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Gaze bias both reflects and influences preference

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Emotions operate along the dimension of approach and aversion, and it is reasonable to assume that orienting behavior is intrinsically linked to emotionally involved processes such as preference decisions. Here we describe a gaze 'cascade effect' that was present when human observers were shown pairs of human faces and instructed to decide which face was more attractive. Their gaze was initially distributed evenly between the two stimuli, but then gradually shifted toward the face that they eventually chose. Gaze bias was significantly weaker in a face shape discrimination task. In a second series of experiments, manipulation of gaze duration, but not exposure duration alone, biased observers' preference decisions. We thus conclude that gaze is actively involved in preference formation. The gaze cascade effect was also present when participants compared abstract, unfamiliar shapes for attractiveness, suggesting that orienting and preference for objects in general are intrinsically linked in a positive feedback loop leading to the conscious choice.

The subject of preference formation has been extensively studied, especially in relation to human faces. Most models seem to rely on the existence of an attractiveness 'template' to which a given stimulus is compared. The vague nature of this template invited numerous speculations, and studies have linked it to averageness or typicality[1], resemblance to self or relatives (for faces), symmetry[1], complexity, evolutionary beneficial cues, and so on. There have also been observations, however, that link preference to processes such as perceptual facilitation[2] (as in the mere exposure effect[3,4]) or gaze contact as a social interaction cue communicating interest, attractiveness or desire to collaborate[5,6].

Orienting behavior, best illustrated by gaze direction, is important in establishing exposure to a stimulus and gathering information about its characteristics. Gazing at an object, not just a face, inevitably leads to its foveation for deeper sensory processing. In this study, we investigated the role of orienting in preference formation. In the main 'face attractiveness' experiments, we presented observers with pairs of human faces and asked them to choose the more attractive face, at their own pace, while we monitored their eye movements.

Our results point to an active role for gazing in preference formation, both for human faces and for unfamiliar abstract shapes. We postulate the direct contribution of orienting behavior, along with the cognitive systems assessing stimulus attractiveness, to the process leading to the decision in a two-alternative forced-choice task. Consistent with both preferential looking in infants[7–9] and the human observer's sensitivity to the gaze direction of the stimulus face[10], our model suggests that the adult process of preference formation is not independent of more implicit, reflexive orienting mechanisms, but rather emerges from them. In another set of experiments, we show that biasing observers' gaze duration, but not just exposure duration, influenced their preference, consistent with the interdependence claim. Our model introduces a new view on how systematically subjective decisions are formed in relation to implicit somatic processes.

RESULTS

Experiment 1: correlation and the likelihood curve

We monitored observers' gaze while they compared two stimuli on a computer monitor and made a two-alternative forced choice about them. The results were expressed in terms of the likelihood of gazing at the (eventually) chosen stimulus as a function of time until decision (**Fig. 1** and Methods).

The main tasks in Experiment 1 involved attractiveness comparisons within pairs of faces. The baseline difference in the attractiveness ratings of the faces in a pair was either minimized (face-attractiveness-difficult) or maximized (face-attractiveness-easy), based upon evaluation data previously collected (see Methods).

To ensure that the gazing behavior in the attractiveness tasks was not due to general factors such as selection bias (observers tend to look at their choice) or memorization of response (gazing is used to 'capture' the chosen stimulus until the actual response is made), we included two control tasks. In one task, we asked observers which face was rounder (face-roundness task), and in the other, which face was less attractive (face-dislike task). Although semantically opposite, assessing stimuli as 'attractive' and 'not attractive' are known to involve different brain areas[11]. For each of the four tasks described above, we performed the gaze likelihood analysis (Methods; **Fig. 1**). Only the last 50 sampling points (1.67 s) before the response were analyzed and are shown.

The first point about the curves is that, although they all start at chance level (no inspection bias early in the trial), they start rising up to levels significantly above chance, with the largest effect in the difficult attractiveness task (up to 83%; **Fig. 1a**). The curves show a progressive bias in observers' gaze toward the chosen stimulus, irrespective of the

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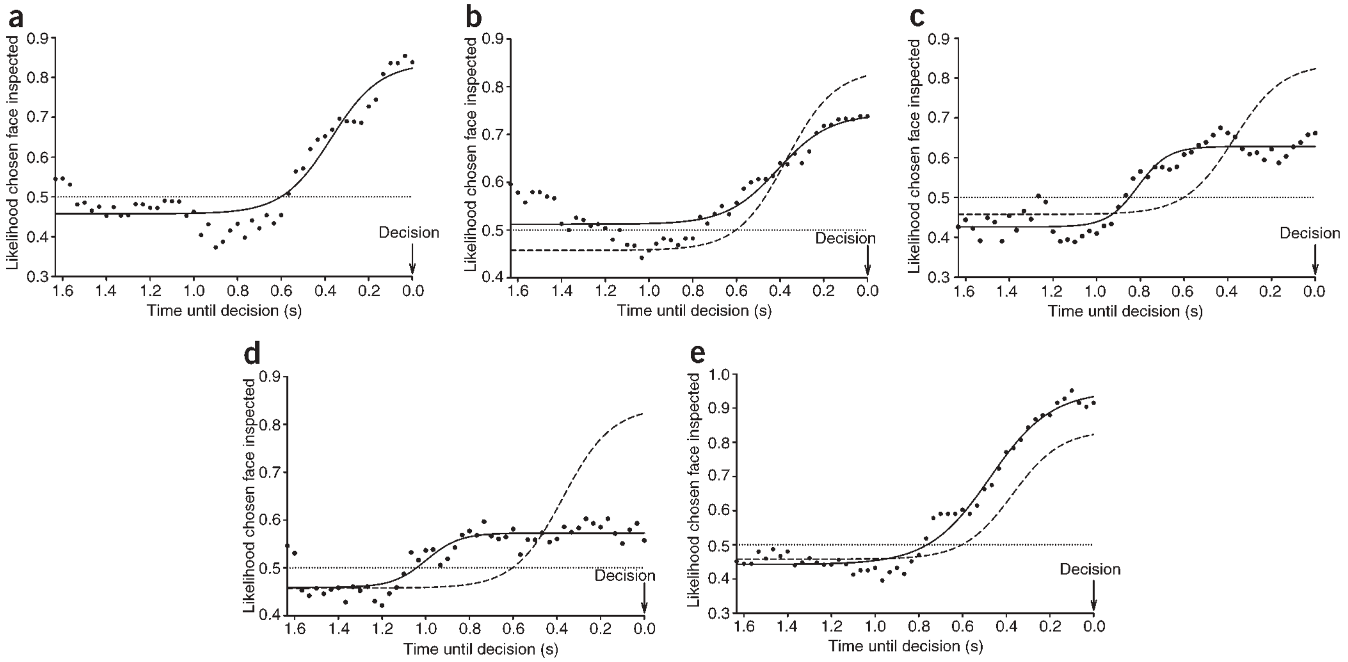

Figure 1 Results of Experiment 1. The likelihood that an observer's gaze was directed toward the chosen stimulus is plotted against the time left until decision (keypress) in all five conditions. The data points represent the average across observers ($n = 5$ in all conditions) and trials (see Methods). The solid lines represent the four-parameter sigmoid regression curves. (**a**) Face-attractiveness-difficult, $R^2 = 0.91$. (**b**–**e**) The curve from **a** was replotted for effect size comparison (dotted line); (**b**) Face-attractiveness-easy, $R^2 = 0.85$; (**c**) face-roundness, $R^2 = 0.91$; (**d**) face-dislike, $R^2 = 0.80$; (**e**) Fourier-descriptor-attractiveness, $R^2 = 0.98$.

task, with eventual saturation either before or at the point of decision. We fitted the raw data points from all tasks to four-parameter (starting level, elevation, inflection point and slope) sigmoid curves. The R^2 (normalized root-mean-square) values, given in the figure legends, are all above 0.8, indicating good fit. Analysis of the curve parameters led to several conclusions and hypotheses to be further tested.

First, there was a significant difference between the heights of likelihood curves in the main tasks (involving attractiveness) and the control tasks (dislike and roundness). Pairwise Kolmogorov-Smirnov tests showed the following distances: $d = 0.52$ between face-attractiveness-difficult and face-roundness ($P < 0.005$); $d = 0.71$ between face-attractiveness-difficult and face-dislike ($P < 0.0001$); $d = 0.32$ between face-attractiveness-easy and face-roundness ($P < 0.01$); $d = 0.36$ between face-attractiveness-easy and face-dislike ($P < 0.05$). Secondly, the curves did not reach a saturation level before decision in the main tasks (**Fig. 1a,b**), unlike in the control tasks (**Fig. 1c,d**), suggesting that the gaze bias is continually reinforced when attractiveness comparisons are to be made. Because such a pattern can only be achieved by gradually increasing the duration of gazing at one of the stimuli, and decreasing inspection time for the other, we called this the 'gaze cascade effect'. On the basis of our findings, we propose a dual-contribution model of preferential decisionmaking with two broad inputs of parallel information processing, one from the cognitive assessment systems and the other from the orienting behavior structures, feeding into a decision module (see Discussion and **Supplementary Fig. 1** online for more details).

This model is consistent with the significant difference found between the effect size in the two main tasks (attractiveness, easy versus difficult). Comparing them (K-S $d = 0.36$, $P = 0.02$) shows that the gaze bias was actually larger when the faces in a pair were close in average attractiveness rating (that is, when the task was more difficult). This finding may seem counterintuitive for the following reason: if the choice is more difficult, should not the observers distribute their gaze more evenly between the two stimuli, gathering as much relevant information as possible about both? This in turn would translate into a smaller gaze bias in the difficult task. However, we found the opposite result: a larger 'cascade effect' in the difficult task, which is consistent with our model's prediction that when the cognitive biases are weak, gaze would contribute more to the decisionmaking.

The cascade effect seen in the face attractiveness tasks might have evolved from social interaction, and thus could be absent when the stimuli were not overly familiar or natural (human faces). On the other hand, the effect could have deeper roots in basic orienting behavior, which may indeed have a longer evolutionary history. To test the generality of the effect for a class of stimuli other than human faces, we performed the same analysis while observers compared abstract shapes (Fourier descriptor–generated shapes[12]) for attractiveness (**Fig. 1e**).

The cascade effect was evident in this task, and in fact it was significantly stronger than in any other task (K-S test for Fourier descriptors versus face attractiveness-difficult, $d = 0.43$, $P = 0.03$). This is consistent with our model, as a prior cognitive bias toward an unfamiliar object was expected to be weak in this task, and thus it had to be helped by the gaze bias to form the decision. We therefore maintain that orienting is essential, particularly when the cognitive systems cannot be discriminative in making preference decisions over a range of stimuli.

Two critical questions remain before our model can be deemed feasible. The first is whether the effect we found accompanies preference decisions in any situation, not only when the stimuli are novel. It could be that the gaze cascade is necessary only for the first encounter of a particular stimulus pair, and the observer may entirely rely on memory of past decisions for subsequent encounters. Alternatively, a

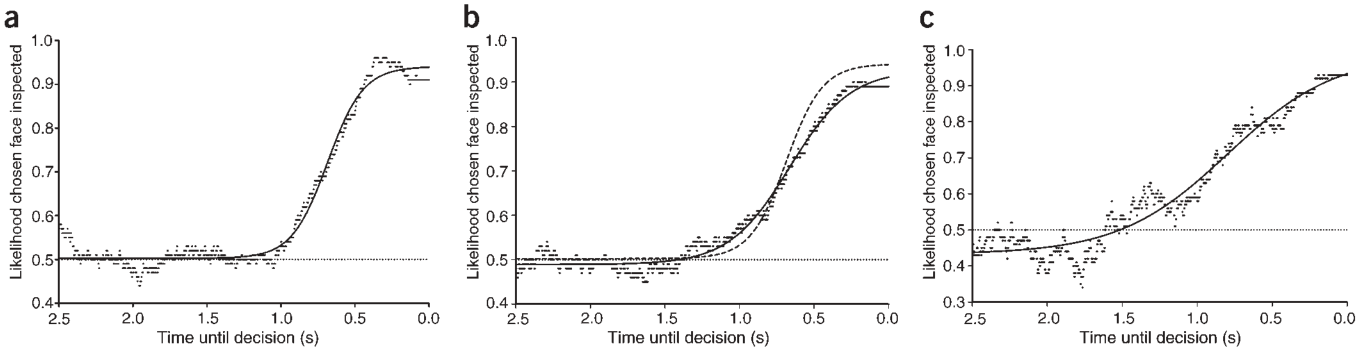

Figure 2 Results of Experiment 1, two-session condition. The likelihood that an observer's gaze was directed toward choice is plotted against the time fleft until decision (keypress). The data points represent the average across observers (n = 10) and trials (n = 20). The task was to indicate which face was more attractive, and the same group of observers performed the task twice. (**a**) First session data; (**b**) second session data, inter-session delay of one day with the curve from **a** replotted for comparison (dashed line); (**c**) likelihood analysis across those trials in which the decision was changed from one session to the next.

sensorimotor commitment such as the gaze cascade may be necessary for all preference decisions. To test this possibility, we designed an experiment in which two identical sessions with the same sequence of face pairs (matched for attractiveness, see Methods) were performed by the same group of observers (n = 9), with an inter-session delay of one day. We expected the majority of trials in the second session to show the same two-alternative choice as in the first, due to both cognitive biases and the implicit and/or explicit memory of the initial choice. Interestingly, this was not the case in 23.3% of trials (42 out of 180). We performed the likelihood analysis on the data from the two sessions as well as on only those trials that had shown reversal in decision between the sessions (**Fig. 2a–c**). The cascade effect was present in all three cases, with the shape and magnitude expected for a difficult attractiveness task. We consider this direct evidence that the effect indeed reflects the process of decisionmaking itself, and is not the consequence of the observers merely relying on memory, switching their preference, or making a particular decision. A remaining question, addressed in Experiment 2 below, is whether preference can be influenced by experimental manipulation of gaze.

Experiment 2: gaze manipulation

For our model to be valid, it must be possible to influence observers' choice in preference decisions by biasing their active gaze toward one of the stimuli. In the second experiment reported here, we manipulated observers' gaze so that one face in a pair is inspected longer than the other. To ensure that observers indeed shifted their gaze and foveated one face at a time, and to avoid any effect of peripheral vision, only one face was present on the computer screen at any time, and the two stimuli alternated between the left and the right side of the screen, with different presentation durations (900 ms versus 300 ms) for a number of repetitions (2, 6 and 12, respectively). Separate groups of naive observers (n = 15, 15 and 13, respectively) participated. Because active gaze biases and exposure biases were difficult to distinguish in this experiment, we also performed two control experiments in which exposure, without orienting, was manipulated. In the first one, the same presentation sequence was used, but participants were instructed to fixate in the center of the screen throughout the trial. This condition, however, requires peripheral rather than foveal vision (as in the original manipulation), so a second control was run in which faces were presented in an alternating manner in the middle of the screen. Although visual stimuli were retinotopically and temporally identical to those in the original experiment, there was no gaze shift in this task.

To ascertain that a certain size or direction of the saccade is not important for a preference bias effect, we ran the same task (attractiveness) while faces alternated between the top and bottom sides of the screen. Finally, to find out whether such manipulation was specific to preference tasks, we used the original gaze-manipulation paradigm asking participants to choose the rounder face.

The results are presented in **Table 1**. The percentage values indicate in how many cases the longer-presented face was chosen in each condition. Any value significantly higher than 50% (t-test) was consid-

Table 1 Results of Experiment 2 (gaze manipulation)

	Gaze manipulation 2 repetitions (n =15)	Gaze manipulation 6 repetitions (n =15)	Gaze manipulation 12 repetitions (n =13)	Gaze manipulation vertical (n =15)	No gaze shift, central (n =10)	Gaze manipulation roundness (n =110)	No gaze shift, peripheral (n = 10)
Percent preference for longer shown face	51.2	59.0	59.2	60.2	45.8	51.8	49.8
P value t-test	0.31	<0.001*	<0.005*	<0.0001*	0.99	0.30	0.56

See Methods for a description of each condition. $P < 0.05$ denotes a preference bias significantly above 50% (chance level). The effect reached significance (*) in three of the gaze manipulation conditions, but not in any of the control conditions. Six repetitions were run in all three control conditions and in the vertical alternation condition.

Table 2 Reaction times (RT) for all free-viewing, one-session comparison tasks

	Face attractiveness difficult	Face attractiveness easy	Face roundness	Face dislike	Fourier descriptors actractiveness
Mean RT + s.e.m. (seconds)	3.55 ± 0.18	3.09 ± 0.12	3.17 ± 0.13	4.63 ± 0.24	3.90 ± 0.19

For experimental details, see Methods. The RT differences across conditions did not correlate with the size of the gaze cascade effect.

ered a preference bias effect. This was the case for the 6- (59.0%, $P < 0.001$) and 12-repetition (59.2%, $P < 0.005$) experiments and for the vertical alternation experiment (60.2%, $P < 0.0001$), but not for the two repetitions or any of the control experiments. We conclude that gaze directly influences preference formation.

DISCUSSION

In the present study, we introduce a novel method of eye movement analysis, meant to reveal trial-average gaze patterns in two-alternative forced-choice tasks. Based on the likelihood that observers will gaze longer at what they choose, the method uncovers a strong correlation between choice and inspection times, especially in the last second before decision. Moreover, in tasks involving attractiveness, the gaze bias is continually reinforced, a pattern that we call the gaze cascade effect. Because of the earlier saturation and lower elevation in control tasks (**Fig. 1c**,**d**), we are ruling out as its cause memory and/or selection bias. In other words, the final moments of gaze are not allocated to the chosen stimulus merely as a means to 'memorize' or 'lock' the choice. Although this probably contributes to the effect, the large, progressive bias seen prior to attractiveness decisions cannot be solely attributed to general factors like selection, memorization or motor response. The gaze cascade effect illustrates the direct contribution that orienting behavior has in the preference decisionmaking process.

In light of our results, we propose a dual-contribution model of preference formation in which two information processing inputs feed into a decision module. Naturally, the cognitive assessment systems (comparing stimulus characteristics with an attractiveness template, for example) would be one such input (see **Supplementary Fig. 1** online). The other input is based on the orienting behavior, and is directly related to the cascade effect. The decision module would then be responsible for integrating information from these two inputs across time, and for making a choice when a certain threshold is reached. Assuming this signal-threshold comparison process is dynamic and continuous, we introduce feedback to ensure the enhancement of the signal through time so that a conscious decision is eventually made.

Although our model includes feedback on both pathways, it is generally thought that cognitive representations are flexible yet stable, and therefore the short-term influence of feedback on the cognitive assessment input cannot be substantial. However, the contribution of gaze becomes important in preference decisions because a gaze bias leads to increased exposure to one of the stimuli, which translates into increased preference. Preference in turn drives the gaze, thus continually reinforcing the attractiveness percept and leading to the conscious decision. Note that the unique shape of the gaze cascade curves (**Fig. 1a**,**b**,**e** and **Fig. 2**) indicates that this positive feedback occurs very quickly and repeatedly within a single decisionmaking process. Preferential looking and mere exposure meet in our model, being responsible for this loop that enhances the orienting input.

As the reinforcement is specific to preference tasks, one would expect the gaze bias part of the likelihood curve to last longer in the control tasks (as shown in **Fig. 1c**,**d**). This is because more time would be needed for the signal to pass the threshold. Quite surprising, however, is the result in the 'dislike' task which, at least semantically, is related to preference. We speculate that the decision about dislike might be based on more objective criteria, like in the roundness task, and thus not be susceptible to perceptual reinforcement by increased exposure, as in the attractiveness task. Such a difference in comparison strategies could be responsible for the lack of the cascade effect.

As an interesting aspect of our results, when the method of gaze analysis was applied to trials aligned at the onset of the stimuli, no predictor or correlation was found in the likelihood data (not shown), indicating that the cascade effect is a late, robust, event that is directly time-locked and contributes to decisionmaking, and not the result of an initial bias in viewing patterns. There was also no correlation between decision latency in various tasks and the size and length of the gaze cascade (**Table 2**), ruling out the possibility that smaller gaze biases are solely the result of shorter reaction times.

Also, in the likelihood plots (**Fig. 1a–e**), the raw data points from 200-300 ms before the start of each gaze bias appear to drop consistently below 50%. Considering the average gaze fixation duration (a few hundred ms), one can naturally expect this dip, i.e., a slight tendency to gaze more at the not-to-be-chosen stimulus before the maximum bias towards choice. The low magnitude of the dip compared with the later gaze bias renders it of little importance to the present study.

To further support our model, we show that manipulating observers' gaze durations leads to significant preference biases, an effect not explained by mere exposure or general perceptual facilitation, as seen from the results of the control experiments (**Table 1**). In fact, in the central alternation condition, the effect was reversed, the shorter shown face being preferred in slightly more than 50% of cases. This weak tendency may be based on the habituation to stimuli that are repeatedly shown, an effect that has long been known in infant psychophysics and recently emphasized in adults as well[13]. Although seemingly inconsistent with the mere exposure prediction, the reversal does not alter our conclusion that orienting is necessary to bias preference. The absence of an effect in the two-repetition task is consistent with the mere exposure literature as well as our model, suggesting that a sufficient amount of gaze bias needs to be achieved for the decision to be biased. We conclude that manipulation of gaze can directly influence preference comparisons and that a particular size and direction of the saccades does not alter this result (as shown in the vertical presentation task, **Table 1**), supporting the existence of strong positive feedback in preference formation.

Our results provide evidence for a significant role of sensorimotor orienting in preference decisions. Our model incorporates and can explain previous findings, such as preferential looking, mere exposure and perceptual facilitation. Furthermore, it adds the substantial specification that the preference decision is an active, short-term process in which the brain uses a circuit that includes the orienting behavior. Many classical psychologists believe[14,15] that body states need to be interpreted cognitively for the emotional experience to happen[16–18].

Likewise, one's own gaze bias may be interpreted as preference at subconscious levels. The model can also account for the increased sensitivity that humans have for other's gaze direction[19]. If gaze participates directly in the process of preference formation, orienting toward someone may indicate interest of some kind, or even 'preference in the making' for that person.

Although our model remains speculative, the gaze cascade effect itself is an entirely new finding whose significance is further reinforced by the gaze manipulation results. Such a contribution of gaze to preference judgments opens the path for further investigation of the role of orienting in human emotional experience and judgment. By revealing the intricate relationship between preference and orienting across the consciousness threshold, our approach may provide a powerful tool for exploring unknown aspects of communication in situations outside the laboratory.

METHODS

All images were presented on a 19-inch ViewSonic CRT screen at 11,52 × 864 pixel resolution. The viewing distance was always 57 cm, and each stimulus (two faces side by side) had an overall size of 30 (H) × 15(V) degrees of visual angle. Two face databases were used: the Ekman face database (www.paulekman.com) and the AR face database (http://rvl1.ecn.purdue.edu/~aleix/aleix_face_DB.html). The approval of California Institute of Technology IRB Committee and informed written consent from participants were obtained for all experiments.

Gaze data analysis. Observers' eye movements were tracked with a video-based eye tracker (S. Egner & C. Scheier, www.mediaanalyzer.com) at a rate of 30 samples per second. After the experiment, we assigned a true value (1) to every sampling point if the observer's gaze was directed toward the chosen stimulus, and a false value (0) if the gaze was on the other stimulus. Gaze data outside either face was treated as 'not-a-number'. We aligned all trials at the moment of response, as we were interested in whether the likelihood curve is in any way correlated with the choice made. By averaging across trials and subjects, we obtained the likelihood that the choice was inspected, at each sampling point. There was a large variance in decision latency across trials, both within and among observers. We chose 1.67 s (50 samples) prior to the decision as the starting point of analysis, as this represents approximately the mean decision latency minus one standard deviation, and thus all sampling points had average values calculated across at least 67% of all trials. Note that in this type of data analysis, the choice, not the task, matters, so comparisons among patterns in various tasks can be made. Once the likelihood was obtained, we plotted it against time to the decision (*i.e.*, the key press response) and fitted it with a sigmoid function (with four parameters: starting level, elevation, inflection point and slope). The degree of fit was expressed by the R^2 value. All observers were naive to the purpose of the experiments.

Face-attractiveness-difficult task. To control for the base attractiveness of the faces in the databases, we asked observers (n = 12 observers for the Ekman database and n = 12 for the AR database) to rate all the faces from 1 (very unattractive) to 7 (very attractive). We then calculated the average rating for each face, and paired them so that the difference in the average rating was lower than or equal to 0.25 points. The faces in a pair were matched for gender and race and displayed a neutral facial expression. Nineteen face pairs were presented. Five observers were instructed to inspect the face pairs freely for as long as they wanted, then to press one of two keys (corresponding to each possible outcome) when they decided which face was more attractive (two-alternative forced-choice task). Eye movements were recorded with a Sony 8 digital camera, and converted to 30 frames/s mpeg files. Eye position was automatically tracked by the MediaAnalyzer software (S. Egner & C. Scheier, www.mediaanalyzer.com). The results were manually corrected when necessary (never more than 7% of the entire number of frames). A likelihood curve was obtained by the method described above.

Face-attractiveness-easy task. Thirty pairs of faces were used from the AR face database; otherwise the procedure was identical to that in the previous task. The only difference was that, as established by the pre-rating we performed, one face was obviously more attractive than its counterpart (rating difference >3.25 on a 1 to 7 scale). A new group of observers (n = 5) were asked to choose the more attractive face. A likelihood curve was obtained by the method described above.

Face-dislike task. The stimuli, procedure and analysis were identical to those in the attractiveness experiments, except that the observers were asked to choose the less attractive face. A new group of observers (n = 5) participated. The face pairs were the same as in the face-attractiveness-difficult task.

Face-roundness task. The stimuli, procedure and analysis were identical to those in the previous experiments, except that the observers were asked to choose the rounder face. A new group of observers (n = 5) participated. The face pairs were the same as in the face-attractiveness-difficult task.

Fourier-descriptor-attractiveness task. Seventeen pairs of abstract shapes were generated using a Fourier-descriptor algorithm[12]. The task and the instructions were identical to those in the previous tasks. A new group of observers (n = 5) were asked to choose the more attractive shape. No attractiveness match was performed before the experiment.

Two-session face attractiveness task. Nine naive observers participated in this experiment. Forty computer-generated faces (Facegen Modeller, www.facegen.com) were grouped into 20 pairs according to gender and each observer's attractiveness ratings. Eye movements were tracked with the EyeLink 2 system (SR Research) at a sampling rate of 500 Hz. Two identical sessions with the same sequence of face pairs were performed by the same observers, with an inter-session delay of one day. The same likelihood analysis, described above, was applied to the gaze data in both sessions, and likelihood curves were generated. The last 2.5 s were included in this analysis. There were 42 trials (23.3% of 180) in which the choice was changed in the second session. Likelihood analysis was performed on those trials as well, treating them as a separate group.

Gaze manipulation. Computer-generated faces were used in all conditions. Observers were first asked to rate attractiveness of 40 male faces, then 40 female faces, on a scale from 1 to 7. Pairing was performed by the computer according to each observer's rating so that only faces with the closest ratings were paired. The faces in each pair were subsequently shown alternatively on the screen, for 900 and 300 ms, respectively, for 2, 6 or 12 repetitions. Three independent sessions with different observer groups were run for the three repetition conditions (n = 15 for 2 and 6 repetitions, and 13 for 12 repetitions). The observers had to effectively follow the display, shifting their gaze toward the visible face on the screen. At the end of the presentation, they decided which face was more attractive. The order and duration of face presentation were randomized across trials. The same procedure was repeated in a separate manipulation condition, but the faces alternated between the top and the bottom halves of the screen, instead of left/right (n = 14). In one control experiment (n = 10), the stimuli, procedure and task were identical (left/right face alternation), except that the observer was asked to maintain gaze at the center of the screen throughout each trial. In another control (n = 10), the faces alternated in the middle of the screen, in the same location, with the same temporal sequence as the original condition. In yet another control (n = 10), we used the manipulation protocol and asked participants to choose the rounder face. All controls were performed with six repetitions. In all conditions, we calculated a correlation coefficient by measuring how likely observers were to prefer the face shown for longer. A percentage significantly higher than 50% meant that faces presented longer were preferred.

Note: Supplementary information is available on the Nature Neuroscience website.

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COMPETING INTERESTS STATEMENT

The authors declare that they have no competing financial interests.

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