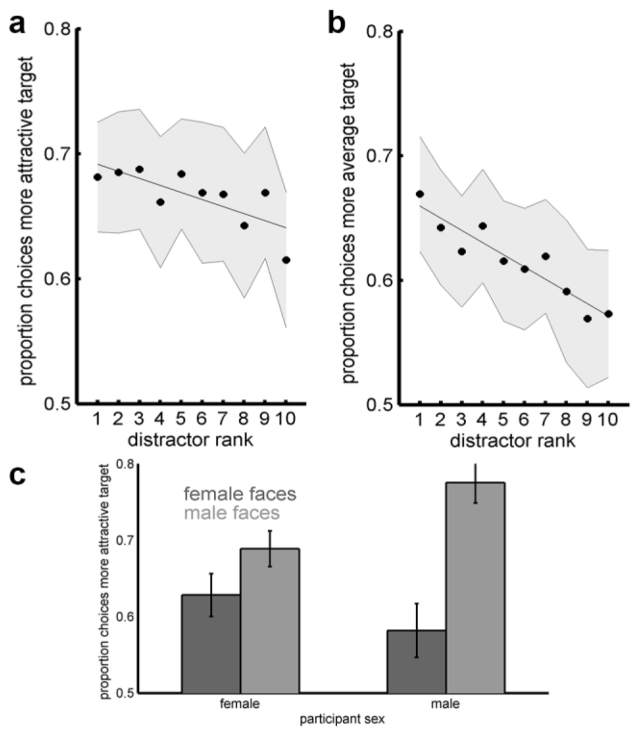

Fig. 2. (a) Proportion choices of the more attractive target are reduced for more attractive (higher ranked) distractors. Shaded area indicates 95% confidence intervals. Least squares regression line fit to group means included for illustrative purposes. (b) Proportion choices of the more average target are also reduced for more attractive (higher ranked) distractors. (c) Face sex by participant sex interaction effect on proportion choices of more attractive target.

Further confirmation for influences of distractor rating on choice behavior was provided by an analysis that directly predicted the choice on each trial (as opposed to proportions of choices in different conditions) using a binomial generalized linear model with a logistic link function (See Louie et al., 2013 for a similar analysis). For each individual participant, a generalized linear model predicted a binary variable encoding whether or not the participant chose the higher rated (more attractive or average) target on each trial using, as regressors, the Phase 1 rating of the leftmost target, the Phase 1 rating of the rightmost target, the Phase 1 rating of the distractor, the sex of the face and the interaction between distractor rating and face sex. Again, magnitudes of the participant-specific beta values for distractor attractiveness were tested for significance across the sample at a second level, treating participant as a random variable. For the Attractiveness Experiment, the hypothesis was confirmed by a negative relationship between distractor attractiveness and choices of the more attractive target, mean β = -1.65, confidence interval -2.46 to -.50, $t(39) = -2.9$, $p = .006$, Cohen's $d = .93$. Thus, the more attractive the distractor was on a trial, the less likely a more attractive target choice was predicted. The Averageness Experiment replicated this negative relationship between distractor rating and choices of the higher rated (more average, in this case) target, mean β = -1.37, confidence interval -1.916 to -.819, $t(38) = -5.0$, $p < .001$, Cohen's d = 1.64.

Louie et al. 2013 showed that the psychometric function that predicts the probability of choosing one of the targets from differences between the values of the two targets exhibits a larger slope for distractors with less reward value. This psychometric function can have a sigmoidal shape. When target 2 is considerably more valuable than target 1 (i.e., target value difference is negative), participants make zero target 1 responses. As the value of target 1 increases, relative to target 2, the proportion target 1 choices will increase. When target 1 becomes considerably more valuable than target 2, participants will always choose target 1. The slope of this sigmoid function measures how sensitive choice preference is to differences between the two targets. If attractiveness or averageness representations are divisively normalized, then low-rated distractors should increase participants' sensitivity to target differences in attractiveness or averageness and thereby increase the slope of the sigmoid function. Hence, divisive normalization predicts that distractor rank will be negatively related to the slope of the psychometric function. This prediction was tested by fitting to the data the logistic curve $y = 1/(1 + \exp(-\beta_1 * (x - \beta_2))$ where y values are the predicted target 1 choices (taken here as the leftmost target on the screen), x values are the target value differences, β_1 represents the slope parameter and β_2 represents the inflection point parameter. Because target rating differences and distractor ratings are different for each participant, there were no fixed values across participants. To facilitate summarizing data over participants (Fig. 3) and to ensure a sufficient number of averaged trials for fitting, logistic functions were fitted to binned distractor ranks (five bins) and target rating difference ranks (12 bins). This yielded logistic function parameters (nlimfit.m in MATLAB, The MathWorks, Natick, MA, USA) separately for each participant and distractor bin.

Although logistic slope values were computed from individual participant logistic fits, for visualization purposes, Figs. 3a, 3b, 3d and 3e shows functions fit to group data. A reduction in slope that changes continuously across distractor bins is apparent for both attractiveness and averageness choices. For analysis of logistic slopes, poor curve fitting occurred on occasion. For the Attractiveness Experiment, two outlying slopes (out of the 40 participants × 5 distractor bins = 200 slopes) were removed, as they exceeded 6 standard deviations from their distractor bin means and were >30 when all other values were <1. For the Averageness Experiment, eight (out of 195) slopes were removed, as they exceeded 2.5 standard deviations from their distractor bin means and were >14 when all others were <1. Next, linear regressions ascertained whether distractor bin was negatively associated with logistic slope by fitting a line to the five logistic slopes separately in each participant (Figs. 3c and 3f). These participant-specific linear regression beta values were submitted to a second-level, left-sided one-sample t-test, which confirmed the prediction of normalization for both Attractiveness and Averageness experiments. Across participants, logistic slopes were negatively related to distractor attractiveness, mean β = -.02, confidence bound -.003, $t(39) = -2.00$, $p = .027$, Cohen's *d* = .32 and to distractor averageness mean β = -.02, confidence bound -.001, t(38) = -1.8, p = .04, Cohen's d = .38

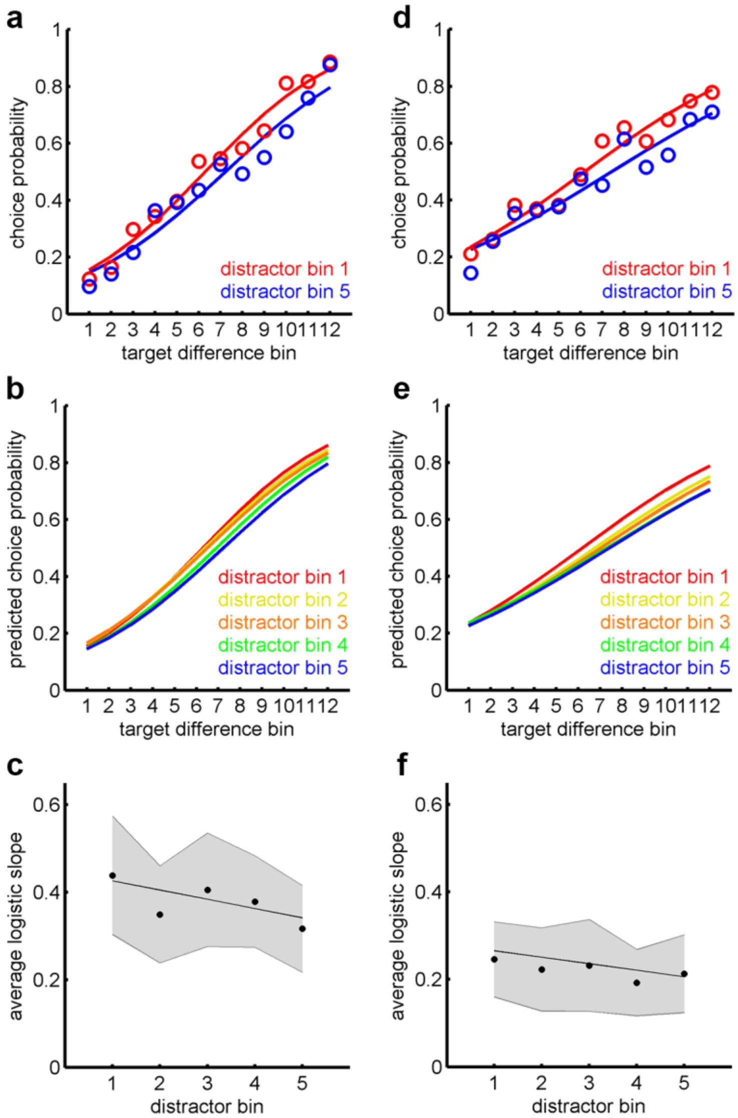

Fig. 3. (a) Proportion of choices of one of the targets as attractive plotted as a function of the difference in target attractiveness for trials for low attractiveness distractors (distractor bin 1, red) and high attractiveness distractors (distractor bin 5, blue). Solid lines show logistic functions fit to group data to illustrate reduced slope for more attractive distractors. (b) Logistic functions fitted to group data illustrate the gradual decrease in slope for higher distractor attractiveness. (c) Slopes of logistic functions fitted to individual participants and averaged over participants. Shaded area indicates 95% confidence interval of the mean logistic slopes. Line represents linear regression fit to group data. (d-f) the same as (a-c), but for averageness choices. All findings replicate.

Discussion

The Attractiveness Experiment showed that participants were more likely to find one target more attractive than another, depending on the unattractiveness of the distractor (Fig. 2a), even though distractors were too unattractive to be chosen (Fig. 1b). Moreover, less attractive distractors increased participants' choice sensitivity to differences in target attractiveness (Fig. 3). The same results occurred when the experiment was repeated for averageness choices (Fig. 2b, Fig 3). These findings could arise from divisive normalization (Carandini & Heeger, 2012), where neural firing rates adapt to span the choice option range. For the Attractiveness Experiment, less attractive distractors widen the attractiveness range of options and so normalization to this wider range "pulls apart" the representations of the two targets. The result is increased choice of the more attractive target (Fig. 2) and more sensitivity of choices to differences in target attractiveness (Fig. 3). These findings support the notion that normalization proliferates throughout the nervous system, as similar effects arise for preferences of monkeys for juice reward and humans for snack foods (Louie et al., 2013). Divisive normalization, moreover, explains neural responses throughout the visual and auditory systems and contributes to sensory integration and decision-making (Carandini & Heeger, 2012). The Attractiveness and Averageness Experiments demonstrate that normalization affects higher-level social domains too.

Although the normalization notion provides theory to predict context effects on social evaluations, there are effects of timing that still need to be explained. Context can also be manipulated using repetitive presentation of stimuli. Adaptation (prolonged exposure) to facial distortions, for example, increases attractiveness of similarly distorted faces (Rhodes et al., 2003; Winkler & Rhodes, 2005). Similar assimilative effects for sequential faces can occur for attractiveness (Taubert, Van der Burg & Alais, 2016) and identity (Liberman, Fischer & Whitney, 2016) and may arise from processes that maintain visual continuity. A different finding, the "Contrast effect", occurs when successive presentation of attractive faces renders faces less attractive (Wedell, et al., 1987) and have been associated with range-frequency normalization (Wedell et al., 1987; Parducci, 1965). I found that range-frequency was not a viable alternative to divisive normalization, using a simulation of the trinary choice paradigm following methods reported in Louie et al. (2013). While this simulation replicated Louie et al. for divisive normalization, range-frequency theory produced an opposite result: relative choices between targets become more confusable, not more distinct, for lower distractor values. It remains to be tested further whether instantaneous presentation and repetitive, successive presentations tap different mechanisms. Although adaptation to sequences and normalization share the goal of adjusting neural firing to match prevailing stimulus conditions (Webster, Kaping, Mizokami, & Duhamel, 2004), in trinary choice, the context changes on each trial, more quickly than in adaptation experiments. Also, in the brain, some types of normalization are best observed after blocking many trials (Rangel & Clithero, 2012), a time course more similar to adaptation and contrast effects. Louie and Glimcher (2012) have already noted a distinction between normalization by more immediate "spatial context" versus a "temporal context", which is dependent instead on the history of previous stimuli. Results from the Attractiveness and Averageness Experiments therefore highlight the time scale of context effects as a variable requiring further study.

Compared to sequence-dependent ratings, trinary choice tasks have an advantageous feature. Multiple target options reveal additional effects of "stretching" or "contraction" to adjust to stimulus range, by showing how distractors pull apart or push together target choices, a finding difficult to infer from sequential Likert ratings. Trinary choice also forms the basis for many decision-making effects (Kowal & Faulkner, 2016) including the similarity (Tversky, 1972), attraction (Huber, Payne & Puto, 1982) and compromise (Simonson, 1989) effects. These involve selectively manipulating the similarity of a distractor to the targets along specific stimulus attributes. Such studies are used to study multiattribute decision making and are often couched as commodity purchases, rather than as social evaluations, where multiple-valued attributes can be experimentally manipulated (e.g., choosing between used cars that vary in both mileage and price). The two experiments reported herein used photographs of natural faces and only manipulated overall attractiveness (or averageness), rather than select attributes. However, facial attributes could, in principal, be manipulated in trinary choice tasks to study multi-attribute decision making phenomena in social contexts.

The Attractiveness and Averageness Experiments also introduce new research questions about which representations are normalized. Many potentially normalized representations could contribute to attractiveness decisions, including visual representations of facial attributes. If attractiveness decisions arise from evaluation of visual information, then they will be influenced when visual representations are normalized. For example, Wedell and Pettibone (1999) manipulated the range of eye and nose width of schematic faces to induce contrast effects on eye and nose width perception and found corresponding shifts in face pleasantness judgements. The Averageness Experiment explored a similar possibility by examining a high-level facial judgment that might resemble some of the perceptual assessment involved in attractiveness perception, but lacking the same overt reward-based assessment. The finding of normalization for averageness decisions suggests that normalization is not limited to reward-based judgments (Louie et al., 2013) and might operate on high-level visual assessments. However, there are many potential visual contributions to attractiveness decisions that could be normalized. Already, evidence exists for normalization of low-level visual responses in visual cortex to luminance, contrast and motion (Carandini & Heeger, 2012) and imaging evidence exists for normalization in visual areas for object representation (Zoccolan et al., 2005). Behavioral and brain response measurements are still needed to fully assess the roles of visual normalization in social evaluation of faces.

Attractiveness decisions are also decisions about potential rewards and the Averageness Experiment cannot exclude the possibility of additional normalization of reward-based representations (Louie et al., 2013). Moreover, the situation is further complicated by evidence for multiple brain representations of reward-related value, any of which might be susceptible to normalization. For faces, several brain areas (amygdala, prefrontal areas, ventral striatum) are associated with reward value (Bzdok, Langner, Hoffstaedter, Turetsky, Zilles & Eickhoff, 2012; Kampe, Frith, Dolan & Frith, 2001; Pegors, Kable, Chaterjee & Epstein, 2015; Smith, Hayden, Troung, Song, Platt & Huettel, 2010; Winston, O'Doherty, Kilner, Perrett & Dolan, 2007). Moreover, ventromedial prefrontal cortex represents "common currency" reward value across stimulus domains (Pegors, et al., 2015; Smith, et al., 2010; Vessel, Stahl, Purton & Starr, 2015). In the monkey, a similar area in orbitofrontal cortex has already been shown to exhibit normalized responses to reward (Cox & Kable, 2014; Padoa-Schioppa, 2009). Behavioral and brain response measurements are needed also to fully assess the roles of normalization of reward-based representations in social evaluation of faces.

Normalization schemes (e.g., divisive normalization) provide theory that motivates quantitative predictions, such as those tested here. The fact that normalization explains preferences in the social domain suggests new applications to applied or naturalistic settings. The ability to predict social evaluations in context might generalize to advertising, website design, consumer behavior, etc. Context effects on social decisions also challenge common assumptions, including those of classical economics, that relative values, such as attractiveness, are constant over time. Although people alter their faces through makeup, hairstyles, etc. to appear attractive, in fact, faces appear more or less attractive depending on context. Indeed, people may even socially evaluate a person differently depending on who is standing nearby.

Author Contributions

N.F. is sole author and responsible for all content.

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