AMERICAN PSYCHOLOGICAL ASSOCIATION

Journal of Personality and Social Psychology: Attitudes and Social Cognition

ISSN: 0022-3514

2024, Vol. 127, No. 3, 518–536
https://doi.org/10.1037/pspa0000395

Nonlinear Relationships Between Eye Gaze and Recognition Accuracy for Ethnic Ingroup and Outgroup Faces

Joshua Correll[1], Joana Quarenta[2], Tomás A. Palma[2], Balbir Singh[3], Michael J. Bernstein[4], and Omar Hidalgo Vargas[1]

[1] Department of Psychology and Neuroscience, University of Colorado, Boulder
[2] Department of Psychology, University of Lisbon
[3] Department of Psychology, Mount Holyoke College
[4] Department of Psychology, Pennsylvania State University, Abington

Researchers have used eye-tracking measures to explore the relationship between face encoding and recognition, including the impact of ethnicity on this relationship. Previous studies offer a variety of conflicting conclusions. This confusion may stem from misestimation of the relationship between encoding and recognition. First, most previous models fail to account for the structure of eye-tracking data, potentially falling prey to Simpson's paradox. Second, previous models assume a linear relationship between attention (e.g., the number of fixations to a to-be-remembered face) and recognition accuracy. Two eye-tracking studies (*N*s = 41, 59), one online experiment that manipulates exposure (*N* = 150), and a mega-analysis examine the effects of ethnicity using what we believe to be more appropriate analytical models. Across studies and measures, we document a novel, critical pattern: The relationship between attention and recognition is nonlinear and negatively accelerating. At low levels of baseline attention, a small increment in attention improves recognition. However, as attention increases further, increments yield smaller and smaller benefits. This finding parallels work in learning and memory. In models that allow for nonlinearity, we find evidence that central features (eyes, nose, and mouth) generally contribute to recognition accuracy, potentially resolving disagreements in the field. We also find that the effects of attention on recognition are similar for ingroup and outgroup faces, which have important implications for theories of perceptual expertise.

Keywords: eye tracking, face processing, repetition effects, ethnicity or race, recognition

Supplemental materials: https://doi.org/10.1037/pspa0000395.supp

The cross-category recognition deficit (CRD) refers to reduced recognition sensitivity for ethnic outgroups relative to ingroup faces (Bothwell et al., 1989; Lee & Penrod, 2022; Meissner & Brigham, 2001).[1] The origin of the CRD has often been discussed in terms of higher order processes, such as categorization, motivation, and attention (Correll et al., 2017; Guillermo & Correll, 2020; Hugenberg et al., 2013; Levin, 2000). A related but distinct set of explanations involves lower level processes that subserve face recognition, including fine-grained attention to particular features. Many relevant studies use eye-tracking equipment to measure these gaze patterns. Others modify stimuli to test the impact of particular cues. These methods allow researchers to explore the relationship between visual information processing and recognition accuracy (Goldinger et al., 2009; Gosselin & Schyns, 2001; Schyns et al., 2002). To understand these effects, we offer three considerations.

Differential Encoding Strategies

The first consideration is whether processing of a to-be-remembered stimulus differs for ingroup and outgroup faces. Perceivers may have different goals when processing ingroup versus outgroup faces (Levin, 2000) and may therefore encode the faces

[1] Wherever possible, we use the term, ethnicity, rather than race, to refer to social groups defined based on culture and/or origin. We neither assume nor intend to imply that race is a meaningful biological category.

This article was published Online First May 30, 2024.

Joshua Correll https://orcid.org/0000-0003-1142-459X

The current work was supported by grants from the National Science Foundation, BCS-1946788 and BCS-2141328 to Joshua Correll and BCS-1946784 to Michael J. Bernstein.

All studies, data, materials, and code for analysis are available on the Open Science Framework at https://osf.io/x59sw/?view_only=e5a57b6593264b43aee61dfd7a79bf8f (Correll, Quarenta, et al., 2024).

Joshua Correll played a lead role in conceptualization, data curation, formal analysis, funding acquisition, investigation, methodology, project administration, resources, supervision, visualization, writing–original draft, and writing–review and editing. Joana Quarenta played a lead role in data collection, Study 2, and a supporting role in conceptualization and writing–review and editing. Tomás A. Palma played a supporting role in conceptualization and writing–review and editing. Balbir Singh played a supporting role in conceptualization and writing–review and editing. Michael J. Bernstein played a supporting role in conceptualization, funding acquisition, and writing–review and editing. Omar Hidalgo Vargas played a lead role in data collection, Study 1.

Correspondence concerning this article should be addressed to Joshua Correll, Department of Psychology and Neuroscience, University of Colorado, Boulder, 345 UCB, Boulder, CO 80309-0345, United States. Email: joshua.correll@colorado.edu

differently. Several studies find that perceivers fixate more frequently and/or for a longer duration on the eyes of ingroup (relative to outgroup) faces (Goldinger et al., 2009; Kawakami et al., 2014; Stelter et al., 2021; Wu et al., 2012). Evidence also suggests that perceivers attend less frequently, for a shorter duration, and/or later to the nose and mouth of ingroup faces (Goldinger et al., 2009; Kawakami et al., 2014; Wu et al., 2012).

Effective Behavior

The second consideration involves the extent to which an encoding behavior aids recognition. For example, does fixating more frequently on the eyes improve recognition accuracy? A wealth of information related to this consideration comes from studies that do not rely on eye tracking. For example, Schyns et al. (2002) asked participants to learn face–name pairs. They then presented face stimuli that had been cleverly degraded in different ways. One stimulus might omit information about the nose, chin, and forehead; another might omit information about the eyes, nose, and cheek. The results suggested that participants were more accurate in identifying faces by name the stimuli included information about the eyes and the mouth. Abudarham manipulated facial features using photoediting software. Identity judgments were sensitive to changes in lip thickness, hair color and length, eye color and shape, and eyebrow thickness (Abudarham et al., 2019; Abudarham & Yovel, 2016). Correll, Ma, et al. (2024) computed the physical differences between pairs of faces on metrics like eye height and chin length. They used the physical differences to predict perceivers' perceptions that the pairs were dissimilar. Physical metrics that showed greater variability (including lip thickness, chin prominence, eye height, nose width) predicted perceived dissimilarity better than low-variability metrics. These studies suggest that central facial features, including the eyes, nose, and mouth, are all useful for individuating and recognizing faces.

Oddly, in eye-tracking research, there is almost no consensus that attention to particular features facilitates recognition. Two articles report positive relationships, but those relationships emerge for different features (Burgund, 2021, eyes; McDonnell et al., 2014, nose). One study reports a trending negative relationship (e.g., McDonnell et al., 2014, mouth). Many studies report no significant relationships (e.g., Stelter et al., 2021), which seems odd on its face. How can it be true that attention to the features of a face does *not* improve recognition?

Differentially Effective Behavior

The third consideration involves the possibility that a given encoding behavior affects ingroup and outgroup recognition differently. One prominent theoretical account of CRD, perceptual expertise, proposes (a) that perception is "tuned" to dimensions of physical variation that optimally differentiate ingroup faces and (b) variation on different dimensions of the face differentiates outgroup faces. For example, Hills and Lewis (2006) argued that White faces are better individuated by the eyes, whereas Black faces are better individuated by the nose and mouth. If this is the case, when viewing outgroup faces, perceivers may fail to encode the correct visual information or they may fail to process the encoded information correctly (Correll et al., 2017; Tanaka & Curran, 2001). Such a process could yield evidence that, say, attention to the eyes improves recognition of ingroup faces but does not improve recognition of outgroup faces. Here again, eye-tracking literature offers inconsistent evidence. (Of course, given the general lack of evidence for effective behavior, as described in the previous paragraph, it is hard to consider behavior that is differentially effective.) Details of published eye-tracking studies are presented in Table 1 and in the Supplemental Material.

Concerns With Previous Studies

The analyses in previous studies may obfuscate the relationship between encoding behaviors and recognition. First, with one exception, prior statistical models fail to account for the structure of eye-tracking data, conflating between-participant and within-participant variation in eye gaze behavior. This confusion can lead to Simpson's paradox, in which a relationship between two variables, estimated for a sample as a whole, changes when it is estimated separately for each subsample (Pearson et al., 1899; Simpson, 1951). Second, previous studies generally assume the attention–recognition relationship is linear, but there is good reason to believe that the relationship should be quadratic, with an initially positive but negatively accelerating relationship (Ebbinghaus, 1885/1964). We consider both issues.

The Structure of Eye-Tracking Data

Eye-tracking data involve complex dependence. Studies involve a sample of participants (one random factor), each of whom views a sample of faces (a second random factor). Appropriate analysis of these data usually involves linear mixed-effects models with crossed random factors. Most recent articles have adopted this approach McDonnell et al. (2014), which appropriately parses variation in the dependent variable. However, the *predictors* in these models are similarly complex. On average, one participant might fixate on the mouth of a face more often than another participant. This reflects between-participant variation. In addition, each participant's behavior varies from trial to trial, reflecting within-participant variation. These two sources of variation may have unique effects on recognition, and failing to distinguish between them can lead to Simpson's paradox. By parsing the variance of encoding behavior, analyses can more accurately determine the relationship between eye gaze patterns and recognition. This decomposition also makes it possible to examine the nonlinear patterns, described below.

Nonlinear Relationships Between Attention and Recognition

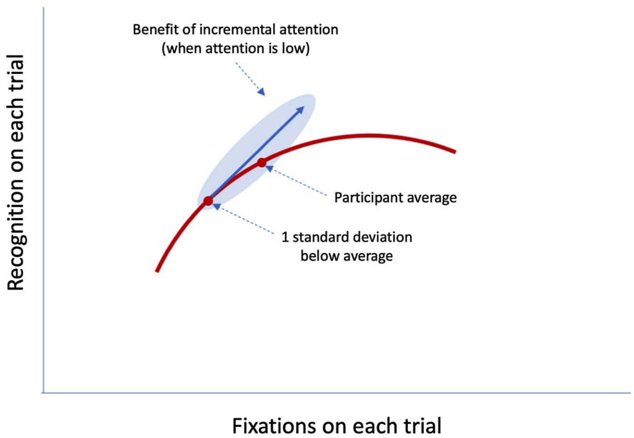
On some level, attention to any facial feature should aid recognition. For example, compared to 0 s of encoding, even a 300-ms glimpse of the nose should improve recognition. It is therefore extremely surprising that eye-tracking studies, reviewed above, find such scattershot evidence for the benefits of feature-based encoding. One problem may be that previous analyses misconceptualize the attention–recognition relationship.

We suggest that increasing visual processing is not linearly related to recognition (see Figure 1). Compared to a baseline of zero, a 300-ms exposure to the nose should improve recognition. But for a perceiver who has already encoded the nose for 5 s, an additional 300 ms exposure may confer no benefit. The suggestion, here, is

Table 1
Summary of Existing Eye-Tracking Studies That Explore the Recognition of Ingroup and Outgroup Faces

Study	Method	Evidence of differential encoding strategy	Evidence of behavior that promotes recognition	Evidence that effective behavior depends on face ethnicity
Burgund (2021)	Asian and White participants; Asian, Black, and White faces; 5-s presentation; faces presented in random order	No evidence; only the effects of face race	Dwell time to eyes positively related to recognition	Dwell time to nose and mouth positively related to recognition, but only for Black faces
Blais et al. (2008)	Asian and White participants; Asian and White faces; 5-s presentation; face presentation blocked by face race	No evidence; only effects of perceiver race	Not tested	Not tested
Caldara et al. (2010)	Asian and White participants; Asian and White faces; 10-s presentations; face presentation blocked by face race	No evidence; only effects of perceiver race	Not tested	Not tested
Goldinger et al. (2009), Studies 1 and 2	Asian and White participants; Asian and White faces; 5- and 10-s presentations; faces presumably presented in random order	More fixations to eyes, fewer fixations to nose and mouth, more total fixations, shorter fixations, greater distance, and more unique areas for same-race versus cross-race	Total fixations, distance traveled, and unique areas positively related to recognition; longer fixations and a number of regressions negatively related to recognition (assessed indirectly and only for cross-race faces)	Not tested
Hills & Pake (2013)	Black and White participants; Black and White faces; faces presented until response	No evidence; only effects of perceiver race	Not tested	Not tested
Kawakami et al. (2014), Study 1	White participants; Black and White faces; 5-s presentation; faces presented in pairs in two fixed random orders	Greater dwell time for eyes, reduced dwell time for nose and mouth for same-race versus cross-race	Inconclusive	Inconclusive
Kelly et al. (2011)	Asian participants; Asian and White faces; 5-s presentation; face presentation blocked by face race	No evidence	Not tested	Not tested
McDonnell et al. (2014)	White participants; Black and White faces; 3-s presentation; faces presented in random order	Greater dwell time for hair, reduced dwell time for mouth, earlier fixations to hair and nose, later fixation to mouth for same-race versus cross-race	Greater dwell time to mouth marginally negatively related to recognition; earlier fixations to nose marginally positively related to recognition (no effects of dwell time or timing of fixation to eyes; effects of global attention were not tested)	Greater dwell time to hair more positively predictive for same-race; faster fixations to mouth more positively predictive for cross-race
Stelter et al. (2021)	White participants; Asian, Black, Middle Eastern, and White faces; 5-s presentation; faces presented in random order	More fixations to eyes, greater dwell time to eyes for same-race versus cross-race	More fixations, shorter fixations, wide-ranging saccades were positively related to recognition (no effects of fixations or dwell time to eyes, mouth, or nose)	No evidence
Wu et al. (2012)	White participants; Asian and White faces; 5-s presentation; faces presented in random order	Greater dwell time for eyes, reduced dwell time for nose for same-race versus cross-race (no effects on total number or length of fixations)	Total fixations positively related to recognition (tested indirectly)	No evidence

Figure 1
Hypothetical Relationship Between Fixations and Recognition



Note. The curve represents the relationship between a participant's attention to a particular feature and subsequent recognition. When attention is low, there is a benefit of incremental attention (the solid arrow); but the curve is negatively accelerating, suggesting that, as attention increases, incremental attention offers less and less benefit. See the online article for the color version of this figure.

that the relationship between attention and recognition should be quadratic, characterized by negative acceleration. The idea of diminishing returns in memory is well-documented, dating back to Ebbinghaus (1885/1964). Ebbinghaus showed that the impact of repetition on learning follows a negatively accelerated curve. Most learning occurs with the first repetitions. Learning decreases with subsequent repetitions until it is barely noticeable. Nonlinear effects of repetition learning have been observed across tasks and stimuli (e.g., De Chastelaine et al., 2009; Greene, 2008; Szpunar et al., 2004), including facial stimuli (Bornstein et al., 2012; Deffenbacher et al., 2008; Ellis et al., 1977). Excessive concentration on any one feature may also invoke opportunity costs. For instance, too much attention to the eyes of a to-be-remembered face may deprive the perceiver of a chance to attend to the nose or mouth or other potentially useful information.

These two processes (diminishing returns and opportunity costs) should yield a negatively accelerating nonlinear relationship between attention and recognition. When baseline attention is low, additional attention may have a positive impact; when baseline attention is high, additional attention may have a muted (or even negative) impact. We can find only one case in which a quadratic effect seems to have been tested: McDonnell et al. (2014) mentioned a nonsignificant quadratic between-participant effect.

The Current Research

These studies seek to clarify the relationship between overt attention (as measured by eye gaze) and recognition. In particular, we examine whether there are nonlinear relationships between attention and recognition and whether the relationships depend on the ingroup–outgroup status of the to-be-remembered face. We report two eye-tracking studies involving a standard encode-recognition task. During encoding, we recorded eye gaze and assessed two measures of attention (number of fixations and dwell time) to three features (eyes, nose, and mouth). Our analysis used mixed-effects models to predict recognition, with a decomposition of variance in the encoding behaviors. We also allowed for nonlinear relationships. We report an additional study, which manipulates attention to different features. By varying the number of exposures to the eyes (rather than the nose and mouth), we test whether exposure has a nonlinear effect on recognition. Finally, we conduct a mega-analysis across the three studies.

We have three predictions. First, we predict a negative quadratic effect of within-participant variation, such that the benefit of incremental attention decreases as baseline attention increases. In models that allow for this nonlinearity, we ask two additional questions that have important theoretical implications. Our second question is "When baseline attention is low, does additional attention to discrete features aid recognition?" Our third question is "Does attention to discrete features have different consequences for ingroup compared to outgroup faces?"

Study 1

Study 1 was originally designed to examine linear relationships between encoding behavior and recognition. In analyzing the data, it occurred to us that the relationship should be nonlinear, and we tested for quadratic effects. This is therefore an exploratory study.

Method

In all studies, we report how we determined our sample size, all data exclusions (if any), all manipulations, and all measures in the study. These studies were not preregistered. All studies were approved by the Institutional Review Board at the University of Colorado Boulder. All studies, data, materials, and code for analysis are available on the Open Science Framework at https://osf.io/x59sw/?view_only=7a55caf97ac648c0a7e2ed06f39c2054 (Correll, Quarenta, et al., 2024). Additional details regarding eye-tracking methods are included in the Supplemental Material (Fiedler et al., 2020).

Design and Power

This study involved a standard encode-recognition task. At encoding, participants viewed a series of ingroup and outgroup faces. At test, they viewed the encoding faces and a number of never-before-seen lures and indicated whether or not they had seen each face. We used eye gaze behavior, measured during encoding, to predict recognition accuracy. The core design of this study involves face ethnicity (Black vs. White, within participants) and eye gaze behavior (e.g., the total number of fixations to the face, which varies both between and within participants). The sample size was determined by a power analysis to detect a relationship that does not bear directly on the current argument. We conducted a sensitivity analysis using the R package, simr (Green & MacLeod, 2016). Simr uses Monte Carlo simulation to estimate power for a given fixed effect in complex linear mixed models. Based on the model of fixations to the eyes as a predictor of recognition, the sensitivity analysis suggested we had power of .79 to detect a quadratic effect of b = .013 and power of .84 to detect an interaction between linear attention and face ethnicity of b = .057. These analyses are for unstandardized effects. At present, we know of no option for sensitivity/power analyses using standardized effects with these mixed-effects models.

Participants

A total of 41 White undergraduates (31 females, 10 males, zero nonbinary, $M_{\text{age}} = 18.71$ years, $SD = 1.03$) participated in partial fulfillment of a class requirement. An additional group of participants (eight Asian, three Latinx, one Middle Eastern) were excluded because the study requires a clear ingroup to which cross-category recognition can be compared. One other participant, who identified as both White and Black, was also excluded because both sets of faces could, conceivably, be viewed as ingroup members. Though we would have preferred to examine these effects with samples of White and Black participants, the population from which these participants were drawn is disproportionately White. We address this issue in Study 3.

Stimuli

Thirty-two self-identified Black and 32 self-identified White male faces were selected from the Chicago Face Database (CFD). The CFD norming data suggest that all faces were reliably classified by raters in line with the model's identification. The faces were randomly split into two sets, each with 16 Black faces and 16 White faces, allowing us to present one set during encoding. Stimuli were grayscaled. Images were 1,096 pixels wide × 770 pixels high. Faces encompassed the central portion of the image, and to the extent possible, we standardized the position of the eyes, nose, and mouth across all stimuli. Presented on the screen, faces were roughly 16 cm wide × 25 cm high, subtending 17 × 26 degrees of visual angle.

Apparatus

Eye movements were recorded using an EyeLink1000 eye tracker (SR Research Ltd., Ontario, Canada), which measures both the pupil and the corneal reflection, allowing the system to determine the location of the participant's gaze with high reliability (Ehinger et al., 2019). During stimulus presentation, fixation was recorded at 1,000 Hz at a resolution of 0.01° of visual angle. Stimuli were presented using SR's Experiment Builder software. Participants sat at a desk equipped with a chin and forehead rest to minimize movement. A 17-in. monitor was positioned 53 cm from the participants' eyes.

Procedure

Participants were run individually. A research assistant identified the participant's dominant eye (used for tracking) and then calibrated the system. Participants were seated at a computer and told that they would view a series of faces. They were instructed to try to remember the faces. They then viewed one set of 32 faces comprised of 16 Black and 16 White faces. Faces were presented one at a time, for 7 s each, in a different random order for each participant. Before each trial, a fixation point appeared in the center of the screen. The experimental program required participants to fixate on that point before the stimulus appeared, which enabled a drift correction. If calibration was compromised (e.g., if the participant shifted in the chin rest), the system paused the encoding sequence and prompted the researcher to recalibrate the system before continuing. Practically, this fixation check also artificially constrained the participant's first fixation to the central upper portion of the face. These initial fixations were excluded from the analysis. There was a 1,000-ms intertrial interval.

During encoding, we monitored eye gaze. To create a short delay before the memory test, participants completed a questionnaire, which took approximately 5 min, involving items unrelated to ethnicity. Finally, they completed a memory test, during which they viewed all 64 faces in random order and indicated which faces they had seen during the encoding phase. For each face, participants first indicated whether they believed they had seen it or not and then they rated their confidence on a 3-point scale (*not at all confident*, *moderately confident*, or *very confident*). Responses were made using radio buttons. This allowed us to create a 6-point scale of recognition confidence, ranging from *very confident that the face had not been seen* to *very confident that the face had been seen*. This dependent variable has greater variance than a simple binary recognition measure and so increases power.

Results

Analysis of Eye Gaze Behaviors

We assessed fixations and dwell time to each of the three features (e.g., eyes, nose, and mouth). We defined a common set of five rectangular areas of interest (AOIs) in the Experiment Builder software: right eye, left eye, upper nose, lower nose, and mouth (see Figure 2). Across all faces, these areas were held constant. For each trial, the number of fixations to the eyes was computed by counting the number of fixations to either eye AOI; the number of fixations to the nose was computed by counting the number of fixations to either the upper or lower nose AOI; the number of fixations to the mouth was computed by counting the number of fixations to the mouth AOI. Time fixating on the eyes, nose, and mouth was computed by summing the duration of all fixations in their respective AOIs. It is critical to note that each of these six measures was computed once for every trial performed by each participant. We will refer to these variables as *behavioral measures*.[2]

We examined whether the ethnicity of an encoding face affected these behavioral measures. Each measure was analyzed using a linear mixed-effects model in which we estimated the fixed effect of face ethnicity, allowing for random intercepts for both perceiver and face and random face-ethnicity slopes for each perceiver whenever possible.[3] The means and standard deviations are presented in Table 2.

The perceivers, who all identified as White, typically performed more fixations to the eyes and nose of White (rather than Black) faces, $\hat{\beta} = 0.24$, 95% CI [0.07, 0.41], $t(38.19) = 2.71$, $p = .010$, $\eta_p^2 = .0057$, and $\hat{\beta} = 0.20$, 95% CI [0.02, 0.38], $t(61.01) = 2.17$, $p = .034$, $\eta_p^2 = .0045$, respectively.[4] But perceivers performed more fixations

[2] In this multistudy article, we discuss marginal effects for two primary reasons. First, we do not want to minimize evidence that challenges our predictions or indicates inconsistencies across studies, even if those effects do not reach conventional significance. Second, due to sampling error, *p* values for a given effect will fluctuate. We want to highlight patterns across studies, even if the pattern is marginal in one study and significant in another.

[3] The model for dwell time to the mouth showed singular fit when the random slopes were included. This model was reestimated with only random intercepts for both perceiver and face.

[4] We report effect sizes for linear mixed models using the direct estimation of error approach outlined by Correll et al. (2021). Effect sizes for linear mixed models are often much smaller than ordinary least squares estimates with similar *t* values.

Figure 2
Examples of Faces and Areas of Interest, Studies 1 and 2

Note. From "The Chicago Face Database: A Free Stimulus Set of Faces and Norming Data," by D. S. Ma, J. Correll, & B. Wittenbrink, 2015, *Behavior Research Methods*, *47*, pp. 1122–1135 (https://doi.org/10.3758/s13428-014-0532-5).

to the mouth of Black (rather than White) faces, $\hat{\beta} = -0.20$, 95% CI [−0.35, −0.05], $t(38.81) = -2.62$, $p = .012$, $\eta_p^2 = .0057$. The perceivers also dwelled for a longer time on the nose of White faces, $\hat{\beta} = 0.06$, 95% CI [0.01, 0.12], $t(45.44) = 2.16$, $p = .036$, $\eta_p^2 = .0044$, and on the mouth of Black faces, $\hat{\beta} = -0.12$, 95% CI [−0.17, −0.06], $t(61.38) = -4.35$, $p < .001$, $\eta_p^2 = .0124$, but we found no evidence for differences in dwell time to the eyes, $\hat{\beta} = 0.04$, 95% CI [−0.02, 0.09], $t(39.38) = 1.33$, $p = .191$, $\eta_p^2 = .0022$.

Analysis of Recognition

Quantification of the Criterion Variable. Our raw criterion in this study is the degree to which participants were able to recognize a face that they had seen during the encoding phase, measured by the 6-point scale of confidence that the face had been presented. As a standard of comparison, we examined the recognition confidence ratings of the 32 faces that had not been presented during encoding. These means are akin to false alarms. For each participant, we computed the mean recognition rating of never-before-seen Black faces and, separately, the mean of the never-before-seen White faces. We then subtracted these participant- and face-ethnicity-specific baseline averages from the participant's ratings of the Black and White faces that had been presented. The resulting score, computed separately for each participant and (within participant) for each face that had been presented during encoding, represents the degree to which the participant rated that particular face higher on the recognition scale than the average never-before-seen face of the same ethnicity. This is, in essence, a recognition score corrected for guessing and scale usage.

Effect of Ethnicity on Recognition. Before exploring the effects of the behavioral measures on recognition, we present evidence for the CRD. In a mixed-effects model, we estimated corrected recognition as a function of the ethnicity of the face, allowing random intercepts for each participant and stimulus, and a random face-ethnicity slope for each participant. There was clear evidence of the CRD, $\hat{\beta} = 0.26$, 95% CI [0.10, 0.42], $t(58.40) = 3.15$, $p = .003$, $\eta_p^2 = .0203$. This effect indicates that perceivers were more confident that they had seen the White faces rather than the Black faces. This basic effect of ethnicity is robust. For the sake of simplicity, we will not present the test of the ethnicity effect for each model that is reported, below, but the output is available in the Supplemental Material.

Effect of Eye Gaze Behavior on Recognition.

Decomposing the Predictors. Each behavioral measure can be decomposed into two separate sources of variation. We computed two *indices* for each source for each measure. We will thus distinguish between behavioral measures and behavioral indices. The nature of each index is described below. Means and standard deviations are presented in Table 2.

An index reflecting each participant's mean was computed to reflect between-participant variability. For each participant, we computed the average of the behavioral measure across the 32 encoding trials. For example, we computed the average amount of time a participant fixated on the eyes by averaging dwell time to the eyes across the 32 encoding trials. This participant-level average index reflects each participant's typical behavior, regardless of the ethnicity of the face. Higher scores suggest that the participant generally performs the behavior more (e.g., spends more time fixated on the eyes). This index was mean-centered (at the mean of the sample) in the model.

The second index reflects within-participant variation in behavior. For each participant, for each trial, we computed an index of extra attention (Extra.Attn) as the degree to which the participant devoted more attention to the current face than to a typical face. For example, Participant 21 might normally fixate on the eyes of a face seven times. However, when Stimulus 03 is presented, she fixates on the eyes nine times. For that stimulus, this participant has a positive discrepancy: She devoted two extra fixations to the eyes. This index reflects trial-to-trial variation relative to the participant average. In the primary models, this index was mean-centered (i.e., centered around the participant's mean), and we allowed for both linear and quadratic effects of extra attention. Accordingly, when we estimate the simple linear effect of extra attention, we estimate the line that is tangent to the curve at a point that represents an average level of attention for the participant. In secondary models, extra attention was recentered at a point 1 *SD* below the mean for each participant (both the mean and the standard deviation were computed separately for each participant). This second model allows us to test the simple linear relationship at relatively low levels of attention. It estimates the line tangent to the curve at a low level of attention, which is critical for our hypotheses (see Figure 1). Again, we predict that, when attention is minimal, an

Table 2
Means and Standard Deviations of Behavioral Measures, Study 1

Measure	Overall *M*	Overall *SD*	Black *M*	Black *SD*	White *M*	White *SD*
Eyes: Fixations	6.77	3.52	6.54	3.54	7.01	3.49
Eyes: Time (s)	1.85	1.01	1.81	1.04	1.89	0.98
Nose: Fixations	5.91	2.96	5.71	2.98	6.11	2.93
Nose: Time (s)	1.81	0.94	1.75	0.93	1.87	0.96
Mouth: Fixations	4.21	2.73	4.41	2.75	4.01	2.70
Mouth: Time (s)	1.27	1.03	1.39	1.10	1.16	0.94

increase in attention to any feature should facilitate recognition. We also predict diminishing returns, such that the benefit of extra attention decreases as overall attention increases. This curvature is tested by the quadratic effect of extra attention.

Analytical Model. We examined the effects of each behavioral measure (e.g., fixations to the mouth) on recognition using a separate mixed-effects model. This common model allows for fixed effects of face ethnicity, each of the indices (P.Mean and Extra.Attn), the quadratic effect of Extra.Attn, and the interactions of face ethnicity with Extra.Attn and the quadratic effect of Extra.Attn. These interactions test the extent to which incremental attention yields differential benefits for ingroup (vs. outgroup) faces and the extent to which diminishing returns are more pronounced for ingroup (vs. outgroup) faces. We allowed for random intercepts for both participants and face and random face-ethnicity slopes for participants. The model is fully specified and described in the Supplemental Materials. Data and R code are available in the Supplemental Materials. This model was run once for each behavior under investigation.

Fixations to the Eyes. This model treated fixations to the eyes of a face (measured during encoding) as a predictor of subsequent recognition. When extra attention was mean-centered, we found no meaningful evidence that increasing attention was associated with improved recognition, $\hat{\beta} = 0.01$, 95% CI [−0.03, 0.04], $t(1250.42) = 0.32$, $p = .748$, $\eta_p^2 = -.0000$. That is, for a typical trial, a small change in attention to the eyes had no significant effect. We did observe a quadratic effect, however, $\hat{\beta} = -0.02$, 95% CI [−0.03, −0.01], $t(1254.10) = -4.00$, $p < .001$, $\eta_p^2 = .0118$. The quadratic effect suggests that the incremental effect of additional attention weakens as baseline attention increases. It is therefore interesting to consider how additional attention influences recognition when overall attention is low. A test of the simple linear effect at a point 1 *SD* below the participant's mean shows that the effect is strong and positive, $\hat{\beta} = 0.10$, 95% CI [0.03, 0.17], $t(1240.88) = 2.98$, $p = .003$, $\eta_p^2 = .0096$. This suggests that, for trials on which attention was fairly low, a small increase in attention confers benefits. There was no indication that the ethnicity of the face moderated either the linear or the quadratic effect, $\hat{\beta} = 0.01$, 95% CI [−0.02, 0.05], $t(1239.54) = 0.75$, $p = .456$, $\eta_p^2 = .0003$ and $\hat{\beta} = 0.01$, 95% CI [0.00, 0.02], $t(1217.65) = 1.44$, $p = .150$, $\eta_p^2 = .0022$, respectively. This suggests that the rate (and change in rate) of learning via fixations to the eyes were similar for White and Black faces, even though overall memory was better for White faces. The results of this (and the analyses below) are reflected in Table 3 and Figure 3.

Dwell Time to the Eyes. Considering dwell time to the eyes, the primary analysis (with extra attention centered at the participant mean) showed no clear evidence of a simple linear effect, $\hat{\beta} = -0.03$, 95% CI [−0.16, 0.09], $t(1265.22) = -0.51$, $p = .607$, $\eta_p^2 = .0002$, but we again observed a quadratic effect, $\hat{\beta} = -0.10$, 95% CI [−0.17, −0.02], $t(1276.03) = -2.41$, $p = .016$, $\eta_p^2 = .0052$. The benefit of incremental attention decreased as baseline attention increased. When baseline attention was low (1 *SD* below the participant's mean), we found a trending but nonsignificant positive linear relationship, $\hat{\beta} = 0.13$, 95% CI [−0.08, 0.34], $t(1259.82) = 1.23$, $p = .220$, $\eta_p^2 = .0051$. Again, we observed no clear evidence that face ethnicity moderated either the linear or the quadratic effect, $\hat{\beta} = 0.07$, 95% CI [−0.06, 0.19], $t(1263.03) = 1.07$, $p = .284$, $\eta_p^2 = .0009$ and $\hat{\beta} = -0.03$, 95% CI [−0.10, 0.05], $t(1154.90) = -0.69$, $p = .489$, $\eta_p^2 = .0007$, respectively.

Fixations to the Nose. For fixations to the nose, in the mean-centered model, we observed a simple linear effect of extra attention, $\hat{\beta} = 0.05$, 95% CI [0.01, 0.09], $t(1253.01) = 2.57$, $p = .010$, $\eta_p^2 = .0051$, and a quadratic effect, $\hat{\beta} = -0.01$, 95% CI [−0.03, 0.00], $t(1274.21) = -2.33$, $p = .020$, $\eta_p^2 = .0029$. These effects suggest that, even at mean levels, additional attention helps recognition, but the benefit levels off as attention increases further. It is therefore no surprise that, when baseline attention is low (1 *SD* below the participant's mean), there is a very strong linear relationship, $\hat{\beta} = 0.11$, 95% CI [0.04, 0.19], $t(1242.45) = 3.06$, $p = .002$, $\eta_p^2 = .0031$. Once again, we found no clear evidence that the simple linear effect or the quadratic depended on face ethnicity, $\hat{\beta} = -0.01$, 95% CI

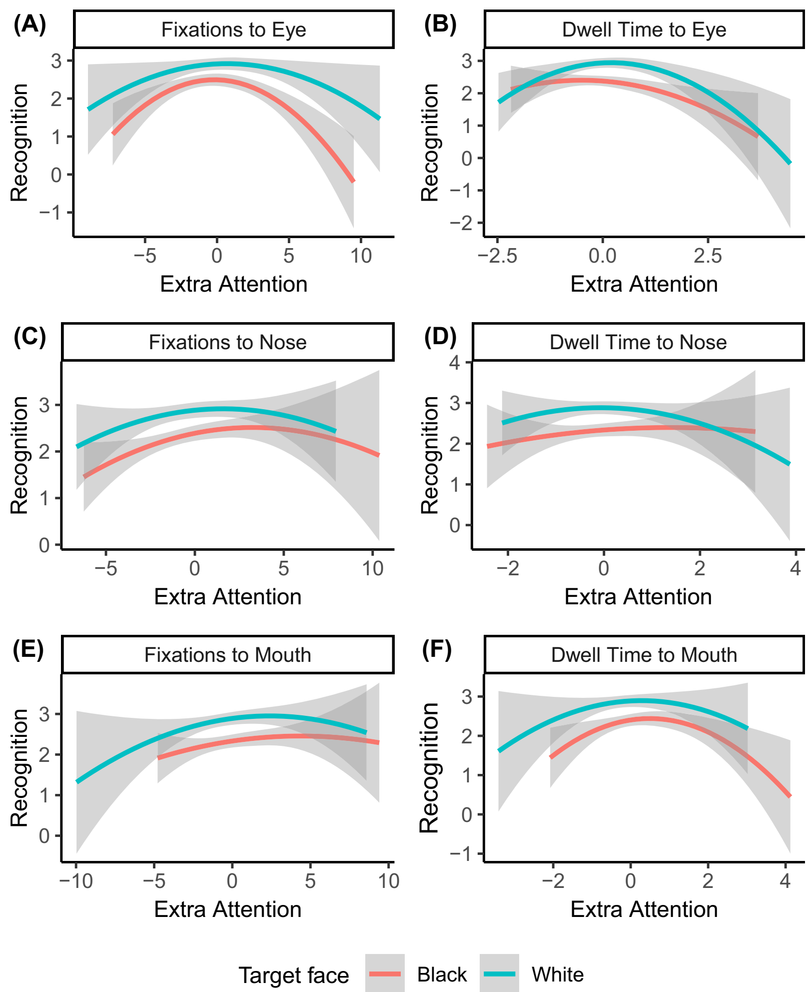
Table 3
Statistics (t and p) Testing Linear and Quadratic Effects of Extra Attention on Recognition as Well as the Interaction of Extra Attention and Between-Participant Variation, Study 1

Behavioral measure	Linear *t*	Linear *p*	Quadratic *t*	Quadratic *p*	*L* × FaceEth *t*	*L* × FaceEth *p*	*Q* × FaceEth *t*	*Q* × FaceEth *p*
Fixations: Eyes	2.98	0.00	−4.00	0.00	0.75	0.46	1.44	0.15
Dwell time: Eyes	1.23	0.22	−2.41	0.02	1.07	0.28	−0.69	0.49
Fixations: Nose	3.06	0.00	−2.33	0.02	−0.54	0.59	0.12	0.90
Dwell time: Nose	1.37	0.17	−1.27	0.20	−0.78	0.44	−0.29	0.77
Fixations: Mouth	1.72	0.09	−1.27	0.20	−0.12	0.91	−0.83	0.41
Dwell time: Mouth	2.06	0.04	−3.02	0.00	−0.55	0.58	0.21	0.83

Note. The linear effect estimates the line tangent to the curve 1 *SD* below the participant's mean level of attention.

Figure 3

Quadratic Effects of Extra Attention, Study 1



Note. Predicted recognition as a function of target face ethnicity and linear and quadratic effects of attention, as measured by fixations to the eyes (A), dwell time to the eyes (B), fixations to the nose (C), dwell time to the nose (D), fixations to the mouth (E), and dwell time to the mouth (F). See the online article for the color version of this figure.

[−0.05, 0.03], $t(1239.17) = -0.54$, $p = .590$, $\eta_p^2 = .0004$ and $\hat{\beta} = 0.00$, 95% CI [−0.01, 0.01], $t(1249.19) = 0.12$, $p = .902$, $\eta_p^2 = -.0000$, respectively.

Dwell Time to the Nose. The mean-centered analysis of dwell time to the nose showed neither a simple linear effect, $\hat{\beta} = 0.04$, 95% CI [−0.08, 0.17], $t(1256.31) = 0.68$, $p = .494$, $\eta_p^2 = .0003$, nor a quadratic, $\hat{\beta} = -0.06$, 95% CI [−0.16, 0.03], $t(1276.02) = -1.27$, $p = .203$, $\eta_p^2 = .0013$. Given the lack of curvature in the primary analysis, it is not particularly surprising that, even when baseline attention was low (1 *SD* below the participant's mean), we found no clear evidence of a linear relationship, $\hat{\beta} = 0.15$, 95% CI [−0.07, 0.37], $t(1253.97) = 1.37$, $p = .171$, $\eta_p^2 = .0019$. Again, there was no indication that the ethnicity of the face moderated either the linear or the quadratic effect, $\hat{\beta} = -0.05$, 95% CI [−0.18, 0.08], $t(1244.50) = -0.78$, $p = .438$, $\eta_p^2 = .0004$ and $\hat{\beta} = -0.01$, 95% CI [−0.11, 0.08], $t(1213.22) = -0.29$, $p = .772$, $\eta_p^2 = .0002$, respectively.

Fixations to the Mouth. The mean-centered analysis of fixations to the mouth showed a marginal simple linear effect, $\hat{\beta} = 0.04$, 95% CI [0.00, 0.09], $t(1255.45) = 1.83$, $p = .067$, $\eta_p^2 = .0039$, but no evidence of a quadratic, $\hat{\beta} = -0.01$, 95% CI [−0.02, 0.00], $t(1286.03) = -1.27$, $p = .203$, $\eta_p^2 = .0024$. Even when attention was low, the benefit of additional attention remained marginal, $\hat{\beta} = 0.07$, 95% CI [−0.01, 0.15], $t(1256.37) = 1.72$, $p = .086$, $\eta_p^2 = .0017$. And there was no significant interaction between face ethnicity and either the linear or quadratic effects, $\hat{\beta} = 0.00$, 95% CI [−0.05, 0.04], $t(1247.11) = -0.12$, $p = .907$, $\eta_p^2 = -.0000$ and $\hat{\beta} = -0.01$, 95% CI [−0.02, 0.01], $t(1180.37) = -0.83$, $p = .409$, $\eta_p^2 = .0003$, respectively.

Dwell Time to the Mouth. For the mean-centered analysis of dwell time to the mouth, there was no evidence of a simple linear effect of extra attention, $\hat{\beta} = 0.07$, 95% CI [−0.07, 0.20], $t(1265.66) = 0.98$, $p = .327$, $\eta_p^2 = .0019$, but we observed a quadratic effect, indicating negative acceleration, $\hat{\beta} = -0.13$, 95% CI [−0.21, 0.04], $t(1268.02) = -3.02$, $p = .003$, $\eta_p^2 = .0110$. In light of this curvature, when baseline attention was low (1 *SD* below the participant's mean), the linear relationship between additional attention and recognition was positive, $\hat{\beta} = 0.24$, 95% CI [0.01, 0.46], $t(1267.75) = 2.06$, $p = .040$, $\eta_p^2 = .0071$. Again, neither the linear effect nor the quadratic were significantly moderated by face ethnicity, $\hat{\beta} = -0.04$, 95% CI [−0.17, 0.10], $t(1269.36) = -0.55$, $p = .581$, $\eta_p^2 = -.0000$ and $\hat{\beta} = 0.01$, 95% CI [−0.07, 0.09], $t(994.88) = 0.21$, $p = .833$, $\eta_p^2 = .0003$, respectively.

Discussion

We observed evidence of nonlinearity in the relationship between feature-based attention and subsequent recognition in four of six tests. The pattern is consistent with diminishing returns of incremental attention and/or opportunity costs. The argument that, when baseline attention to a feature is low, additional attention should improve recognition received support in three of six tests. Although White participants generally recognized White faces more accurately than Black faces, these analyses offered no evidence that the linear or quadratic effects of attention depended on face ethnicity. Across all behavioral measures, the degree to which attention improved recognition (and the degree of nonlinearity) was comparable for White and Black faces.

Study 2

Study 2 represents a confirmatory test of nonlinear relationships between eye gaze and recognition, documented in Study 1.

Method

Design and Power

The design was identical to Study 1. Applying simr (Green & MacLeod, 2016) to the data from Study 1, we estimated the power to detect (a) the quadratic relationship between fixations to the eyes and recognition. The analysis suggested that a replication of Study 1 with 60 participants would yield a power of .99, 95% CI [0.946, 0.999]. With 60 participants, we also estimated power to detect the interaction between extra attention and face ethnicity at .81, 95% CI [71.93, 88.16], for an interaction of $b = .05$. A supplemental post hoc sensitivity analysis suggested we had power of .80 to detect a quadratic effect of $b = .0106$ and power of .81 to detect an interaction of $b = .04$.

Participants

A total of 59 White undergraduates (43 females, 15 males, one nonbinary, $M_{\text{age}} = 19.19$ years, $SD = 0.97$) participated in partial fulfillment of a class requirement. As in Study 1, non-White participants (seven Asian, six Latinx, one Middle Eastern) were excluded because the study requires a clear racial ingroup to which outgroup recognition can be compared. We also excluded two participants who identified as both Black and White because both groups of faces could be perceived as ingroup members and three participants who identified as Black because the sample is too small to analyze.

Stimuli, Apparatus, and Procedure

The stimuli, apparatus, and procedure were identical to Study 1 with the following exceptions. In conjunction with the collection of these data, we collected a small sample of data from participants who, in a previous study, had been identified as extremely accurate in cross-category recognition. We ultimately hope to compare these high performers to more typical participants (the current data) on a range of measures, including categorization and outgroup contact. Accordingly, after completing the recognition task, these participants completed several additional measures. We have not yet analyzed the ancillary measures nor have we analyzed data from the high-performing sample.

Results

Analysis of Eye Gaze Behaviors

We again assessed fixations and dwell time to each of three features (e.g., eyes, nose, and mouth), the total number of fixations, and the total distance traveled by the perceiver's gaze. The process was identical to Study 1.

As in Study 1, we examined whether the ethnicity of an encoding face affected the behavioral measures using linear mixed-effects models in which we estimated the fixed effect of face ethnicity, allowing for random intercepts for both perceiver and face and random face-ethnicity slopes for each perceiver (when possible).[5] The means and standard deviations are presented in Table 4.

The results partially replicated Study 1. The White perceivers typically performed more fixations to the eyes of White (rather than Black) faces, $\hat{\beta} = 0.18$, 95% CI [0.03, 0.33], $t(40.49) = 2.36$, $p = .023$, $\eta_p^2 = .0037$, but performed more fixations to the mouths of Black (rather than White) faces, $\hat{\beta} = -0.13$, 95% CI [−0.25, −0.02], $t(61.24) = -2.31$, $p = .024$, $\eta_p^2 = .0021$. Fixations to the nose did not vary significantly as a function of face ethnicity, $\hat{\beta} = 0.00$, 95% CI [−0.15, 0.16], $t(62.49) = 0.06$, $p = .956$, $\eta_p^2 = -.0000$. The perceivers also dwelled for a marginally longer time on the mouth of Black faces, $\hat{\beta} = -0.05$, 95% CI [−0.10, 0.01], $t(60.85) = -1.72$, $p = .090$, $\eta_p^2 = .0013$, but we found no evidence for differences in dwell time to the eyes or nose, $\hat{\beta} = 0.02$, 95% CI [−0.04, 0.09], $t(60.89) = 0.75$, $p = .458$, $\eta_p^2 = .0003$ and $\hat{\beta} = 0.00$, 95% CI [−0.05, 0.05], $t(49.53) = 0.07$, $p = .948$, $\eta_p^2 = .0000$, respectively.

Analysis of Recognition

Quantification of the Criterion Variable. We computed a corrected recognition score, as in Study 1. This represents the degree to which a participant's rating for a given encoded face was higher than the participant's average rating of a never-before-seen face of the same ethnicity.

Effect of Ethnicity on Recognition. We again tested the CRD using a mixed-effects model to estimate corrected recognition as a function of the ethnicity of the face, allowing random intercepts for each participant and stimulus, and a random ethnicity slope for each participant. There was evidence of the CRD, $\hat{\beta} = 0.26$, 95% CI [0.11,

[5] The models for fixations to the mouth and dwell time to the eyes and mouth showed singular fit when the random slopes were included. These models were reestimated with only random intercepts for both perceiver and face. The model for distance showed singular fit due to the random intercept for face, so that model only included random effects for perceiver.

Table 4
Means and Standard Deviations of Behavioral Measures, Study 2

Measure	Overall *M*	Overall *SD*	Black *M*	Black *SD*	White *M*	White *SD*
Eyes: Fixations	6.76	3.68	6.58	3.66	6.93	3.69
Eyes: Time (s)	2.30	1.41	2.28	1.43	2.32	1.38
Nose: Fixations	4.76	3.10	4.76	3.04	4.76	3.15
Nose: Time (s)	1.63	1.06	1.63	1.06	1.63	1.06
Mouth: Fixations	4.17	2.86	4.30	2.89	4.03	2.82
Mouth: Time (s)	1.51	1.32	1.55	1.33	1.46	1.31

0.40], $t(72.36) = 3.44$, $p < .001$, $\eta_p^2 = .0208$. The (White) perceivers more successfully recognized White faces than Black faces.

Effect of Eye Gaze Behavior on Recognition.

Fixations to the Eyes. Considering participant mean-centered fixations to the eyes as a measure of attention, we found no meaningful evidence that increasing attention was associated with improved recognition, $\hat{\beta} = -0.01$, 95% CI [−0.03, 0.02], $t(1804.84) = -0.44$, $p = .660$, $\eta_p^2 = -.0002$. Given a typical level of attention, then, a small change in attention had no significant effect. As in Study 1, we observed a quadratic effect, $\hat{\beta} = -0.01$, 95% [−0.02, −0.01], $t(1756.37) = -3.92$, $p < .001$, $\eta_p^2 = .0146$, such that the incremental effect of additional attention weakened as baseline attention increased. A test of the simple linear effect at a point 1 *SD* below the participant's mean was not significant, $\hat{\beta} = 0.03$, 95% CI [−0.02, 0.08], $t(1821.53) = 1.30$, $p = .193$, $\eta_p^2 = .0063$. As in Study 1, the interactions between face ethnicity and (a) the linear and (b) the quadratic effect were not significant, though both effects were approaching significance (which was not the case in Study 1), $\hat{\beta} = 0.02$, 95% CI [0.00, 0.05], $t(1791.41) = 1.68$, $p = .092$, $\eta_p^2 = .0023$ and $\hat{\beta} = 0.00$, 95% CI [−0.01, 0.00], $t(1068.21) = -1.55$, $p = .122$, $\eta_p^2 = .0023$, respectively. The lack of significance again suggests that the rate (and change in rate) of learning via fixations to the eyes were similar for White and Black faces. This is notable because, overall, the data still show clear evidence of the CRD. The results of this (and the analyses below) are reflected in Table 5 and Figure 4.

Dwell Time to the Eyes. Considering dwell time to the eyes, the primary analysis (with extra attention centered at the participant mean) showed a *negative* linear effect, $\hat{\beta} = -0.11$, 95% CI [−0.18, −0.04], $t(1797.40) = -3.13$, $p = .002$, $\eta_p^2 = .0044$, suggesting that, at typical levels of baseline attention, an increase in attention is associated with worse recognition. We again observed a quadratic effect, $\hat{\beta} = -0.04$, 95% CI [−0.07, 0.00], $t(1786.02) = -1.97$, $p = .049$, $\eta_p^2 = .0051$, suggesting that the benefit of additional attention decreased as baseline attention increased. When baseline attention was low (1 *SD* below the participant's mean), the linear effect of extra attention was not significant, $\hat{\beta} = -0.15$, 95% CI [−0.27, −0.02], $t(1835.41) = -2.33$, $p = .020$, $\eta_p^2 = -.0003$. An interaction of face ethnicity and the linear effect of extra attention suggested that the negative impact of extra dwell time on the eyes was especially pronounced for Black faces, $\hat{\beta} = 0.08$, 95% CI [0.01, 0.15], $t(1775.20) = 2.19$, $p = .029$, $\eta_p^2 = .0021$. The interaction of face ethnicity and the quadratic was not significant, $\hat{\beta} = -0.01$, 95% CI [−0.05, 0.02], $t(1190.80) = -0.71$, $p = .476$, $\eta_p^2 = .0011$, respectively.

Fixations to the Nose. For fixations to the nose, in the mean-centered model, we again observed a simple positive linear relationship between extra attention and recognition, though the effect was marginal, $\hat{\beta} = 0.03$, 95% CI [0.00, 0.07], $t(1815.04) = 1.77$, $p = .077$, $\eta_p^2 = .0022$. The quadratic effect was not significant, but somewhat strangely, it was directionally positive, $\hat{\beta} = 0.00$, 95% CI [−0.01, 0.01], $t(1823.75) = 0.72$, $p = .473$, $\eta_p^2 = -.0001$. This is the only test of the quadratic that actually yields a positive estimate. When baseline attention was low (1 *SD* below the participant's mean), the linear relationship was not significant, $\hat{\beta} = 0.01$, 95% CI [−0.05, 0.08], $t(1806.80) = 0.41$, $p = .681$, $\eta_p^2 = -.0002$. As usual, there was no meaningful evidence that the simple linear effect or the quadratic depended on face ethnicity, $\hat{\beta} = 0.01$, 95% CI [−0.03, 0.04], $t(1804.57) = 0.36$, $p = .718$, $\eta_p^2 = .0001$ and $\hat{\beta} = 0.00$, 95% CI [−0.01, 0.01], $t(1792.43) = 0.20$, $p = .842$, $\eta_p^2 = -.0000$, respectively.

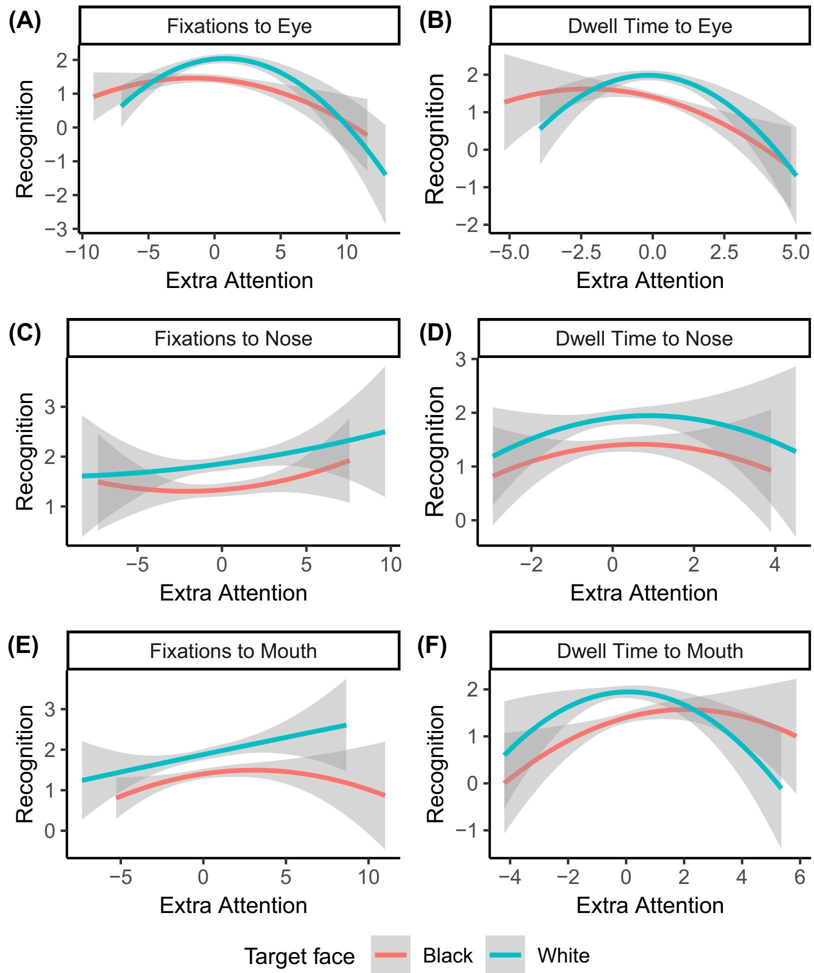
Dwell Time to the Nose. As in Study 1, the mean-centered analysis of dwell time to the nose showed neither a simple linear effect, $\hat{\beta} = 0.03$, 95% CI [−0.07, 0.13], $t(1822.64) = 0.60$, $p = .551$, $\eta_p^2 = .0008$, nor a quadratic, $\hat{\beta} = -0.01$, 95% CI [−0.06, 0.05], $t(1830.78) = -0.18$, $p = .860$, $\eta_p^2 = .0004$. When baseline attention was low (1 *SD* below the participant's mean), the linear relationship remained nonsignificant, $\hat{\beta} = 0.04$, 95% CI [−0.13, 0.20], $t(1824.37) = 0.43$, $p = .666$, $\eta_p^2 = .0006$. And again, there was no indication that the ethnicity

Table 5
Statistics (t and p) Testing Linear and Quadratic Effects of Extra Attention on Recognition as Well as the Interaction of Extra Attention and Between-Participant Variation, Study 2

Behavioral measure	Linear *t*	Linear *p*	Quadratic *t*	Quadratic *p*	*L* × FaceEth *t*	*L* × FaceEth *p*	*Q* × FaceEth *t*	*Q* × FaceEth *p*
Fixations: Eyes	1.30	0.19	−3.92	0.00	1.68	0.09	−1.55	0.12
Dwell time: Eyes	−2.33	0.02	−1.97	0.05	2.19	0.03	−0.71	0.48
Fixations: Nose	0.41	0.68	0.72	0.47	0.36	0.72	0.20	0.84
Dwell time: Nose	0.43	0.67	−0.18	0.86	0.16	0.87	0.56	0.58
Fixations: Mouth	3.09	0.00	−1.22	0.22	0.39	0.70	0.96	0.34
Dwell time: Mouth	2.48	0.01	−1.95	0.05	−1.83	0.07	−0.37	0.71

Note. The linear effect estimates the line tangent to the curve 1 *SD* below the participant's mean level of attention.

Figure 4
Quadratic Effects of Extra Attention, Study 2



Note. Predicted recognition as a function of target face ethnicity and linear and quadratic effects of attention, as measured by fixations to the eyes (A), dwell time to the eyes (B), fixations to the nose (C), dwell time to the nose (D), fixations to the mouth (E), and dwell time to the mouth (F). See the online article for the color version of this figure.

of the face moderated the linear or quadratic effects, $\hat{\beta} = 0.01$, 95% CI [−0.09, 0.10], $t(1818.08) = 0.16$, $p = .870$, $\eta_p^2 = .0001$ and $\hat{\beta} = 0.02$, 95% CI [−0.04, 0.07], $t(1456.21) = 0.56$, $p = .578$, $\eta_p^2 = -.0002$, respectively.

Fixations to the Mouth. The mean-centered analysis of fixations to the mouth showed a positive simple linear effect, $\hat{\beta} = 0.07$, 95% CI [0.04, 0.11], $t(1801.70) = 3.91$, $p < .001$, $\eta_p^2 = .0080$, and a nonsignificant (but negative) quadratic effect, $\hat{\beta} = -0.01$, 95% CI [−0.02, 0.00], $t(1817.93) = -1.22$, $p = .223$, $\eta_p^2 = .0017$. When attention was low, the benefit of additional attention remained significant, $\hat{\beta} = 0.10$, 95% CI [0.04, 0.16], $t(1810.44) = 3.09$, $p = .002$, $\eta_p^2 = .0018$. Once again, there was no significant interaction between face ethnicity and either the linear or quadratic effects, $\hat{\beta} = 0.01$, 95% CI [−0.03, 0.04], $t(1806.32) = 0.39$, $p = .695$, $\eta_p^2 = .0001$ and $\hat{\beta} = 0.00$, 95% CI [0.00, 0.01], $t(1323.84) = 0.96$, $p = .338$, $\eta_p^2 = .0003$, respectively.

Dwell Time to the Mouth. The mean-centered analysis of dwell time to the mouth yielded a positive simple linear effect of extra attention, $\hat{\beta} = 0.08$, 95% CI [−0.01, 0.16], $t(1833.33) = 1.80$, $p = .071$, $\eta_p^2 = .0028$, and a marginal negative quadratic effect, indicating negative acceleration, $\hat{\beta} = -0.04$, 95% CI [−0.07, 0.00], $t(1753.08) = -1.95$, $p = .052$, $\eta_p^2 = .0059$. As expected, when baseline attention was low (1 *SD* below the participant's mean), the linear relationship between additional attention and recognition remained significant, $\hat{\beta} = 0.17$, 95% CI [0.04, 0.31], $t(1822.09) = 2.48$, $p = .013$, $\eta_p^2 = .0039$. The interaction of face ethnicity and the linear effect was marginal, $\hat{\beta} = -0.08$, 95% CI [−0.16, 0.01], $t(1796.35) = -1.83$, $p = .068$, $\eta_p^2 = .0001$, but it suggested that the benefit of additional attention was greater when viewing Black faces rather than White faces. The interaction between face ethnicity and the quadratic effect was not significant, $\hat{\beta} = -0.01$, 95% CI [−0.04, 0.03], $t(782.77) = -0.37$, $p = .711$, $\eta_p^2 = .0003$, respectively.

Discussion

We again observed negative quadratic effects, especially for the eyes. In conjunction with Study 1, the results suggest that nonlinear effects may be fairly common. Though nonlinearity was not always significant, in 11 of 12 tests across both studies, the direction of curvature was negative. As in Study 1, we also found partial support for the idea that, when the baseline is low, attention to a feature aids recognition. Finally, we found little evidence that the relationship between attention and recognition depended on the ethnicity of the face. A significant interaction emerged in one of the six tests. Although the White participants recognized White faces more accurately than Black faces, in general, attention impacted recognition similarly for ingroup and outgroup faces.

Study 3

In Studies 1 and 2, the consequences of attention to any one feature, say the eyes, may be influenced by attention to other aspects of the face. For example, a perceiver might fixate on the eyes four times on Trial 1 and five times on Trial 2. In estimating the effect of the additional fixation for Trial 2, our analysis does not account for what *else* the perceiver looked at on each trial. Does additional attention to the nose alter the benefit of each fixation to the eye? Unfortunately, simultaneously estimating simple effects of attention to each feature and all interactions presents challenges for both computation and interpretation. But this ambiguity makes it hard to draw strong conclusions about the effects of, say, one additional unit of attention.

Rather than measuring eye gaze, Study 3 manipulated exposure, with discrete trials that presented either the eyes of the face or the nose and mouth of the face (combined). Because the study controls what information the perceiver sees, the analysis improves internal validity (with a corresponding reduction in external validity, based on the more artificial stimuli). Again, we predict that increasing attention to a feature confers greater benefit when the baseline attention to that feature is low but less benefit when the baseline is high. Within the context of this curvilinear pattern, we also test the linear benefit of attention when the baseline is low and the effect of face ethnicity on the relationship between attention and recognition. Study 3 also included both White and Black participants, allowing us to examine whether the effects of attention differ as a function of participant ethnicity.

Method

Design and Power

Participants completed a modified encode-recognition task. During the encoding phase, they viewed constrained portions of each face: either a portion that included the eyes and eyebrows or a portion that included the nose and mouth. For each encoding face, participants viewed a total of four images, and we varied the number of eye portions (vs. nose-and-mouth portions). On some trials, the eyes were presented zero times (and the nose and mouth were presented four times), on other trials, the eyes were presented one, two, three, or four times (and nose-and-mouth were presented three, two, one, and zero times, respectively). In a full ingroup–outgroup design, participants who identified as either Black or White viewed the faces of models who identified as either Black or White. This study employed a 2 (participant ethnicity: Black vs. White) × 2 (face ethnicity: Black vs. White) × 5 (eye presentations: zero, one, two, three, or four) design. We sampled as many participants and faces as was practical and economically feasible. A sensitivity analysis suggested we had power of .81 to detect a quadratic effect of b = .042 and power of .80 to detect an interaction between extra attention, face ethnicity, and perceiver ethnicity of b = .062. (Note that the slopes in this study involve the number of stimulus presentations, each with a duration of 1 s. This is a very different metric than fixations, so the raw effect sizes differ dramatically.)

Participants

A total of 61 Black and 89 White participants (80 females, 67 males, three nonbinary, M_{age} = 39.59 years, SD = 13.19) were recruited from Prolific and participated online in return for $2. An additional group of participants who identified as something other than Black or White or who identified as both Black and White were excluded (one Latinx, one Middle Eastern, three identified as both Black and White).

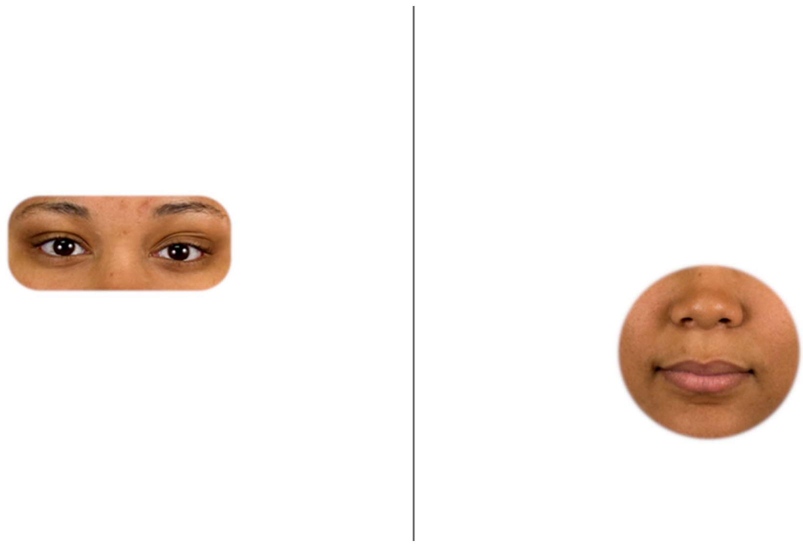
Stimuli

We selected 32 White and 32 Black faces from the CFD. Each face was cropped twice to create the encoding stimuli. To create eye stimuli, we cropped the image to a rounded rectangle including the eyes and eyebrows of each face. To create nose-and-mouth stimuli, we cropped the image to a circle including the nose and mouth (see Figure 5). The stimuli presented at test included the complete, unedited, full-color faces.

Procedure

Participants were routed to a Qualtrics site where they read an online consent form and indicated agreement. They then received written instructions stating that they would view different portions of 32 faces and that they should attempt to remember each face. They then began the encoding phase, during which they viewed images of the eyes or nose-and-mouth of 16 Black and 16 White faces. Each trial began with a prompt instructing the participant to remember the face. After the perceiver pressed a button to continue, a fixation cross appeared for 1 s followed by four 1-s exposure of portions of the encoding face (the entire face was never shown). Each exposure presented either the eyes of the face or the nose and mouth of the face. The set of to-be-remembered faces and the number of eye presentations for each face were determined in advance. The set of 64 faces was initially split into two groups, Set A and Set B, with 16 Black and 16 White faces in each group. The number of eye exposures was randomly determined for each face with the following constraints. To maximize power and reduce the length of the task, four faces were assigned to each of the exposure conditions that are critical for testing the linear and quadratic effects: zero, two, and four eye exposures. Because they contribute less to the study's power to detect linear and quadratic effects, only two faces were assigned to the remaining exposure conditions: one and three eye exposures. Further, the order of exposures was constrained to maximize the number of transitions between the eye portion and the nose-and-mouth portion. So, for a trial that involved a 3-1 combination, the order was always ABAA. For trials involving two eye exposures and two nose-and-mouth exposures, the order was

Figure 5
Example Stimuli, Study 3



Note. From "The Chicago Face Database: A Free Stimulus Set of Faces and Norming Data," by D. S. Ma, J. Correll, & B. Wittenbrink, 2015, *Behavior Research Methods*, *47*, pp. 1122–1135 (https://doi.org/10.3758/s13428-014-0532-5). See the online article for the color version of this figure.

counterbalanced (ABAB and BABA). This entire process (splitting the faces and assigning a different number of exposures to each) was then performed a second time to yield Set C and Set D, creating a total of four different sets of encoding faces (along with their predetermined number of eye exposures). Once randomly assigned to a particular set, the order of encoding faces was randomly determined for each participant.

After the encoding phase, participants completed a short demographic questionnaire and proceeded to the recognition phase. During recognition, they viewed all 64 unedited faces (i.e., they saw the entire face, not just the eyes or nose-and-mouth) in a random order. They indicated their recognition (and confidence) on the same 6-point scale used in Studies 1 and 2.

Results

Analysis of Recognition

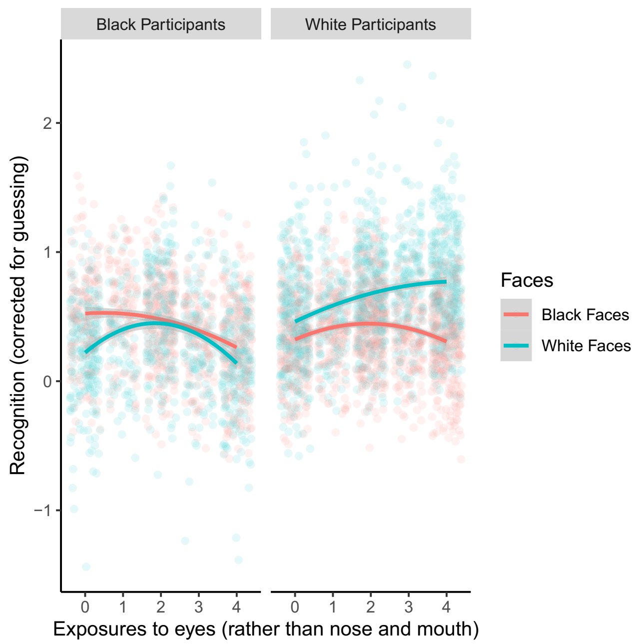
Quantification of the Criterion Variable. We computed a corrected recognition score, as in Studies 1 and 2. Again, this score represents the degree to which a participant's rating for a given encoded face was higher than the participant's average rating of a never-before-seen face of the same ethnicity.

Effects of Ethnicity on Recognition. We tested the CRD using a mixed-effects model to estimate corrected recognition as a function of participant ethnicity, face ethnicity, and their interaction, allowing random intercepts for each participant and stimulus, and a random face-ethnicity slope for each participant. (A model that also included a random perceiver-ethnicity slope for each face failed to converge.) This model also controlled for the set of faces that participants were randomly assigned to learn during the encoding phase. We also tested models in which the effects of interest were allowed to interact with set. This yields nine additional interactions, none of which were significant. We will therefore focus on the simpler models, which only control for set.

We observed clear evidence of the CRD, tested by the interaction of perceiver ethnicity and face ethnicity, $\hat{\beta} = 0.10$, 95% CI [0.04, 0.16], $t(143.37) = 3.43$, $p < .001$, $\eta_p^2 = .0042$. Perceivers who identified as White more successfully recognized White faces than Black faces, $\hat{\beta} = 0.13$, 95% CI [0.04, 0.23], $t(110.64) = 2.86$, $p = .005$, $\eta_p^2 = .0049$. Perceivers who identified as Black recognized Black faces slightly, but not significantly, better than White faces, $\hat{\beta} = -0.06$, 95% CI [−0.17, 0.04], $t(137.14) = -1.16$, $p = .246$, $\eta_p^2 = .0009$. We also observed an unexpected main effect of participant ethnicity, such that White perceivers had higher recognition scores than Black perceivers, $\hat{\beta} = 0.08$, 95% CI [0.00, 0.15], $t(144.94) = 2.07$, $p = .040$, $\eta_p^2 = .0025$. Finally, there was marginal evidence that the faces in Set D yielded greater accuracy than the faces in Set C, $\hat{\beta} = 0.10$, 95% CI [−0.01, 0.22], $t(209.54) = 1.82$, $p = .071$, $\eta_p^2 = .0015$. No other effects approached significance.

Effects of Eye Presentations on Recognition. We next examined recognition as a function of perceiver ethnicity, face ethnicity, and the number of times the eyes (rather than the nose and mouth) were presented on a given trial. In the primary model, we centered the number of eye fixations. To examine nonlinear relationships between encoding time and recognition, we allowed for the quadratic effect of the number of eye presentations. Accordingly, the simple linear effect of eye fixations in this model estimates the line tangent to the curve when a participant saw two eye presentations (and two nose/mouth presentations). The linear mixed models also allowed for random intercepts for each participant and each face, as well as a random target-ethnicity slope for each participant. Again, we controlled for the set of encoding faces. A model that tested for all 33 possible interactions with encoding set yielded only one significant result, which we view as a Type I error (and which does not alter the conclusions below).

Figure 6
Relationship Between Exposure to Eyes (vs. Nose and Mouth) and Recognition, Study 3



Note. See the online article for the color version of this figure.

The results are presented in Figure 6. The main analysis, with eye fixations centered at its mean, did not yield clear evidence of a simple linear relationship between eye presentations (vs. nose-and-mouth presentations) and recognition, $\hat{\beta} = -0.01$, 95% CI [−0.05, 0.02], $t(377.44) = -0.74$, $p = .460$, $\eta_p^2 = -.0001$. In other words, for a participant who saw two presentations of the eyes and two presentations of the mouth and nose, one additional fixation (of either stimulus) did not change performance. However, we observed evidence that the relationship between eye presentations and recognition was nonlinear, $\hat{\beta} = 0.08$, 95% CI [0.03, 0.12], $t(572.94) = 3.36$, $p < .001$, $\eta_p^2 = .0014$. The significant quadratic effect again indicated the predicted negative acceleration. Accordingly, we tested the simple linear effect of eye fixations at both low and high levels. First, we recentered eye fixations at zero and fit the corresponding model, allowing for quadratic effects. In this model, the linear effect tests the benefit of one eye fixation for a participant who would otherwise never see the eyes (and see only the nose and mouth). The linear effect was significant and positive, $\hat{\beta} = 0.19$, 95% CI [0.06, 0.32], $t(550.76) = 2.81$, $p = .005$, $\eta_p^2 = .0183$, indicating that a single presentation was predicted to improve recognition by 0.19 points. Second, we recentered fixations at four and refit the model. In this case, we focused our test on a participant who saw the eyes four times (and never saw the mouth and nose). The simple linear effect estimates the benefit of *reducing* the number of eye presentations to three (and thus presenting the nose and mouth once). This effect was also significant, $\hat{\beta} = -0.21$, 95% CI [−0.34, −0.09], $t(589.93) = -3.34$, $p < .001$, $\eta_p^2 = .0173$. Here, the negative effect suggests that, as eye presentations decrease by one, recognition improves by .21 points.

Another critical question involves the degree to which participants used the visual information differently for ingroup versus outgroup faces. These questions are tested by the interactions of eye fixation conditions with both perceiver ethnicity and face ethnicity. Neither interaction was significant, linear: $\hat{\beta} = 0.01$, 95% CI [−0.02, 0.04], $t(3986.19) = 0.59$, $p = .553$, $\eta_p^2 = .0001$ and quadratic: $\hat{\beta} = -0.02$, 95% CI [−0.06, 0.01], $t(3963.85) = -1.26$, $p = .209$, $\eta_p^2 = .0004$. In line with the results of both Studies 1 and 2, these tests offer no evidence that the effects of visual information on learning did not differ systematically for ingroup and outgroup faces. However, we observed an interaction between participant ethnicity and the linear effect of eye presentations, $\hat{\beta} = 0.04$, 95% CI [0.01, 0.07], $t(3994.14) = 2.65$, $p = .008$, $\eta_p^2 = .0014$. The linear slope was nonsignificantly positive for White participants, indicating trivially greater accuracy when exposed more frequently to the eyes, $\hat{\beta} = 0.03$, 95% CI [−0.02, 0.07], $t(667.62) = 1.14$, $p = .255$, $\eta_p^2 = .0008$. By contrast, the linear slope was negative for Black perceivers, indicating greater accuracy when exposed more frequently to the nose and mouth (rather than the eyes), $\hat{\beta} = -0.05$, 95% CI [−0.10, 0.00], $t(1068.55) = -1.94$, $p = .053$, $\eta_p^2 = .0005$. Critically, this effect involves only perceiver ethnicity, and it is not further moderated by the ethnicity of the face. Other than the simple effect of participant ethnicity, the interaction testing the CRD, and the marginal effect of set, which were discussed above and which also emerged in this model, no other effects approached significance.

Discussion

Study 3 presented faces for a total of 4 s, manipulating exposure to the eyes versus nose-and-mouth. We observed clear nonlinear effects. As exposure to the eyes increased from 0 to 1 s, recognition accuracy increased; as exposure increased further, the benefit attenuated. These data can also be considered relative to the number of exposures to nose-and-mouth, increasing from 0 to 4 s, with the same conclusions. This study demonstrates a negatively accelerating pattern. It also demonstrates the benefit of additional exposure to either subset of features when baseline attention is low.

Again, we observed no evidence that the effects of attention differed for ingroup and outgroup faces. Perceivers benefited from visual information in similar ways when viewing both ingroup and outgroup faces.

The data revealed an interesting effect of perceiver ethnicity. Participants who identified as Black benefited more from exposure to the mouth and nose, whereas participants who identified as White tended to benefit more (in relative terms) from exposure to the eyes. This effect was not moderated by the ethnicity of the face. The pattern is evocative of arguments that culture influences the way perceivers tend to encode faces (cf. Blais et al., 2008, see Supplemental Material).

Mega-Analysis

To provide a higher power test, we conducted a mega-analysis to address our three primary questions. First, is the relationship between attention and recognition nonlinear? Second, when baseline attention is low, is there a beneficial effect of additional attention? Third, does the relationship between attention and recognition differ for ingroup and outgroup faces?

Method

Data from the studies were combined. We treated the Black-participant and White-participant groups in Study 3 as separate samples. The analysis predicts recognition as a function of the ethnicity of the target (ingroup vs. outgroup), visual attention (linear and quadratic), and their interaction. It is important to note that, for Studies 1 and 2, differences in visual attention were measured, whereas in Study 3, we manipulated exposure duration and infer that longer exposure affords more extensive attention. Because the various operationalizations of attention (e.g., fixations and dwell time in Studies 1 and 2, number of stimulus presentations in Study 3) have different scaling, the Extra.Attn index was standardized before aggregating the data, and the quadratic term was recomputed.

These analyses combine tests in which several measures of attention each predict a common outcome variable. For example, in Study 1, fixations to the nose and dwell time to the eyes both predict the same recognition data. To accommodate this dependence, we allowed random intercepts for each study and for each participant nested within the sample. Crossed with these, we allowed random intercepts for each stimulus. The ethnicity of the face was coded as a fixed factor in terms of its ingroup–outgroup status. This factor was allowed to interact with the linear and quadratic effects. We also treated type of behavioral measure (fixations vs. dwell time) and feature (eyes, nose, and mouth for Studies 1 and 2; "eyes vs. nose and mouth" for Study 3) as fixed factors. We did not allow interactions with these factors in our primary model, but models that do so reveal only sporadic evidence of moderation that does not alter our basic conclusions. Those supplemental analyses will be discussed whenever relevant.

Results

Concerning our first question, the results suggest that, across studies and measures of attention, there is a pronounced negative curvilinear relationship between attention and recognition, $\hat{\beta} = -0.04$, 95% CI [−0.05, −0.03], $t(23321.49) = -6.35$, $p < .001$, $\eta_p^2 = .0033$. In a supplemental model that allowed the curvature to depend on feature, we found evidence that negative acceleration was more pronounced for the eyes, but even for the nose and mouth, the relationship was significantly nonlinear, $\hat{\beta} = -0.03$, 95% CI [−0.04, −0.01], $t(23132.53) = -3.76$, $p = .001$, $\eta_p^2 = .0011$.

To address the second question, we modified the Study 3 data. Specifically, we included both (a) the simple linear effect of additional attention to the eyes (rather than nose-and-mouth) when baseline attention to the eyes was low and (b) the simple linear effect of additional attention to nose-and-mouth (rather than the eyes) when baseline attention to nose-and-mouth was low. In essence, we estimated the tangent to the curve at two points to capture the benefit of increased attention to either feature. On average, across studies and behavioral measures, when baseline attention to a given feature was low, additional attention improved recognition, $\hat{\beta} = 0.11$, 95% CI [0.07, 0.14], $t(27532.98) = 6.25$, $p < .001$, $\eta_p^2 = .0025$. A supplemental model that examined whether this relationship depended on feature revealed some evidence of variation, but even for the eyes (which showed the weakest effect), the simple linear effect was significant, $\hat{\beta} = 0.15$, 95% CI [0.07, 0.23], $t(20501.32) = 3.80$, $p < .001$, $\eta_p^2 = .0005$.

Finally, concerning the third question, the results offered little reason to believe that the effects of additional attention differ for ingroup and outgroup faces. The linear effect was trivially (nonsignificantly) more positive for ingroup than outgroup faces, $\hat{\beta} = 0.02$, 95% CI [0.00, 0.04], $t(23075.01) = 1.50$, $p = .135$, $\eta_p^2 = .0001$, and the quadratic effect was trivially (nonsignificantly) more negative for ingroup than outgroup faces, $\hat{\beta} = -0.01$, 95% CI [−0.02, 0.00], $t(23067.74) = -1.22$, $p = .222$, $\eta_p^2 = .0001$. Even in this combined analysis, aggregating 250 participants and multiple tests, face ethnicity did not moderate either effect.

General Discussion

We report an exploratory eye-tracking study, a confirmatory eye-tracking study, an experimental manipulation of exposure to facial features, and a mega-analytic integration of the three studies. Results show that the relationship between attention and face recognition is generally nonlinear. The pattern may be particularly strong for attention to the eyes. Allowing for this nonlinearity, we can test theoretically important questions.

The introduction discussed three considerations relevant to the relationship between attention and recognition. These studies yield fairly clear conclusions regarding each consideration. *Differential encoding* refers to the idea that gaze patterns differ for ingroup and outgroup faces. In Studies 1 and 2, White participants showed differential encoding behaviors, consistent with prior work. They devoted greater attention to the eyes of ingroup/White faces and greater attention to the mouths of outgroup/Black faces. (Differential encoding could not be tested in Study 3.) *Effective behavior* concerns the capacity of a particular behavior to improve recognition. These data show that attention to central features (eyes, nose, and mouth) tends to enhance recognition (for similar ideas, see Correll, Ma, et al., 2024; Gosselin & Schyns, 2001; Schyns et al., 2002). The caveat is that the relationship is curvilinear. The efficacy of a behavior is typically more evident when the baseline of that behavior is low. *Differentially effective behavior* involves the idea that an encoding behavior may have different effects for ingroup versus outgroup faces.

These studies offer virtually no support for this possibility (cf. Hills & Lewis, 2006). Only in the mega-analysis do we see the slightest (nonsignificant) hint that perceivers utilize information more effectively for the ingroup, which may support predictions based on perceptual expertise.

Nonlinearity and the Benefit of Additional Attention When Baseline Attention Is Low

Nonlinear effects of repetition have been extensively documented in other domains (Bornstein et al., 2012; Ebbinghaus, 1885/1964), but to our knowledge, this is the first demonstration in eye-tracking research.

Study 3 probably constitutes the strongest test of our nonlinearity hypothesis. Study 3's experimental manipulation of exposure to the eyes (vs. the nose and mouth) offered evidence that increasing exposure causes negative acceleration. In this study, participants' exposure to eyes, nose, and mouth was constrained. This reduces concerns about confounding variables, which may affect Studies 1 and 2.

It might be argued that nonlinearity emerged because our eye-tracking studies presented the faces for a relatively long period (7 s). But Study 3 involved only a 4-s presentation, and it revealed the same pattern. We also reanalyzed older unpublished data from our lab that involved a 5-s presentation and open-access eye-tracking data from other researchers. We consistently find evidence of nonlinearity.

These findings suggest that analytical models used in prior work may be misspecified. If nonlinearity was present in the data, but not accounted for in the analysis, previous work may have mischaracterized effects of attention and ethnicity, which may partially account for the confusing pattern of results reviewed in the introduction.

We found more pronounced nonlinearity for the eyes. The eyes provide information about more than identity. They signal intentions (Adams & Kleck, 2005; Macrae et al., 2002; Mason et al., 2004), mental states (Khalid et al., 2016; Looser & Wheatley, 2010), and emotions (Adams & Kleck, 2005; Baron-Cohen et al., 2001; Friesen et al., 2019; Niedenthal et al., 2010). Perceivers also utilize information gained from eye contact to navigate interpersonal dynamics (Hessels et al., 2019). Accordingly, perceivers may devote extensive attention to the eyes (see Tables 2 and 4). If they attend to the eyes because they seek information about the target's mental state, perceivers may obtain sufficient information for identification. Overattention to the eyes may lead to weaker linear effects and stronger quadratic effects.

Evidence of nonlinearity was weaker for measures of attention to the nose. Because the nose is located in the center of the face (proximal to eyes and mouth), attention to the nose may allow perceivers to encode multiple features and/or configural and holistic information (Caldara et al., 2010; Hsiao & Cottrell, 2008). Accordingly, the nose may not entail the same kind of trade-offs as the eyes and mouth. To be clear, with higher power tests (such as the mega-analysis), we would expect all measures of feature-specific attention to show diminishing returns, but the lack of inherent trade-offs may lead to more linear relationships between attention to the nose and recognition.

Comparable Effects of Attention to Ingroup Versus Outgroup

A perceptual expertise account suggests that perceivers more effectively encode individuating information from ingroup faces than from outgroup faces. Accordingly, one might predict that every additional fixation or additional second of dwell time to, say, the nose would yield a bigger payoff for ingroup than for outgroup faces.

To the contrary, our results suggest that attention has similar effects on recognition, regardless of face ethnicity. Even when we mega-analytically combined the results, we find no meaningful support for the idea that additional attention has different effects for ingroup and outgroup faces. These null effects are intriguing because, in these same data, we find a profound recognition advantage for the ingroup. How can it be true that (a) a given unit of attention (1 s or one fixation) yields the same benefit for ingroup and outgroup faces, but (b) recognition is better for ingroup faces across the board? One answer may involve differential encoding strategies. In general, participants process ingroup and outgroup faces differently. Perhaps they employ more effective behavior when encoding ingroup. In Studies 1 and 2, participants devoted greater attention to ingroup eyes, so this explanation would require that the benefit of attention to the eyes is greater than the benefit of attention to other features (at least when baseline attention is low). The simple slopes and mega-analysis, reported above, certainly do not support this argument. In fact, we find some evidence that attention to the eyes has a smaller standardized effect than attention to other features (a pattern that seems inconsistent with Kawakami et al., 2014; but see Correll & Hudson, 2020).

An alternative possibility comes from recent work, which estimates the informational value of different physical aspects of the face, such as the length of the nose or the width of the eyes (Correll, Ma, et al., 2024). This work suggests that the informational value communicated by different features is comparable for Black and White faces. This equivalence might account for the parallel effects for ingroup and outgroup faces in the present studies. Additional attention to features, which contain valuable information for both the ingroup and the outgroup, yields similar benefits. We suggest that the CRD may not depend simply on the extent of attention to features. It has been argued that the CRD reflects differences in the *integration* of visual information across features. For example, participants seem to process ingroup faces more holistically than outgroup faces (DeGutis et al., 2013), and event-related brain potential studies suggest that the N170 differs for ingroup and outgroup faces, though the nature of the effects depends on the participant's goals during encoding (e.g., Ito & Urland, 2005; Senholzi & Ito, 2013; Walker et al., 2008). The N170 seems to reflect the integration of visual/structural information about the face, which may require greater effort for unfamiliar (outgroup) faces. This kind of integrative processing may not be reflected in simple eye gaze behaviors. That is, dwell time and fixations may reasonably measure the degree to which features are encoded, but they may provide relatively little information about how the brain integrates that information after it is encoded. Two alternatives seem plausible.

One possibility is that more complex or more nuanced measures of eye gaze correspond to differences in higher order integrative processing that give rise to the CRD. For example, researchers have identified repetitive patterns of fixations during face encoding. A perceiver's gaze may start at the left eye, move to the right eye, then to the nose, then back to the right eye, and then to the mouth. These patterns may occur again and again, during a single trial or across trials. Chuk et al. (2014) used hidden Markov models, and our lab has begun to use multidimensional recurrence quantification analysis to identify complex patterns in face processing. These patterns may differ for ingroup and outgroup faces, and these differences may explain ingroup–outgroup differences in recognition. (Though these analyses seem promising, we have not yet found evidence that they can explain the CRD.)

A second possibility is that the kind of integrative, holistic processing associated with the CRD simply does not manifest itself in the behavior of the eyes. Eye gaze measures may provide valuable information about the extent of encoding, but researchers may require other measures (like the N170) to gauge subsequent processing.

Limitations

Table 6 details information, including potential limitations of this work. The most obvious issue involves the sampling of only two populations, people who identify as Black and people who identify as White. Though the CRD, as a phenomenon, characterizes many populations, replicating these mechanistic effects with other groups in other cultural settings, including settings that vary in cross-category contact, would be valuable (for a review of cultural variation, see Kawakami et al., 2022; for a review of contact and the CRD, see Singh et al., 2022). Another issue in the current work is that the same stimuli are presented both at encoding and test. It would ultimately be valuable to replicate these findings using

Table 6
Summary of Limitations

Dimension	Assessment
Internal validity	
Is the phenomenon diagnosed with experimental methods?	Yes. Studies 1 and 2 manipulated face ethnicity. Study 3 manipulated face ethnicity and exposure and sampled participants of varying ethnicity.
Is the phenomenon diagnosed with longitudinal methods?	No
Were the manipulations validated with manipulation checks, pretest data, or outcome data?	Outcome data. To manipulate the ethnic group of facial stimuli, we selected male Black and White faces from a normed database of faces, the Chicago Face Database (Ma et al., 2015). The fact that recognition was better for ingroup faces across all studies suggests this manipulation is valid. Regarding the exposure manipulation employed in Study 3, the clear nonlinear effects obtained in Study 3's outcome variable, replicating typical nonlinear effects of repetition on memory (Greene, 2008), as well as in Studies 1 and 2 suggest this manipulation was valid.
What possible artifacts were ruled out?	Studies 1 and 2 used grayscaled stimuli, minimizing the impact of low-level image characteristics on recognition. Study 3 presented full-color images, including complete, unedited faces at the test phase, which ruled out the possibility that these effects are limited to grayscale versus color photos. By presenting eyes and nose-to-mouth stimuli in the encoding phase, Study 3 ruled out the possibility that these effects apply only to a single feature. By manipulating exposure to discrete trials that presented either the eyes of the face or the nose and mouth of the face (combined), Study 3 ruled out the possibility that these effects only emerge when perceivers can flexibly trade-off between features. The inclusion of White and Black participants in Study 3 shows that our effects were not exclusive to White participants and eliminates the confound between ingroup and outgroup status and face ethnicity.
Statistical validity	
Was the statistical power at least 80%?	Analyses using the R package simr (Green & MacLeod, 2016) suggested we had a power of .79 to detect a quadratic effect of $b = .013$ and a power of .84 to detect an interaction between linear attention and face ethnicity with $b = .057$.
Was the reliability of the dependent measure established in this publication or elsewhere in the literature?	The recognition measure, tested in the current data, had reliability >.795 in all studies. The eye-tracking measures' reliability is tested in Ehinger et al. (2019).
Generalizability to different methods	
Were different experimental manipulations used?	Studies 1 and 2 presented full grayscale faces and measured natural viewing using eye-tracking. Study 3 manipulated the presentation of full-color face portions (eyes and nose–mouth).
Were different images used during encoding and test?	Studies 1 and 2 presented the same full grayscale faces at encoding and testing. In Study 3, we presented full-color face portions at encoding and complete full-color faces at test.
Generalizability to field settings	
Was the phenomenon assessed in a field setting?	No, our designs were best suited for controlled settings to maximize internal validity.
Are the methods artificial?	Yes, the methods were designed to prioritize experimental control, sacrificing external validity.
Generalizability to times and populations	
Are the results generalizable to different years and historic periods?	Our studies cannot speak to this question. We can only speculate. The CRD has been intensively studied for over 50 years. Meta-analyses (Bothwell et al., 1989; Meissner & Brigham, 2001; Lee & Penrod, 2022) suggest that, though robust, the CRD may be declining. The smallest effect size was reported in the most recent and largest meta-analysis by Lee and Penrod (2022). Given ethnic integration worldwide and in the United States in particular, these results may not generalize to different years and historic periods.
Are the results generalizable across populations?	Our studies aimed to test broad, theory-driven ideas about nonlinear relationships between eye gaze and the recognition of ethnic ingroup and outgroup faces. However, our experimental operationalizations were limited to Black and White faces selected from an American database. The study participants were Black and White individuals from the United States. Due to this reliance on American participants and stimuli, caution is warranted when generalizing the findings to other cultures.
Theoretical limitations	
What are the main theoretical limitations?	The present studies examined self-identified White and Black perceivers. The results may not generalize to other intergroup scenarios. It also seems important to examine whether interracial contact impacts eye gaze patterns and/or the relationship between eye gaze and memory.

Note. CRD = cross-category recognition deficit.

different test stimuli (to ensure that participants were recognizing faces rather than images). The current work focuses on ethnicity as a basis for defining groups. It would be interesting to examine these effects with groups based on gender or age or coalition (Rhodes & Anastasi, 2012; Wright & Sladden, 2003).

Conclusions

These studies demonstrate a powerful and (to our knowledge) hitherto undocumented pattern of negative acceleration in the relationship between eye-tracking measures of attention and recognition accuracy. This pattern emerges in several independent tests and in a mega-analysis. In models that allow for this nonlinearity, we also see that, when the baseline is low, additional attention to central features is generally beneficial for recognition. This analysis may resolve inconsistent findings in the literature. We also see that the benefit gleaned per unit of attention is roughly comparable for ingroup and outgroup faces, which has consequences for theories of perceptual expertise.

Statement of Limitations

These studies examined perceivers and stimuli from two ethnic groups (people who identify as Black or White). Studies 1 and 2 only involve White participants; Study 3 involves both Black and White participants. Studies 1 and 2 measure natural viewing; Study 3 manipulates viewing. All stimuli are static images of faces, used both at encoding and test.

References

Abudarham, N., Shkiller, L., & Yovel, G. (2019). Critical features for face recognition. *Cognition*, *182*, 73–83. https://doi.org/10.1016/j.cognition.2018.09.002

Abudarham, N., & Yovel, G. (2016). Reverse engineering the face space: Discovering the critical features for face identification. *Journal of Vision*, *16*(3), Article 40. https://doi.org/10.1167/16.3.40

Adams, R. B., Jr., & Kleck, R. E. (2005). Effects of direct and averted gaze on the perception of facially communicated emotion. *Emotion*, *5*(1), 3–11. https://doi.org/10.1037/1528-3542.5.1.3

Baron-Cohen, S., Wheelwright, S., Hill, J., Raste, Y., & Plumb, I. (2001). The "Reading the Mind in the Eyes" Test revised version: A study with normal adults, and adults with Asperger syndrome or high-functioning autism. *Journal of Child Psychology and Psychiatry*, *42*(2), 241–251. https://doi.org/10.1111/1469-7610.00715

Blais, C., Jack, R. E., Scheepers, C., Fiset, D., & Caldara, R. (2008). Culture shapes how we look at faces. *PLOS ONE*, *3*(8), Article e3022. https://doi.org/10.1371/journal.pone.0003022

Bornstein, B. H., Deffenbacher, K. A., Penrod, S. D., & McGorty, E. K. (2012). Effects of exposure time and cognitive operations on facial identification accuracy: A meta-analysis of two variables associated with initial memory strength. *Psychology, Crime & Law*, *18*(5), 473–490. https://doi.org/10.1080/1068316X.2010.508458

Bothwell, R. K., Brigham, J. C., & Malpass, R. S. (1989). Cross-racial identification. *Personality and Social Psychology Bulletin*, *15*(1), 19–25. https://doi.org/10.1177/0146167289151002

Burgund, E. D. (2021). Looking at the own-race bias: Eye-tracking investigations of memory for different race faces. *Visual Cognition*, *29*(1), 51–62. https://doi.org/10.1080/13506285.2020.1858216

Caldara, R., Zhou, X., & Miellet, S. (2010). Putting culture under the 'spotlight' reveals universal information use for face recognition. *PLOS ONE*, *5*(3), Article e9708. https://doi.org/10.1371/journal.pone.0009708

Chuk, T., Chan, A. B., & Hsiao, J. H. (2014). Understanding eye movements in face recognition using hidden Markov models. *Journal of Vision*, *14*(11), Article 8. https://doi.org/10.1167/14.11.8

Correll, J., & Hudson, S. M. (2020). An error in the analysis of "An eye for the I". *Journal of Personality and Social Psychology*, *119*(5), 1030–1036. https://doi.org/10.1037/pspa0000200

Correll, J., Hudson, S. M., Guillermo, S., & Earls, H. A. (2017). Of kith and kin: Perceptual enrichment, expectancy, and reciprocity in face perception. *Personality and Social Psychology Review*, *21*(4), 336–360. https://doi.org/10.1177/1088868316657250

Correll, J., Ma, D. S., Kenny, D. A., & Palma, T. A. (2024). Examining the contribution of physical cues for same- and cross-race face individuation. *Personality and Social Psychology Bulletin*, *50*(5), 694–714. https://doi.org/10.1177/01461672221141510

Correll, J., Mellinger, C., & Pedersen, E. J. (2021). Flexible approaches for estimating partial eta squared in mixed-effects models with crossed random factors. *Behavior Research Methods*, *54*(4), 1626–1642. https://doi.org/10.3758/s13428-021-01687-2

Correll, J., Quarenta, J., Palma, T. A., Singh, B., & Bernstein, M. J. (2024, March 11). *Nonlinear relationships between eye gaze and recognition accuracy for ethnic ingroup and outgroup faces*. https://osf.io/x59sw/

De Chastelaine, M., Friedman, D., Cycowicz, Y. M., & Horton, C. (2009). Effects of multiple study-test repetition on the neural correlates of recognition memory: ERPs dissociate remembering and knowing. *Psychophysiology*, *46*(1), 86–99. https://doi.org/10.1111/j.1469-8986.2008.00754.x

Deffenbacher, K. A., Bornstein, B. H., McGorty, E. K., & Penrod, S. D. (2008). Forgetting the once-seen face: Estimating the strength of an eyewitness's memory representation. *Journal of Experimental Psychology: Applied*, *14*(2), 139–150. https://doi.org/10.1037/1076-898X.14.2.139

DeGutis, J., Mercado, R. J., Wilmer, J., & Rosenblatt, A. (2013). Individual differences in holistic processing predict the own-race advantage in recognition memory. *PLOS ONE*, *8*(4), Article e58253. https://doi.org/10.1371/journal.pone.0058253

Ebbinghaus, H. (1964). *Memory: A contribution to experimental psychology* (H. A. Ruger & C. E. Bussenius, Trans.). Teachers College. (Original work published 1885).

Ehinger, B. V., Groß, K., Ibs, I., & König, P. (2019). A new comprehensive eye-tracking test battery concurrently evaluating the Pupil Labs glasses and the EyeLink 1000. *PeerJ*, *7*, Article e7086. https://doi.org/10.7717/peerj.7086

Ellis, H., Davies, G., & Shepherd, J. (1977). Experimental studies of face identification. *National Journal of Criminal Defense*, *3*, 219–234. https://heinonline.org/HOL/LandingPage?handle=hein.journals/njcdnse3&div=13&id=&page=

Fiedler, S., Schulte-Mecklenbeck, M., Renkewitz, F., & Orquin, J. L. (2020). *Guideline for reporting standards of eye-tracking research in decision sciences*. PsyArXiv. https://doi.org/10.31234/osf.io/f6qcy

Friesen, J. P., Kawakami, K., Vingilis-Jaremko, L., Caprara, R., Sidhu, D. M., Williams, A., Hugenberg, K., Rodríguez-Bailón, R., Cañadas, E., & Niedenthal, P. (2019). Perceiving happiness in an intergroup context: The role of race and attention to the eyes in differentiating between true and false smiles. *Journal of Personality and Social Psychology*, *116*(3), 375–395. https://doi.org/10.1037/pspa0000139

Goldinger, S. D., He, Y., & Papesh, M. H. (2009). Deficits in cross-race face learning: Insights from eye movements and pupillometry. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *35*(5), 1105–1122. https://doi.org/10.1037/a0016548

Gosselin, F., & Schyns, P. G. (2001). Bubbles: A technique to reveal the use of information in recognition tasks. *Vision Research*, *41*(17), 2261–2271. https://doi.org/10.1016/S0042-6989(01)00097-9

Green, P., & MacLeod, C. J. (2016). SIMR: An r package for power analysis of generalized linear mixed models by simulation. *Methods in Ecology and Evolution*, *7*(4), 493–498. https://doi.org/10.1111/2041-210X.12504

Greene, R. L. (2008). Repetition and spacing effects. In H. L. Roediger III (Ed.), *Learning and memory: A comprehensive reference. Cognitive psychology of memory* (Vol. 2, pp. 65–78). Academic Press.

Guillermo, S., & Correll, J. (2020). Beyond stereotypes: The complexity of attention to racial out-group faces. *Journal of Theoretical Social Psychology*, *4*(2), 55–74. https://doi.org/10.1002/jts5.58

Hessels, R. S., Holleman, G. A., Kingstone, A., Hooge, I. T. C., & Kemner, C. (2019). Gaze allocation in face-to-face communication is affected primarily by task structure and social context, not stimulus-driven factors. *Cognition*, *184*, 28–43. https://doi.org/10.1016/j.cognition.2018.12.005

Hills, P. J., & Lewis, M. B. (2006). Reducing the own-race bias in face recognition by shifting attention. *Quarterly Journal of Experimental Psychology*, *59*(6), 996–1002. https://doi.org/10.1080/17470210600654750

Hills, P. J., & Pake, J. M. (2013). Eye-Tracking the own-race bias in face recognition: Revealing the perceptual and socio-cognitive mechanisms. *Cognition*, *129*(3), 586–597. https://doi.org/10.1016/j.cognition.2013.08.012

Hsiao, J. H., & Cottrell, G. (2008). Two fixations suffice in face recognition. *Psychological Science*, *19*(10), 998–1006. https://doi.org/10.1111/j.1467-9280.2008.02191.x

Hugenberg, K., Wilson, J. P., See, P. E., & Young, S. G. (2013). Towards a synthetic model of own group biases in face memory. *Visual Cognition*, *21*(9–10), 1392–1417. https://doi.org/10.1080/13506285.2013.821429

Ito, T. A., & Urland, G. R. (2005). The influence of processing objectives on the perception of faces: An ERP study of race and gender perception. *Cognitive, Affective & Behavioral Neuroscience*, *5*(1), 21–36. https://doi.org/10.3758/CABN.5.1.21

Kawakami, K., Friesen, J. P., & Fang, X. (2022). Perceiving ingroup and outgroup faces within and across nations. *British Journal of Psychology*, *113*(3), 551–574. https://doi.org/10.1111/bjop.12563

Kawakami, K., Williams, A., Sidhu, D., Choma, B. L., Rodriguez-Bailón, R., Cañadas, E., Chung, D., & Hugenberg, K. (2014). An eye for the I: Preferential attention to the eyes of ingroup members. *Journal of Personality and Social Psychology*, *107*(1), 1–20. https://doi.org/10.1037/a0036838

Kelly, D. J., Liu, S., Rodger, H., Miellet, S., Ge, L., & Caldara, R. (2011). Developing cultural differences in face processing. *Developmental Science*, *14*(5), 1176–1184. https://doi.org/10.1111/j.1467-7687.2011.01067.x

Khalid, S., Deska, J. C., & Hugenberg, K. (2016). The eyes are the windows to the mind: Direct eye gaze triggers the ascription of others' minds. *Personality and Social Psychology Bulletin*, *42*(12), 1666–1677. https://doi.org/10.1177/0146167216669124

Lee, J., & Penrod, S. D. (2022). Three-level meta-analysis of the other-race bias in facial identification. *Applied Cognitive Psychology*, *36*(5), 1106–1130. https://doi.org/10.1002/acp.3997

Levin, D. T. (2000). Race as a visual feature: Using visual search and perceptual discrimination tasks to understand face categories and the cross-race recognition deficit. *Journal of Experimental Psychology: General*, *129*(4), 559–574. https://doi.org/10.1037/0096-3445.129.4.559

Looser, C. E., & Wheatley, T. (2010). The tipping point of animacy: How, when, and where we perceive life in a face. *Psychological Science*, *21*(12), 1854–1862. https://doi.org/10.1177/0956797610388044

Ma, D. S., Correll, J., & Wittenbrink, B. (2015). The Chicago face database: A free stimulus set of faces and norming data. *Behavior Research Methods*, *47*, 1122–1135. https://doi.org/10.3758/s13428-014-0532-5

Macrae, C. N., Hood, B. M., Milne, A. B., Rowe, A. C., & Mason, M. F. (2002). Are you looking at me? Eye gaze and person perception. *Psychological Science*, *13*(5), 460–464. https://doi.org/10.1111/1467-9280.00481

Mason, M. F., Hood, B. M., & Macrae, C. N. (2004). Look into my eyes: Gaze direction and person memory. *Memory*, *12*(5), 637–643. https://doi.org/10.1080/09658210344000152

McDonnell, G. P., Bornstein, B. H., Laub, C. E., Mills, M., & Dodd, M. D. (2014). Perceptual processes in the cross-race effect: Evidence from eyetracking. *Basic and Applied Social Psychology*, *36*(6), 478–493. https://doi.org/10.1080/01973533.2014.958227

Meissner, C. A., & Brigham, J. C. (2001). Thirty years of investigating the own-race bias in memory for faces: A meta-analytic review. *Psychology, Public Policy, and Law*, *7*(1), 3–35. https://doi.org/10.1037/1076-8971.7.1.3

Niedenthal, P. M., Mermillod, M., Maringer, M., & Hess, U. (2010). The Simulation of Smiles (SIMS) model: Embodied simulation and the meaning of facial expression. *Behavioral and Brain Sciences*, *33*(6), 417–433. https://doi.org/10.1017/S0140525X10000865

Pearson, K., Lee, A., & Bramley-Moore, L. (1899). VI. Mathematical contributions to the theory of evolution.—VI. Genetic (reproductive) selection: Inheritance of fertility in man, and of fecundity in thoroughbred racehorses. *Philosophical Transactions of the Royal Society of London. Series A, Containing Papers of a Mathematical or Physical Character*, *192*, 257–330. https://doi.org/10.1098/rsta.1899.0006

Rhodes, M. G., & Anastasi, J. S. (2012). The own-age bias in face recognition: A meta-analytic and theoretical review. *Psychological Bulletin*, *138*(1), 146–174. https://doi.org/10.1037/a0025750

Schyns, P. G., Bonnar, L., & Gosselin, F. (2002). Show me the features! Understanding recognition from the use of visual information. *Psychological Science*, *13*(5), 402–409. https://doi.org/10.1111/1467-9280.00472

Senholzi, K. B., & Ito, T. A. (2013). Structural face encoding: How task affects the N170's sensitivity to race. *Social Cognitive and Affective Neuroscience*, *8*(8), 937–942. https://doi.org/10.1093/scan/nss091

Simpson, E. H. (1951). The interpretation of interaction in contingency tables. *Journal of the Royal Statistical Society: Series B (Methodological)*, *13*(2), 238–241. https://doi.org/10.1111/j.2517-6161.1951.tb00088.x

Singh, B., Mellinger, C., Earls, H. A., Tran, J., Bardsley, B., & Correll, J. (2022). Does cross-race contact improve cross-race face perception? A meta-analysis of the cross-race deficit and contact. *Personality and Social Psychology Bulletin*, *48*(6), 865–887. https://doi.org/10.1177/01461672211024463

Stelter, M., Rommel, M., & Degner, J. (2021). (Eye-) tracking the other-race effect: Comparison of eye movements during encoding and recognition of ingroup faces with proximal and distant outgroup faces. *Social Cognition*, *39*(3), 366–395. https://doi.org/10.1521/soco.2021.39.3.366

Szpunar, K. K., Schellenberg, E. G., & Pliner, P. (2004). Liking and memory for musical stimuli as a function of exposure. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *30*(2), 370–381. https://doi.org/10.1037/0278-7393.30.2.370

Tanaka, J. W., & Curran, T. (2001). A neural basis for expert object recognition. *Psychological Science*, *12*(1), 43–47. https://doi.org/10.1111/1467-9280.00308

Walker, P. M., Silvert, L., Hewstone, M., & Nobre, A. C. (2008). Social contact and other-race face processing in the human brain. *Social Cognitive and Affective Neuroscience*, *3*(1), 16–25. https://doi.org/10.1093/scan/nsm035

Wright, D. B., & Sladden, B. (2003). An own gender bias and the importance of hair in face recognition. *Acta Psychologica*, *114*(1), 101–114. https://doi.org/10.1016/S0001-6918(03)00052-0

Wu, E. X. W., Laeng, B., & Magnussen, S. (2012). Through the eyes of the own-race bias: Eye-tracking and pupillometry during face recognition. *Social Neuroscience*, *7*(2), 202–216. https://doi.org/10.1080/17470919.2011.596946

Received November 8, 2023
Revision received March 11, 2024
Accepted March 14, 2024 ■