



Contributions of shape and reflectance information to social judgments from faces



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ABSTRACT

Face perception is based on both shape and reflectance information. However, we know little about the relative contribution of these kinds of information to social judgments of faces. In Experiment 1, we generated faces using validated computational models of attractiveness, competence, dominance, extroversion, and trustworthiness. Faces were manipulated orthogonally on five levels of shape and reflectance for each model. Both kinds of information had linear and additive effects on participants' social judgments. Shape information was more predictive of dominance, extroversion, and trustworthiness judgments, whereas reflectance information was more predictive of competence judgments. In Experiment 2, to test whether the amount of visual information alters the relative contribution of shape and reflectance information, we presented faces – varied on attractiveness, competence, and dominance – for five different durations (33–500 ms). For all judgments, the linear effect of both shape and reflectance increased as duration increased. Importantly, the relative contribution did not change across durations. These findings show that the judged dimension is critical for which kind of information is weighted more heavily in judgments and that the relative contribution of shape and reflectance is stable across the amount of visual information available.

Making social judgments from faces is a challenging task, yet humans do it effortlessly (for reviews of the determinants and (in)accuracy of such judgments, see Todorov, 2017; Todorov, Olivola, Dotsch, & Mende-Siedlecki, 2015). It is well established that two types of visual information – face shape and reflectance – are employed in any kind of face processing (Andrews, Baseler, Jenkins, Burton, & Young, 2016; Jiang, Blanz, & O'Toole, 2007; Jiang, Dricot, Blanz, Goebel, & Rossion, 2009; O'Toole, Vetter, & Blanz, 1999; Sormaz, Young, & Andrews, 2016). Shape information refers to the spatial relations among facial features, determined by facial bones, muscles, and fat (i.e., second-order configural information; Maurer, Le Grand, & Mondloch, 2002). Reflectance information (or pigmentation) refers to the way the surface of the face reflects light, determined by the hue, texture, specularity, and translucency of facial skin (Russell & Sinha, 2007; Russell, Sinha, Biederman, & Nederhouser, 2006). Any social inference from a face is based on at least one of these two types of visual information. Here, we investigate the relative contribution of shape and reflectance information to social face perception.

People make face-based inferences of traits, such as aggressiveness and trustworthiness, about others even after brief exposure to their

faces (Bar, Neta, & Linz, 2006; Borkenau, Brecke, Möttig, & Paelecke, 2009; Rule, Ambady, & Adams, 2009; Todorov, Loehr, & Oosterhof, 2010; Todorov, Pakrashi, & Oosterhof, 2009; Willis & Todorov, 2006), and these inferences affect social interactions (for reviews, see Todorov, 2017; Todorov, Mende-Siedlecki, & Dotsch, 2013; Todorov et al., 2015; Todorov, Said, & Verosky, 2011). Although computational models of facial social judgments have been built and validated (Funk, Walker, & Todorov, 2016; Oh, Buck, & Todorov, 2019; Oh, Dotsch, Porter, & Todorov, 2019; Oosterhof & Todorov, 2008; Todorov & Oosterhof, 2011; Walker, Jiang, Vetter, & Sczesny, 2011; Walker & Vetter, 2009, 2016), how shape and reflectance information contribute to social judgments has not been systematically investigated.

Studies investigating face processing suggest that both shape information and reflectance information contribute to face recognition (e.g., Jiang et al., 2007; Lee & Perrett, 2000; Russell et al., 2006; Sinha, Balas, Ostrovsky, & Russell, 2006; Troje & Bühlhoff, 1996) and to facial expression perception (e.g., Sormaz et al., 2016). O'Toole et al. (1999), for example, manipulated faces so that each face had either identical shape and varying reflectance information or identical reflectance and varying shape information. Participants performed equally well in

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recognizing faces in both conditions, indicating that people are as adept in recognizing faces on the basis of shape as they are on the basis of reflectance. Similarly, using functional magnetic resonance imaging (fMRI) adaptation paradigm, Andrews and colleagues (2016) found a comparable level of importance of shape and reflectance information. Face-selective brain areas, such as the fusiform face area, showed the same level of release from adaptation for changes in face shape and changes in face reflectance that corresponded to changes in identity.

Findings showing that one type of information (e.g., shape) is prioritized over the other (e.g., reflectance) seem to be highly inconclusive. Using an event-related potential (ERP) adaptation paradigm, Caharel, Jiang, Blanz, and Rossion (2009) found that shape information was processed earlier than reflectance information, suggesting that shape information is prioritized over reflectance information in face perception. However, participants were equally accurate and fast in discriminating sequentially presented faces based on shape or reflectance cues alone, and performed faster when both types of cues were available. An fMRI adaptation study demonstrated that shape was processed predominantly in face-sensitive areas in the right hemisphere, possibly because these areas are particularly sensitive to global variations in faces (Jiang et al., 2009). Nevertheless, left hemisphere areas were sensitive to both shape and reflectance information. These findings are inconsistent with the findings of Andrews et al. (2016), who failed to find differences between shape and reflectance information in release from adaptation. Moreover, they found that reflectance mattered more than shape information in facial identity recognition of familiar faces. People recognized and matched faces better when reflectance information was preserved than when shape information was preserved. Relatedly, face reflectance information (without any shape information) was sufficient to train a computer algorithm to discriminate face identities, demonstrating human-like properties (e.g., overall high accuracy, more robust recognition of familiar (vs. unfamiliar) faces, categorization of face sex and race in the absence of explicit labels in training; Kramer, Young, & Burton, 2018; Kramer, Young, Day, & Burton, 2017).

In sum, shape and reflectance information both substantially contribute to *face identity perception* with little conclusive evidence that one type of information is processed more efficiently or predominantly than the other. What about *face social perception*? Prior work suggests that different types of judgments might rely on different weighting of shape and reflectance information. Lai, Oruç, and Barton (2012) reported that whereas shape information generated aftereffects more strongly in identity judgment tasks, reflectance information generated aftereffects more strongly in age judgment tasks. In other words, identity perception relied primarily on shape information (but see above), whereas age perception relied primarily on reflectance information, presumably because age-related local features like wrinkles are more strongly represented in reflectance. Freeman and Ambady (2011) investigated the time course of information use in a categorization task by analyzing hand movement trajectories while using a computer mouse: Reflectance was processed at the same time as shape in age categorization, but earlier than shape in gender categorization.

Given the previous research, we suspect that social face perception employs both shape and reflectance information, just like face recognition and age judgments. For instance, judgments of attractiveness have been shown to depend on averageness in terms of shape, but not so much in terms of reflectance (Foo, Simmons, & Rhodes, 2017; Nakamura & Watanabe, 2019; O'Toole, Price, Vetter, Bartlett, & Blanz, 1999; Said & Todorov, 2011). Because reflectance information also predicted attractiveness judgment (Holzleitner, Lee, Hahn, Kandrik, Bovet, Renoult, & Jones, 2019; Nakamura & Watanabe, 2019; Said & Todorov, 2011), these findings provided preliminary evidence that shape and reflectance can have unique contributions to social judgment.

A more direct assessment of the relative contribution of shape and reflectance information to social judgment was conducted by Torrance,

Wincenciak, Hahn, DeBruine, and Jones (2014). The authors selectively eradicated either the idiosyncratic shape or reflectance information from individuals' faces. Participants were asked to judge the faces on attractiveness, physical dominance, and social dominance. While both shape and reflectance affected the judgments, female faces' perceived physical dominance relied more on shape than reflectance information and male faces' attractiveness relied more on reflectance than shape information. Along with other studies, this finding suggests that both shape and reflectance information are important across social dimensions, but their relative contribution might vary depending on the specific social dimension.

However, in all prior studies on social judgment, either the manipulation of shape and reflectance information was limited (e.g., to two levels) or the two types of information were not manipulated together. Even when they were manipulated together (e.g., Said & Todorov, 2011), the potential interaction between shape and reflectance information was never assessed. In this paper, we systematically and orthogonally manipulate shape and reflectance information and study the relative contribution of these kinds of information to multiple social judgments.

Data-driven computational models of social judgments have been indispensable in identifying diagnostic information in social face perception (Oosterhof & Todorov, 2008; Sutherland et al., 2013; Walker & Vetter, 2009; for reviews, see Dotsch & Todorov, 2012; Jack & Schyns, 2017; Todorov, Dotsch, Wigboldus, & Said, 2011). Moreover, these models provide precise control over novel faces across multiple levels of specific social judgments (e.g., Oh, Buck, et al., 2019; Oh, Dotsch, et al., 2019; Todorov, Dotsch, Porter, Oosterhof, & Falvello, 2013; Todorov & Oosterhof, 2011). Oosterhof and Todorov (2008), for example, used a norm-based approach (Valentine, 1991) to model the facial information employed in judgments of social traits, such as trustworthiness, dominance, and threat. Starting as a modeling approach of how shape information influences social judgment, the approach was extended to model the influence of reflectance information too (e.g., Todorov & Oosterhof, 2011).

Todorov, Dotsch, and colleagues (2013) demonstrated the validity of the resulting shape and reflectance models. Manipulating faces with these models simultaneously on shape and reflectance changed the intended trait judgment (e.g., trustworthiness) accordingly, while influencing the judgment of other traits (e.g., competence) to a substantially lesser degree. However, because shape and reflectance information always covaried, it was impossible to identify the unique contributions of shape and reflectance to various social judgments.

Todorov and Oosterhof (2011) estimated the relative contribution of shape and reflectance information to nine social judgments. Using a regression approach, they showed that shape and reflectance information were relatively redundant for most social judgments, although in all cases shape and reflectance together always explained more variance of social judgments than any of the two did separately. Relative explained variance by shape and reflectance varied across different social judgments, implying that indeed different social judgments may rely on shape and reflectance information to various degrees. However, shape and reflectance information were not orthogonally manipulated in order to quantify the relative contributions of each to different social judgments.

In sum, although prior research points to the importance of both shape and reflectance information for social face judgments and potential differences in their relative contribution to these judgments (Todorov & Oosterhof, 2011; Torrance et al., 2014), these effects have never been systematically investigated. Here, we manipulate faces independently on shape and reflectance to study their unique and combined effects on social judgments.

1. Experiment 1

We used previously constructed models that included shape and

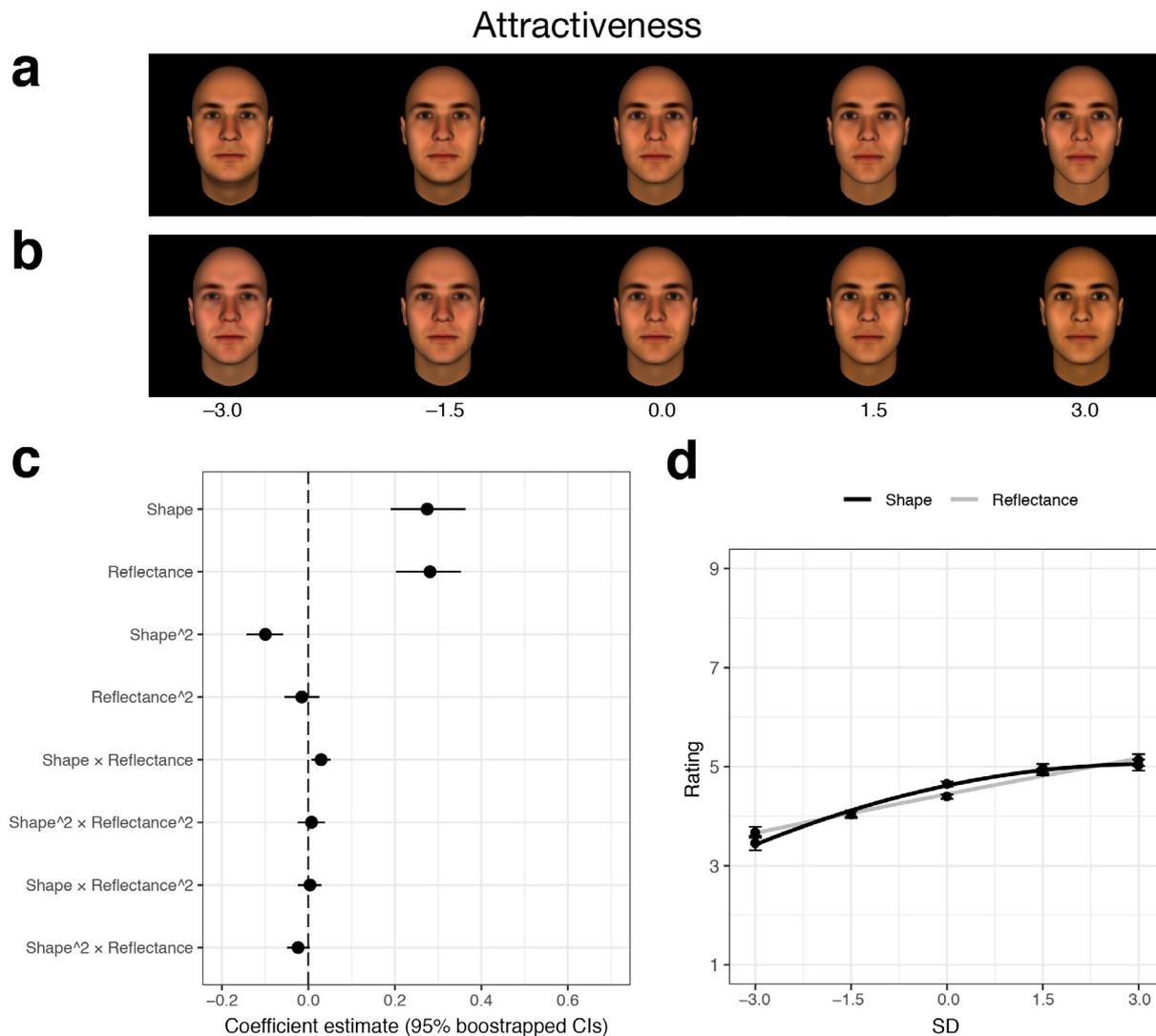


Fig. 1. Judgments of faces manipulated by a computational model of judgments of attractiveness (Experiment 1). A sample face manipulated in the model only for shape (a) and only for reflectance is displayed (b). Increasing values indicate increased perceptions of attractiveness (a, b). Here, only ten faces are shown for illustration purposes, but the actual experiments presented faces orthogonally manipulated on shape and reflectance, 25 faces per identity. Parameter estimates (B) and 95% confidence intervals for the judgments are displayed (c). Confidence intervals were computed via bootstrapping. By-participant regression lines of judgments as a function of the model values of the faces averaged across identities are displayed (d). Overall, shape and reflectance had a linear, additive effect on the judgments, and shape and reflectance had a comparable effect size.

reflectance, validated in [Todorov, Dotsch, et al. \(2013\)](#). From the nine available models, we selected five that represented traits that are spontaneously used in describing faces and are relatively different from one another ([Oosterhof & Todorov, 2008](#); [Todorov, Dotsch, et al., 2013](#)) – attractiveness, competence, dominance, extroversion, and trustworthiness. We asked participants to judge faces manipulated orthogonally on multiple levels of shape and reflectance using one of the trait models. Participants judged faces on the trait on which we manipulated the faces.

Based on the work previously described, we expected that both shape and reflectance information would independently contribute to social judgments, but their relative contribution to vary across different traits (in line with [Lai et al., 2012](#)). We also expected shape to play a dominant role in most trait judgments (in line with [Caharel et al., 2009](#); [Jiang et al., 2009](#)). We did not have a priori expectations with regards to curvilinear effects of shape and reflectance information or interactions between shape and reflectance for any of the trait judgments.

1.1. Methods

1.1.1. Participants

The experimental protocol was approved by the Institutional Review Board for Human Subjects of Princeton University. We obtained informed consent from all participants. Previous validation studies using the same experimental design and models showed that sample size of > 10 raters per trait could find reliable effects of the models ([Oh, Buck, et al., 2019](#); [Todorov, Dotsch, et al., 2013](#); [Todorov, Dotsch, et al., 2011](#)). Seventy-five Princeton University students (32 male, 43 female, mean age 20.5 years) participated for payment.

1.1.2. Materials

The stimuli consisted of computer-generated male faces created with the FaceGen Software Development Kit ([Singular Inversions, 2005](#)). In FaceGen, faces are represented as points in a 100-dimensional face space (50 shape and 50 reflectance dimensions). Moving a point (a face) along a single dimension changes the shape or reflectance of a face in specific ways. Meaningful social dimensions, such as trustworthiness

or dominance, can be modeled as linear combinations of these basic FaceGen dimensions based on trait judgments of random points in the space (see Oosterhof & Todorov, 2008, for a detailed description of this procedure). We have previously modeled social dimensions on both shape and reflectance (Todorov & Oosterhof, 2011). In Experiment 1, we orthogonally manipulate shape and reflectance based on models of five of these dimensions – attractiveness, competence, dominance, extroversion, and trustworthiness (see Todorov, Dotsch, et al., 2013 for the validation of these models). Some methodological details described here are reproduced from Todorov, Dotsch, et al. (2013).

Because we wanted to manipulate a diverse set of faces, we first created a sample of maximally distinctive identities, following a standard procedure (Oh, Buck, et al., 2019; Oh, Dotsch, et al., 2019; Todorov, Dotsch, et al., 2013): To create the stimuli, we generated a random sample of 1000 faces. We then chose the 10 faces that were maximally different from each other based on the average Euclidean distance to all other faces. This resulted in a sample of distinctive faces, but also in faces that looked atypical. To reduce this atypicality, we scaled the face coordinates with a factor of 0.5, essentially bringing them closer to the average face. This procedure preserves the ratio of differences so that the faces are still maximally different from each other yet look more typical.

We then applied the social shape and reflectance dimensions to each identity by projecting the face point on the respective dimension. For example, for our manipulation of trustworthiness, we changed the face space coordinate of an identity such that the resulting face scored precisely 0 on shape trustworthiness and precisely 0 on reflectance trustworthiness, creating the neutral trustworthy face for a given identity. We then generated 24 more faces by moving this identity's neutral face along the trustworthiness shape dimension to -3 , -1.5 , 1.5 , and 3 SD levels of shape trustworthiness (the face dimensions are normally distributed) and along the trustworthiness reflectance dimension to the same SD levels in such a way that each combination of shape and reflectance trustworthiness levels was represented in the stimulus sample. This resulted in 25 faces differing maximally in trustworthiness (relative to differences on other dimensions), varying orthogonally on shape and reflectance, based on one single identity. The a and b panels in Figs. 1–5 show for each social dimension respectively the five shape and the five reflectance levels of faces based on one of the face identities. We repeated this procedure for all 10 identities and for the five social dimensions, resulting in a total of $25 \times 10 \times 5 = 1250$ faces.

1.1.3. Procedure.

Each participant was randomly assigned to one of five social dimension conditions (attractiveness, competence, dominance, extroversion, or trustworthiness) and judged on that dimension the subset of 250 faces that were manipulated on that respective shape and reflectance dimension (5 Shape Levels \times 5 Reflectance Levels \times 10 Identities). Stimuli were presented using E-Prime 3.0 (Psychology Software Tools, 2016). This procedure resulted in 15 participants providing 250 judgments for each of the five traits. Participants judged the faces on how well that face represented the intended trait (“How [trait] is this person?”) using a 9-point scale ranging from 1 (not at all) to 9 (extremely).

Participants were asked to rely on their “gut instinct” and not to spend too much time on any one face, were told that there were no right or wrong answers, and were not informed about the manipulation of the faces. Faces were presented in random order, and participants were given unlimited time to respond to each face. Stimuli appeared approximately 10 by 6 cm on the screen, and the distance between subjects and the screen was 60 cm, yielding on average a stimulus size of approximately 9.5×6 degrees of visual angle. Trials were preceded by a 500-ms fixation cross and followed by a 500-ms blank screen.

1.2. Results

To assess inter-rater reliabilities, we computed Cronbach's α for each dimension. Across dimensions, reliability was high (attractiveness: 0.88, competence: 0.84, dominance: 0.90, extroversion: 0.91, trustworthiness: 0.86; see Supplemental Fig. S1–5 for mean ratings as a function of the shape and reflectance model levels). We estimated the individual contributions of shape and reflectance to the face judgments by fitting mixed models using the *lmer* function of the *lme4* (Bates, Mächler, Bolker, & Walker, 2015) and *lmerTest* packages (Kuznetsova, Brockhoff, & Christensen, 2017) in R (R Core Team, 2018) for each of the five social dimensions separately. *t*-tests for the fixed effects were performed via Satterthwaite's method. We used a significance level (α) of 0.01 to facilitate the interpretation of the findings. However, given the arbitrary nature of the significance level, we report full statistics from all analyses, including those of the effects that did not reach the significance level (Supplemental Tables 1–8). In each model, we included linear and quadratic terms for shape and reflectance levels as fixed factors predicting the respective judgment rating, and all their interactions. Each variable was rescaled to follow a normal distribution and submitted to the multilevel models. We aimed to employ maximal models (i.e., models with as many predictors as allowed by study design) to increase generalizability of the findings (Barr, Levy, Scheepers, & Tily, 2013). Specifically, in order to account for the repeated-measures nature of the task (each participant judged 250 faces, of which 25 were based on the same identity), we included random intercepts for participant and identity, as well as random slopes for all fixed factors within participant and within identity, allowing all fixed factors to vary across participants and identities. We then modified our initial models by removing random slopes with 0 variance until models for all traits reached convergence, starting with highest order effects, first those by identity and then those by participant. Our final models included (i) linear and quadratic terms for shape and reflectance as fixed-factor predictors, (ii) all their interactions, (iii) random intercepts for participant and identity, and (iv) random slopes for linear shape- and reflectance-level terms within participant, allowing the shape and reflectance effects to vary across participants. The final set of predictors was chosen so that it allowed the most maximal model possible across all social judgments. We used the same multilevel model across judgments for consistency of the interpretation of the effects across different social judgments.

We report parameter estimates (B) for the fixed effects. We computed 95% confidence intervals for each estimate by generating a bootstrap distribution via sampling from raw data for 1,000 times using the *confint* function from the *lme4* R package. The results of this analysis are reported in Fig. 1c–5c and discussed below (see Supplemental Tables 1–5 for the full results; all significant effects are p 's < 0.001 unless noted otherwise in text). Separate by-participant regressions on judgments averaged across identities with linear and quadratic shape or reflectance predictors are depicted in Figs. 1d–5d for illustration.

1.2.1. Linear effects.

Both shape and reflectance information predicted all social judgments in a linear and additive fashion (Fig. 1c–5c). Dominance and extroversion judgments clearly relied more on shape information, $B = 0.50$ [CI = 0.40; 0.59], $B = 0.51$ [CI = 0.37; 0.64], respectively, than on reflectance information, $B = 0.22$ [CI = 0.12; 0.32], $B = 0.19$ [CI = 0.14; 0.24], respectively. Similarly, trustworthiness judgments relied more on shape information, $B = 0.34$ [CI = 0.24; 0.44], than on reflectance information, $B = 0.19$ [CI = 0.09; 0.28], $p = .002$, but this difference was less pronounced. In contrast, competence judgments seemed to rely more on reflectance information, $B = 0.31$ [CI = 0.19; 0.44] than on shape information, $B = 0.19$ [CI = 0.10; 0.27]. Lastly, shape and reflectance information contributed more or less equally to attractiveness judgments, $B = 0.27$ [CI = 0.19; 0.36] and $B = 0.28$ [CI = 0.20; 0.35], respectively.

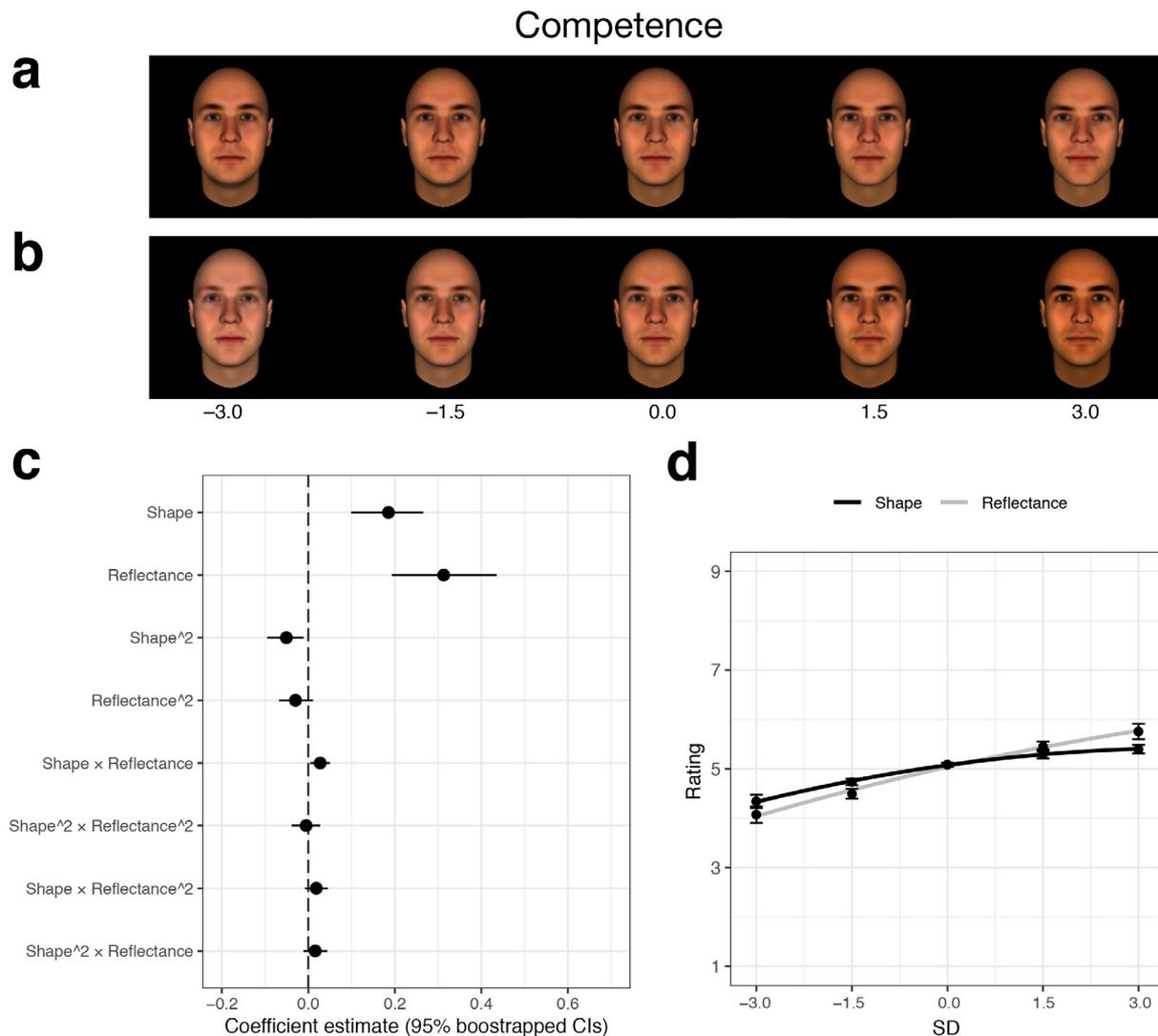


Fig. 2. Judgments of faces manipulated by a computational model of judgments of competence (Experiment 1). A sample face manipulated in the model only for shape (a) and only for reflectance is displayed (b). Parameter estimates (B) and 95% confidence intervals for the judgments are displayed (c). By-participant regression lines of judgments as a function of the model values of the faces averaged across identities are displayed (d). Overall, shape and reflectance had a linear, additive effect on the judgments, and reflectance had a stronger effect than shape did.

1.2.2. Quadratic effects

We observed fewer and weaker quadratic effects of shape and reflectance information, compared to the linear effects (Fig. 1c–5c and 1d–5d). We observed a negative quadratic effect of shape on attractiveness judgments, $B = -0.10$ [CI = -0.14 ; -0.06], indicating that these judgments increased less on higher levels of the shape dimension (Fig. 1c and 1d). In contrast, we observed a positive quadratic effect of shape on extroversion judgments, $B = 0.06$ [CI = 0.02 ; 0.10], $p = .008$, indicating the judgments increased more on higher levels of the extroversion shape dimension (Figs. 3d–4d). No other significant quadratic effects were observed.

1.2.3. Interactions.

We observed an interaction between quadratic shape and linear reflectance information ($\text{Shape}^2 \times \text{Reflectance}$) on extroversion judgments, $B = -0.04$ [CI = -0.07 ; -0.01], $p = .003$. No other significant interactions were observed.

2. Experiment 2

In Experiment 1, we found that different social judgments relied on

shape and reflectance information to different degrees. Shape information was more predictive of dominance, extroversion, and trustworthiness judgments, whereas reflectance information was more predictive of competence judgments. This is consistent with prior work showing that the relative explained variance by shape and reflectance varied across different social judgments (Todorov & Oosterhof, 2011; Torrance et al., 2014). However, it remains unclear whether the relative contribution of shape and reflectance to social judgments might vary when the amount of visual information available to the observer changes.

In Experiment 2, we manipulated the duration of face exposure, while maintaining the orthogonal manipulation of shape and reflectance as in Experiment 1. Exposure to faces as brief as 34 ms is long enough for human observers to form a specific judgment, and these judgments do not change with exposures longer than 200 ms (Todorov et al., 2010; Todorov et al., 2009; for review, see Todorov et al., 2015). We expected that for short exposures (e.g., between 34 ms and 200 ms), the contribution of shape information would be stronger than the contribution of reflectance information, because shape information has more impact on the earlier stages of face processing than reflectance information (in line with Caharel et al., 2009; see Fig. 6, Prediction 1).

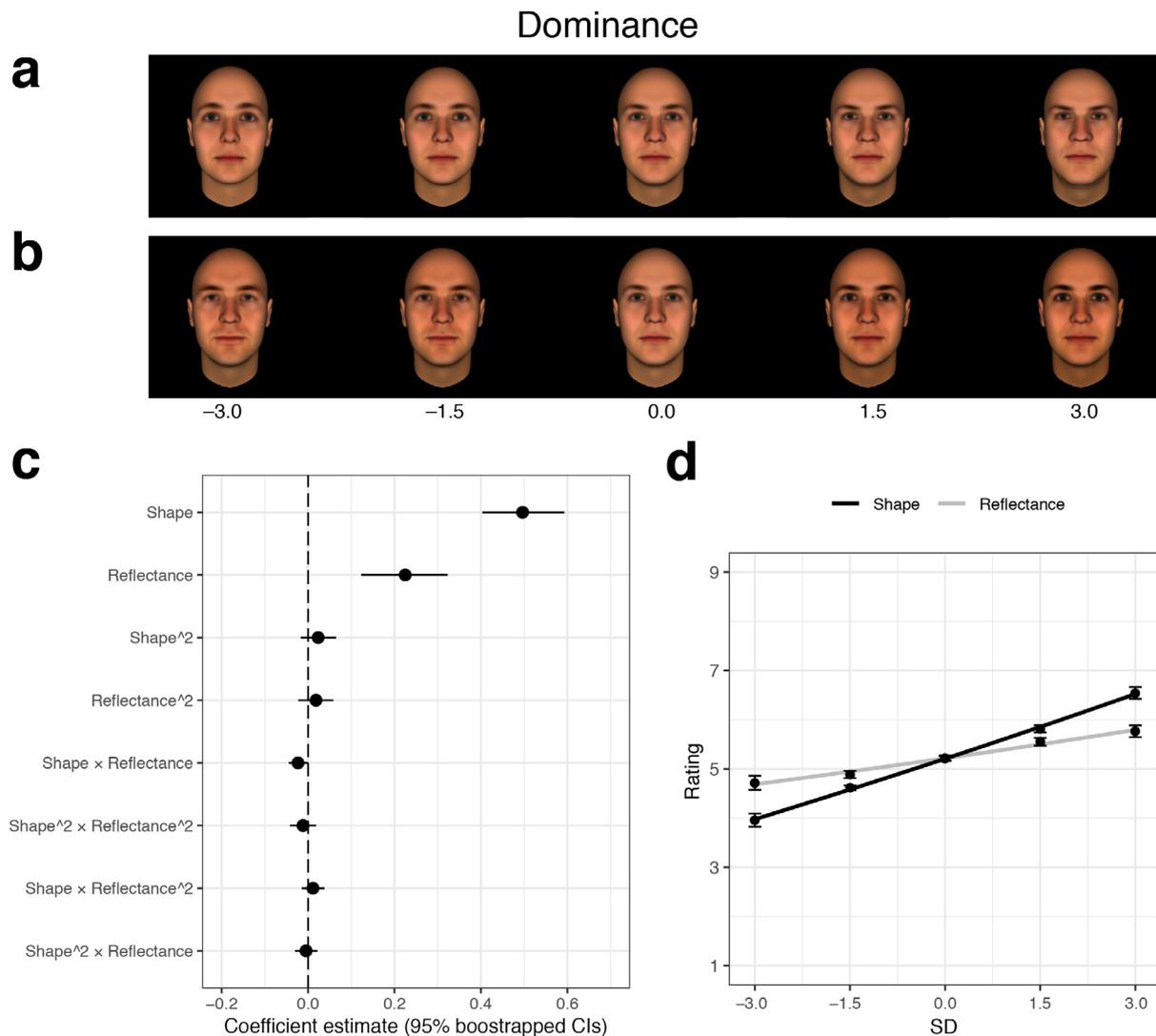


Fig. 3. Judgments of faces manipulated by a computational model of judgments of dominance (Experiment 1). A sample face manipulated in the model only for shape (a) and only for reflectance is displayed (b). Parameter estimates (B) and 95% confidence intervals for the judgments are displayed (c). By-participant regression lines of judgments as a function of the model values of the faces averaged across identities are displayed (d). Overall, shape and reflectance had a linear, additive effect on the judgments, and shape had a stronger effect than reflectance did.

Alternatively, the contribution of both shape and reflectance might be constant across different exposure durations (see Fig. 6, Prediction 2). In all cases, we expected that the effect of both shape and reflectance would increase with the increase in exposure duration (in line with Todorov et al., 2009, 2010). These two competing predictions are graphically described in Fig. 6.

To test these ideas, we varied the shape and reflectance levels as well as stimulus exposure time of faces on three social dimensions attractiveness, competence, and dominance. These three dimensions were chosen because Experiment 1 showed that shape and reflectance had differential contributions: (i) shape and reflectance were equally important for attractiveness judgments, (ii) reflectance was more important for competence judgments, and (iii) shape was more important for dominance judgments. As in Experiment 1, the final set of predictors was chosen so that it allowed the most maximal model possible across all social judgments.

2.1. Methods

2.1.1. Participants.

The experimental protocol was approved by the Institutional

Review Board for Human Subjects of Princeton University. We obtained informed consent from all participants. Sixty Princeton University students (26 male, 33 females, 1 unreported, mean age 19.7 years) participated for course credit or payment.

2.1.2. Materials.

To systematically vary the amount of facial information, in Experiment 2, we manipulated exposure time of the face in addition to shape and reflectance levels in the face models. To allow for balanced manipulation of stimulus exposure time (which consisted of five levels), we created 25 maximally distinctive novel face identities (not ten identities as in Experiment 1). To avoid exponential increase in trial number per participant, faces were manipulated orthogonally on four levels of shape and reflectance for each model: -3, -1, 1, and 3 SD (not five levels as in Experiment 1). We manipulated the faces on three social judgment dimensions – attractiveness, competence, and dominance – which differed in terms of the relative contribution of shape and reflectance to the respective judgment (Figs. 1–3). Each face identity was manipulated on each social dimension by the four shape and the four reflectance levels. We repeated this procedure for all 25 identities and for the three social dimensions, resulting in a total of

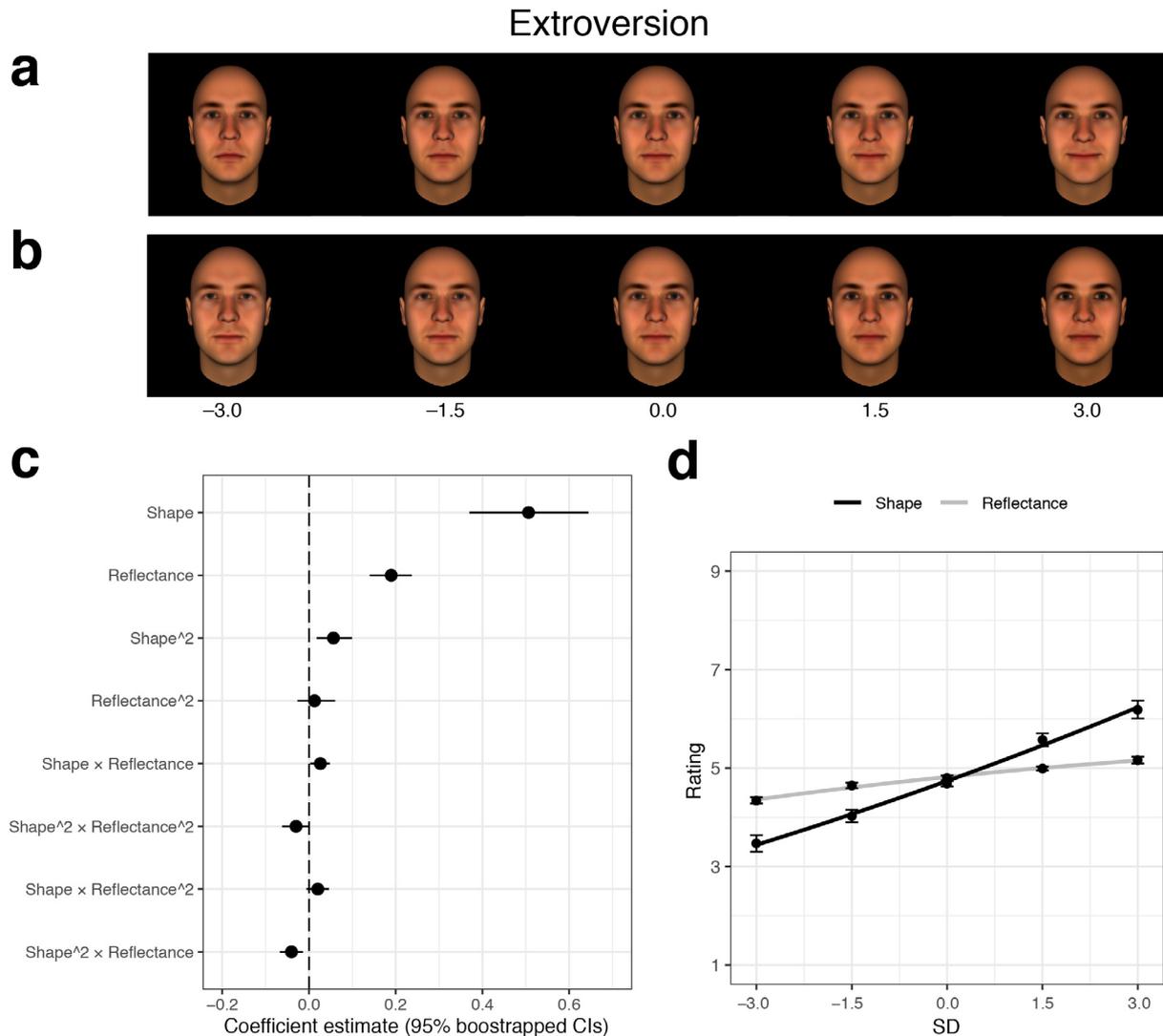


Fig. 4. Judgments of faces manipulated by a computational model of judgments of extroversion (Experiment 1). A sample face manipulated in the model only for shape (a) and only for reflectance is displayed (b). Parameter estimates (B) and 95% confidence intervals for the judgments are displayed (c). By-participant regression lines of judgments as a function of the model values of the faces averaged across identities are displayed (d). Overall, shape and reflectance had a linear, additive effect on the judgments, and shape had a stronger effect than reflectance did.

$25 \times 16 \times 3 = 1200$ faces.

2.1.3. Procedure

Each participant was randomly assigned to one of three social dimension conditions (attractiveness, competence, or dominance) and judged on that dimension the subset of 400 faces that were manipulated on the respective shape and reflectance dimensions (4 Shape Levels \times 4 Reflectance Levels \times 25 Identities). This procedure resulted in 20 participants providing 400 judgments for each of the three traits. Participants judged the faces on how well that face represented the intended trait (“How [trait] is this person?”) using a 9-point scale, ranging from 1 (not at all) to 9 (extremely). Crucially, unlike in Experiment 1, each face was presented for one of five temporal exposures. Specifically, the 25 identities were grouped into five subgroups, and the faces within each subgroup were presented for either 33, 67, 100, 167, or 500 ms. The subgroups of faces and the stimulus exposure time were counterbalanced across participants.

2.2. Results

To assess inter-rater reliabilities, we computed Cronbach’s α for

each dimension. Across dimensions, reliability was moderately high, although lower than in Experiment 1 due to the conditions with brief stimulus exposure times (attractiveness: 0.80, competence: 0.71, dominance: 0.86; see Supplemental Figures S6–8 for mean ratings as a function of the shape and reflectance model levels). As in Experiment 1, we estimated the individual contributions of shape and reflectance by fitting mixed models. To test for the effect of exposure time, we added exposure time as well as its interactions with the linear and quadratic effects of shape and reflectance levels. Our final models included (i) linear and quadratic terms for shape and reflectance as fixed-factor predictors, (ii) linear and quadratic terms for exposure time as fixed-factor predictors, (iii) interactions between the fixed-factor predictors, (iv) random intercepts for participant, identity, and time, and (v) random slopes for linear shape- and reflectance-level terms as well as the exposure-time term within participant, allowing all three effects to vary across participants. Models more complicated than the final models did not converge. As in Experiment 1, we report parameter estimates (B) for the fixed effects and bootstrapped 95% confidence intervals for significant effects with a significance level (α) of 0.01. When reporting each of subgroups of effects (i.e., linear, quadratic, and interactive effects), we first report the effects of shape and reflectance

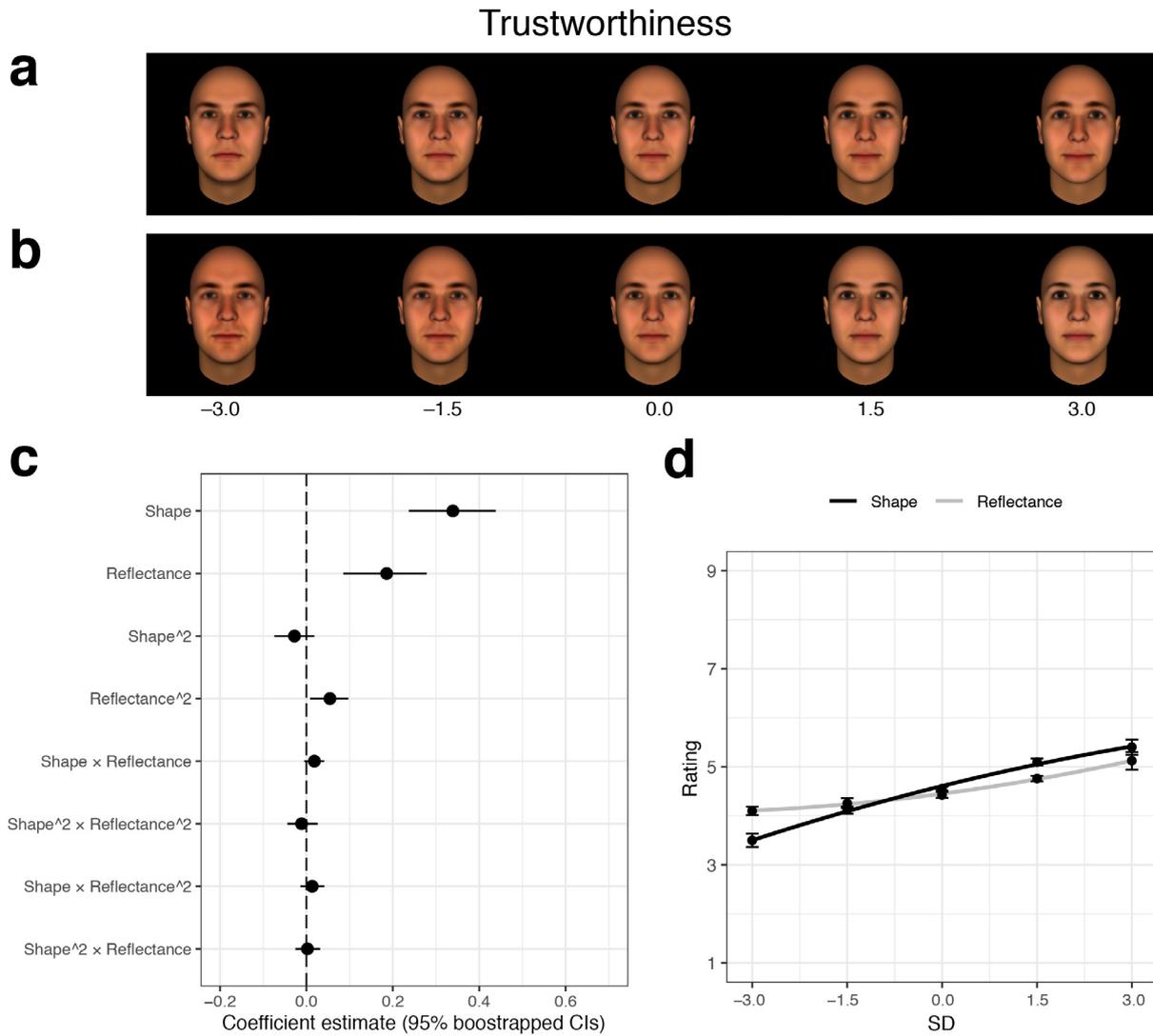


Fig. 5. Judgments of faces manipulated by a computational model of judgments of trustworthiness (Experiment 1). A sample face manipulated in the model only for shape (a) and only for reflectance is displayed (b). Parameter estimates (B) and 95% confidence intervals for the judgments are displayed (c). By-participant regression lines of judgments as a function of the model values of the faces averaged across identities are displayed (d). Overall, shape and reflectance had a linear, additive effect on the judgments, and shape had a stronger effect than reflectance did.

(common predictors between Experiments 1 and 2), and then the effects that involve stimulus exposure time (new predictors in Experiment 2; see Supplemental Tables 6–8 for the full results; all significant effects are p 's < 0.001 unless noted otherwise in text).

2.2.1. Linear effects.

Both shape and reflectance information predicted all social judgments in a linear and additive fashion, consistent with Experiment 1 (Fig. 7). Dominance judgments relied more on shape information, $B = 0.36$ [CI = 0.26; 0.45], than on reflectance information, $B = 0.27$ [CI = 0.20; 0.33]. In contrast, competence judgments relied more on reflectance information, $B = 0.26$ [CI = 0.14; 0.38], than on shape information, $B = 0.10$ [CI = 0.06; 0.15]. Shape and reflectance information contributed more or less equally to attractiveness judgments, $B = 0.21$ [CI = 0.11; 0.31], $B = 0.18$ [CI = 0.13; 0.23], respectively. Notably, across Experiments 1 and 2, the direction of the difference in the effects was identical for all three judgments (dominance: shape > reflectance; competence: shape < reflectance; attractiveness: shape \approx reflectance).

Attractiveness judgment ratings decreased as exposure time increased, $B = -0.21$. [CI = -0.27; -0.15]. Dominance judgment

ratings also decreased as time increased, $B = -0.08$ [CI = -0.14; -0.03], $p = .004$, although the effect was less pronounced than for attractiveness judgments. This is consistent with prior research finding more positive evaluation of briefly presented faces (e.g., more attractive or competent; Oh, Shafir, & Todorov, in press; Willis & Todorov, 2006).

2.2.2. Quadratic effects.

We observed a negative quadratic effect of shape on attractiveness, $B = -0.12$ [CI = -0.14; -0.10], and competence judgments, $B = -0.03$ [CI = -0.05; -0.01], $p = .004$, as well as a negative quadratic effect of reflectance on competence judgments, $B = -0.04$ [CI = -0.06; -0.02], indicating that the ratings of these judgments increased less for higher levels of the models' manipulation (Fig. 7). In Experiment 1, we only observed the quadratic effect for attractiveness judgments. We observed a positive quadratic effect of shape on dominance judgments, $B = 0.08$ [CI = 0.05; 0.10], indicating that the ratings of dominance judgments increased more for higher levels of the shape manipulation. This quadratic effect was also found in Experiment 1.

We observed a positive quadratic effect of exposure time on attractiveness judgments, $B = 0.15$ [CI = 0.12; 0.18], in addition to the

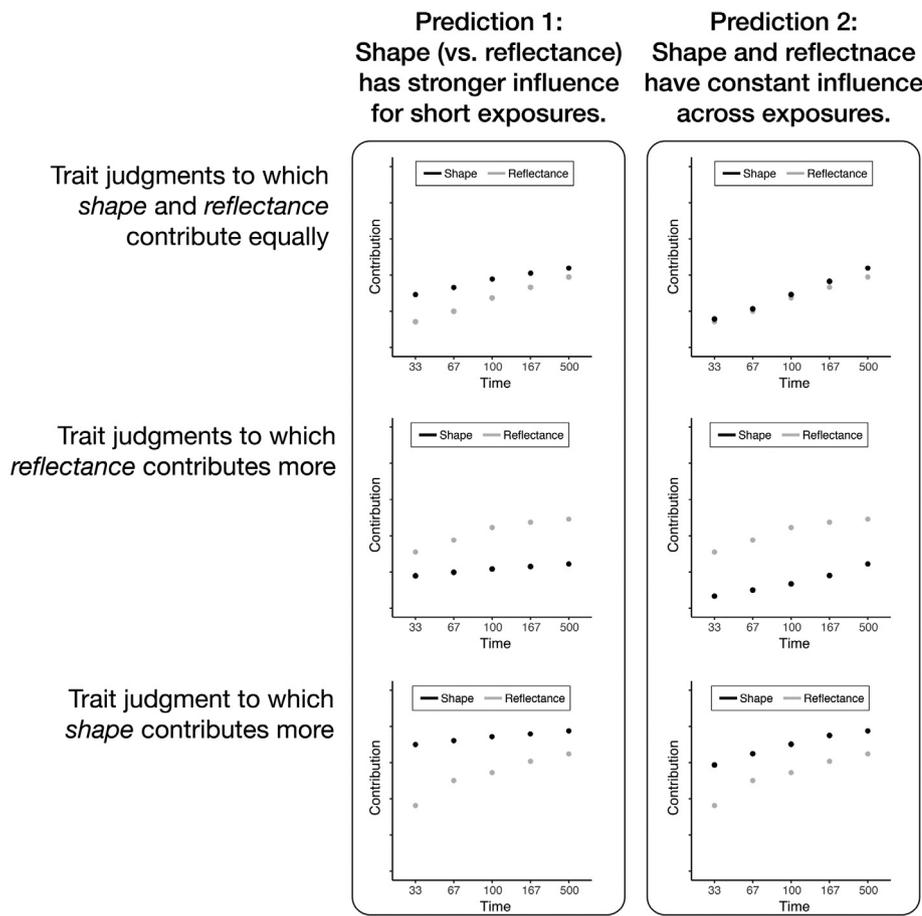


Fig. 6. Potential results consistent with two competing predictions about the effect of stimulus exposure durations on the influence of shape and reflectance information on trait judgments (Experiment 2). Based on previous research, we predicted that either the contribution of shape information may be stronger than the contribution of reflectance information for short exposures (e.g., 34 – 200 ms; Prediction 1) or the contribution of both shape and reflectance may be constant across different exposure durations (Prediction 2). In all cases, we predicted that the effect of shape and reflectance will increase as exposure duration increases (see main text for details). Example patterns of results consistent with each of the two predictions are displayed here. Consistent with Prediction 2, our findings revealed that shape and reflectance information had a constant amount of relative contribution across different exposure durations (see Fig. 7 and main text for details).

negative linear effect of time (see *Linear effects*), indicating that the ratings of attractiveness decreased to a smaller extent for longer exposures. We also observed a positive quadratic effect of time on competence judgments, $B = 0.10$ [CI = 0.07; 0.13], with no linear effect of time, indicating that the ratings of competence increased on the extreme ends of exposure time relative to middle-level exposure time. No other significant quadratic effects were observed.

2.2.3. Interactions.

Both shape and reflectance information interacted with exposure time (Fig. 6b, 6d, and 6f). We observed a positive Shape \times Time interaction for attractiveness, $B = 0.05$ [CI = 0.04; 0.07], and competence judgments, $B = 0.03$ [CI = 0.01; 0.04], $p = .004$, indicating that as exposure time increased, the linear effect of shape information on these judgments increased. We also observed a positive Reflectance \times Time interaction for attractiveness, $B = 0.05$ [CI = 0.04; 0.07], competence, $B = 0.04$ [CI = 0.02; 0.06], and dominance judgments, $B = 0.04$ [CI = 0.02; 0.06], indicating that as exposure time increased, the linear effect of reflectance information on these judgments increased. Overall, longer exposure to faces resulted in bigger effects of shape and reflectance information on social judgments, although these effects were relatively small.

We observed a positive Shape \times Reflectance interaction for attractiveness judgments, $B = 0.02$ [CI = 0.01; 0.04], $p = .004$. This interaction effect was not observed in Experiment 1 and was smaller in size than the two-way interactions involving exposure time. We observed a negative Shape² \times Time interaction for attractiveness judgments, $B = -0.04$ CI = [-0.06; -0.02], and a negative Reflectance² \times Time interaction for dominance judgments, $B = -0.03$ CI = [-0.05; -0.01], $p = .007$. We also observed a positive Shape \times Reflectance \times Time interaction for attractiveness, $B = 0.02$

[CI = 0.01; 0.04], $p = .005$, and competence judgments, $B = 0.03$ [CI = 0.01; 0.05], $p = .001$. Notably, all these effects were relatively small in size. No other two- or three-way interactions were observed.

3. Discussion

The present findings show that both shape and reflectance information are critical for social judgments. In Experiment 1, we found that for all studied social judgments from faces – attractiveness, competence, dominance, extroversion, and trustworthiness – people relied on both shape and reflectance information in a linear and additive fashion. We found no evidence for consistent quadratic or interaction effects. In general, the few significant quadratic (found for two judgments) and interaction effects (found for one dimension) were smaller than all linear effects. In Experiment 2, we replicated these findings for attractiveness, competence, and dominance judgments. People relied on both shape and reflectance information in a linear, additive fashion. These effects were detectable even after extremely brief exposure to faces (33 ms). The linear effects of shape and reflectance increased with longer exposures, but importantly their relative contribution to judgments did not change. As in Experiment 1, the few quadratic and interactions effects were all small in size.

The findings also show that the relative importance of shape and reflectance information varies as a function of the specific judgment, suggesting that people rely on different types of facial information for different social judgments. First, shape information was more predictive of dominance, extroversion, and trustworthiness judgments than reflectance information. This might be because face shape might provide more perceivable cues for dominance, extroversion, and trustworthiness than face reflectance. For example, people judge a person as dominant in the presence of a mature facial bone structure, e.g., a

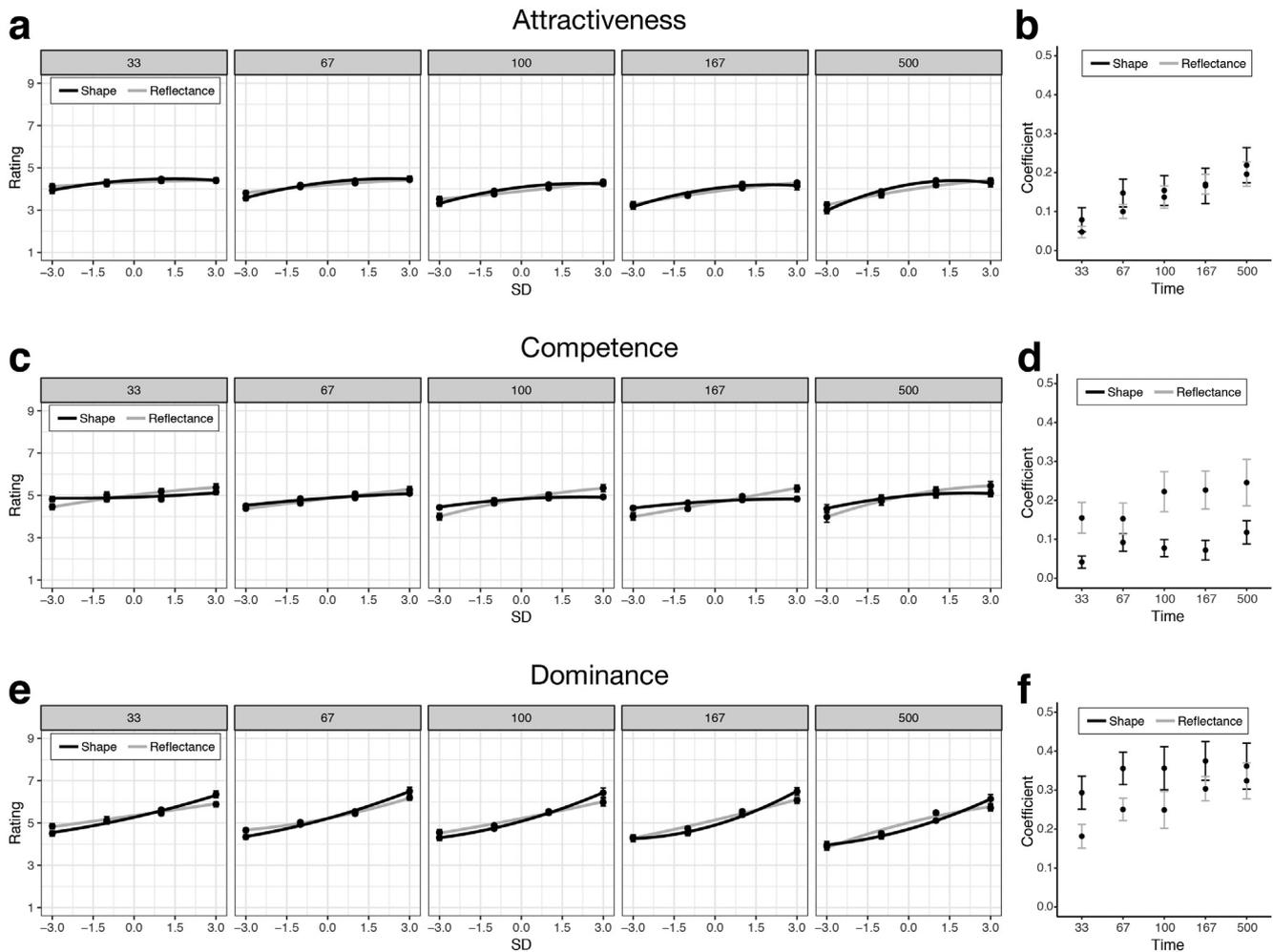


Fig. 7. Judgments of faces manipulated by models of attractiveness, competence, and dominance as a function of shape, reflectance, and exposure time (Experiment 2). By-participant regression lines for the prediction of attractiveness (a), competence (c), and dominance judgments (e) are displayed as a function of the stimulus exposure time of faces averaged across identities. Parameter estimates (B) for exposure time in attractiveness (b), competence (d), and dominance judgments (f) are displayed. Across all exposure times, reflectance had a stronger effect on competence judgments than shape (d). In contrast, shape had a stronger effect on dominance judgments than reflectance (f). Overall, as exposure time increased, the linear effects of both reflectance and shape on the judgments increased too, as evidenced by a significant positive Shape \times Time interaction (in the cases of attractiveness and competence) and Reflectance \times Time interaction (in the cases of attractiveness, competence, and dominance). Graphically, this is indicated by the steeper slopes (a, c, e) and the higher linear coefficient values of shape and reflectance for longer exposure times (b, d, f). The relative contribution of shape and reflectance to judgments remained the same across exposure times.

distinct jaw structure (Keating, Mazur, Segall, et al., 1981; Oosterhof & Todorov, 2008; Sutherland et al., 2013). People judge a person as extroverted (Masip, North, Todorov, & Osherson, 2014; Todorov, Dotsch, et al., 2013; Walker et al., 2011; Walker & Vetter, 2016) or trustworthy (Hess, Blairy, & Kleck, 2000; Keating, Mazur, & Segall, 1981; Montepare & Dobish, 2003; Oosterhof & Todorov, 2008, 2009; Said, Sebe, & Todorov, 2009; Sutherland et al., 2013; Zebrowitz, Kikuchi, & Fellous, 2007) in the presence of positive facial features, e.g., a smiley mouth shape. These visual components are represented better in face shape than in reflectance information.

Second, shape and reflectance information were predictive of attractiveness judgments to a comparable extent. This might be because both types of information provide perceivable cues for attractiveness. People judge a person as attractive in the presence of (i) less bulk around the cheeks and upper neck (Coetzee, Perrett, & Stephen, 2009; Fisher, Hahn, DeBruine, & Jones, 2014; Holzleitner et al., 2019; Nakamura & Watanabe, 2019; Rantala et al., 2012; Said & Todorov, 2011), and (ii) darker brows and eye lines (Said & Todorov, 2011) and more yellowness in the skin color (b^* ; Scott, Pound, Stephen, Clark, & Penton-Voak, 2010; Stephen et al., 2012). These two types of visual components are represented in face shape and face reflectance,

respectively.

Third, reflectance information was more predictive of competence judgments than shape information. This might be because face reflectance might provide more perceivable cues for competence than face shape. Competence judgments from faces are strongly correlated with facial attractiveness (Dion, Berscheid, & Walster, 1972; Landy & Sigall, 1974; Oh, Buck, et al., 2019; Thorndike, 1920; Todorov, Dotsch, et al., 2013), suggesting that people use shape and reflectance information related to attractiveness when judging the competence of others. Further, people might judge a person as competent in the presence of facial cues that indicate apparent (Henderson, Holzleitner, Talamas, & Perrett, 2016; Stephen, Coetzee, & Perrett, 2011; Stephen, Law Smith, Stirrat, & Perrett, 2009; Stephen et al., 2012; Whitehead, Re, Xiao, Ozakinci, & Perrett, 2012) and actual health, e.g., skin yellowness (b^* ; which increases through healthy diet and other healthy behavior; Alaluf, Heinrich, Stahl, Tronnier, & Wiseman, 2002; Stephen et al., 2012; Tan, Graf, Mitra, & Stephen, 2015; Whitehead, Ozakinci, & Perrett, 2014; Whitehead et al., 2012). These visual components are represented better in face reflectance than in face shape.

Notably, the relative contribution of face shape vs. reflectance remained stable (Fig. 6b, 6d, and f; attractiveness: shape \approx reflectance;

competence: shape < reflectance; dominance: shape > reflectance) across exposure times. These findings demonstrate that people are able to perceive cues from both shape and reflectance information after extremely brief exposures to faces. Longer exposures simply increase the weight of these cues in social judgments, but do not change the nature of these cues or their relative weighting.

3.1. How shape and reflectance information influence social face judgments

In contrast to the strong, consistent linear effects of shape and reflectance information on judgments across social dimensions, we found no evidence for strong, consistent curvilinear effects within the investigated range of faces, except for the quadratic effect of shape on attractiveness judgments (Experiment 1: $B = -0.10$, Experiment 2: $B = -0.12$). In both experiments, the added attractiveness value of one unit increase in shape diminished for higher values of shape. This finding is consistent with Said and Todorov (2011), who showed that faces were more attractive to the extent that they were closer to the average shape, but not average reflectance, indicating a quadratic effect of shape but a linear effect of reflectance.

One explanation for the absence of other strong or consistent quadratic effects in our data is that in the orthogonally manipulated set of stimuli, the linearity of the manipulations becomes salient and, thus, participants resort to a linear judgment model themselves. Unlike the current findings, Todorov and Oosterhof (2011) found that a quadratic model of shape components provided better fit for judgments than a purely linear model did for all five judgments investigated here. In this prior work, the faces randomly varied on all face space dimensions, thereby revealing no clues to participants about whether a linear or quadratic judgment model is appropriate for the task. A second explanation relates to the range of faces used: In the current work, the range in which faces were varied was precisely manipulated. Unlike the current work, the Todorov and Oosterhof study (2011) employed a much broader range, which may be necessary in order to observe non-linear effects. Lastly, it is also possible that previously observed quadratic effects were an artifact of averaging across participants and identities. The analyses reported here controlled for idiosyncratic effects of participants and identities.

We also did not find evidence for any strong interaction effects between shape and reflectance information, indicating that in most cases a purely additive (and linear) model of shape and reflectance is sufficient to explain social face judgments.

In sum, we found that (i) both shape and reflectance information contribute to social judgments of faces in a linear, additive fashion, accumulating over presentation time, and (ii) the relative contribution of shape and reflectance information depends on the judged dimension, possibly reflecting people's biases to rely on different types of information as a function of its perceived relevance for the specific social judgment.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.visres.2019.10.010>.

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