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# Supplementary Information for

## Individual differences in visual salience vary along semantic dimensions

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## Supplementary Information Text

## Supplementary Methods

**Subjects.** The study comprised three original datasets (the *Lon*, *Gi_1* and *Gi_2* samples) and the re-analysis of a public dataset (the *Xu et al*. sample (1)).

54 healthy adults with normal or corrected-to normal vision participated in the experiment conducted at University College London, UK. Reimbursement was 25£. Eye tracking failed for three participants due to technical problems, leaving 51 in the *Lon* sample (25 males, 4 left handed, mean age 23 with a standard deviation of 4 years). For two of these participants, data from one block was missing due to a recording failure; the remaining data from these participants were entered into the analysis nonetheless. Control-analysis showed that the results remained virtually unchanged when these data were excluded. 46 of the *Lon* participants additionally completed three personality questionnaires administered online: The IPIP-NEO 120 (NEO)(2) to measure the Big Five (3); the Highly Sensitive Person Scale (HSP) (4) and the Brief Sensation Seeking Scale (BSSS) (5).

51 healthy adults with normal or corrected-to normal vision participated in the experiment conducted at Justus-Liebig Universität Giessen, Germany (the *Gi_1* sample; 11 males, 5 left handed, mean age 24, with a standard deviation of 4 years). For one of these participants, data from one block was missing due to a recording failure; the remaining data from this participants were entered into the analysis nonetheless. Control-analysis showed that results remained virtually unchanged when these data were excluded. Reimbursement was 30€ or course credits.

48 of the *Gi_1* participants returned to the lab for a re-test (the *Gi_2* sample). The period between tests was 16 days on average (minimum 6 days; maximum: 43 days; standard deviation: 7 days). 46 of the *Gi* participants additionally completed an online version of the Cambridge Face Memory Test (CMFT) (6).

The public *Xu et al*. dataset comprises 15 participants with a reported age range of 18-30 years (1).

**Stimuli.** Participants were presented with 700 natural images depicting a wide variety of complex everyday scenes (http://www-users.cs.umn.edu/~qzhao/predicting.html). Semantic metadata (1) consist of binary pixel maps for 5551 objects in these images and accompanying labels for 12 semantic dimensions. We modified the provided labels to minimize overlap between them in the following way: The (neutral) *Faces* label was removed from all objects with the *Emotion* label (i.e. emotional faces); The *Smell* label was removed from all objects with the *Taste* label; The *Operable* and *Gazed* labels were removed from all objects with the *Touched* label; The *Watchable* label was removed from all objects with the *Text* label. This step allowed to test individual differences in fixation attraction for a given dimension largely independently from the others. Without this step some of the attributes would have been perfectly confounded (for instance, all text is watchable; all emotional faces are faces).

In each experiment, participants viewed seven blocks of 100 images on a screen. Stimulus presentation and data collection was coded in MATLAB Version R2016b (MathWorks, Natick, MA) using Psychtoolbox Version 3.0.12 (7, 8). For the *Lon* and *Gi_1* samples the order of images was fixed across all participants and each image was presented for 3s, with a self-paced period of a central fixation dot in between. Participants were simply instructed to 'look at the images in any way [they] want' and initiated the onset of each image with a press of the space bar. The re-test of the Giessen sample (*Gi_2*) followed the same procedure as the first appointment, with the exception of the order of images presented, which was shuffled relative to the first appointment (but again constant across participants).

Participants in the *Lon* sample sat at a distance of ~65 cm from a screen and saw the stimuli at a resolution of 800 x 600 pixels and a size of 19.9 x 15.0 degrees visual angle. Participants in the *Gi* samples sat with their head in a chinrest, at a distance of 46 cm from the screen and saw the stimuli at a resolution of 1000x750 pixels and a size of 41.9 x 32.1 degrees visual angle. The *Xu et al*. sample saw stimuli at a size of 33.7 x 25.3 degrees visual angle. Further details on this sample can be found in the original publication by Xu et al. (1).

**Data Collection.** The gaze of participants in the *Lon* sample was sampled remotely and binocularly with a Tobii EyeX (Tobii Technologies, Danderyd, Sweden) at a frequency of ~55 Hz(9). Eyetracking data from the *Gi* samples was collected from the left eye with a tower mounted Eyelink 1000 (SR Research, Ottawa, Canada) at a frequency of 1 kHz (the *Xu et al*. data were collected with a remote Eyelink 1000(1)).

At the beginning of each block, participants completed a nine-point calibration and validation procedure, which was repeated if necessary. For the *Gi* samples, fixation data was collected online using the 'normal' setting of the Eyelink parser (saccade velocity and acceleration thresholds of 30 d.v.a./s and 9500 d.v.a./$s^2$, respectively) and the default drift check procedure in each inter-trial interval. Raw data from the *Lon* sample was converted to fixation data offline (see below).

**Data Processing and Analyses.** Raw eye tracking data from the *Lon* sample were transformed into fixation data applying a saccade threshold of 30 d.v.a./s and taking the median x and y position of fixation samples as the respective fixation location. Fixations were drift-corrected in a block-wise fashion, centering on the median of fixation locations registered at image onsets during the respective block.

Onset fixations and fixations with a duration below 100 ms were disregarded for all datasets (minimum fixation duration following standard recommendations by SR Research and Xu *et al.* (1)). Fixations that fell on or within a distance of ~0.5 d.v.a from a labeled object were assigned the corresponding label. Unlabeled fixations were disregarded for the calculation of cumulative fixation times and the individual proportion of *first* fixations (see below).
In order to quantify the individual tendency to fixate objects bearing a given attribute label, we first calculated the cumulative fixation time for all labeled fixations made by a given observer to a given image set. This allowed us to calculate the proportion of this time spent on a given attribute in a second step.

The *first* fixations analysis considered the proportion of labeled *first* fixations (after image onset) landing on objects with a given attribute for a given observer and image set. Individual proportions of cumulative fixation time and first fixations were expressed in %.

**Consistency and re-test correlations.** To estimate the consistency of individual differences in % cumulative fixation time or % first fixations along a given attribute dimension, we calculated these measures independently for two random halves of the images for each observer and calculated the split-half Pearson correlation. This procedure was repeated 1000 times. We inspected the frequency histograms of all correlations (Fig. 2 and Fig. S1) and considered the median correlation coefficient across random image splits as an indicator of consistency. The accompanying two-sided *P*-values were Bonferroni adjusted for twelve comparisons in the *Lon* sample (Table S1).

To estimate the re-test reliability of individual differences in % cumulative fixation time or % first fixations for a given attribute, we correlated the corresponding values for the first session of the *Gi* sample with those of the second.

**Individual predictions.** To test whether individual gaze predictions could improve on the noise ceiling of an ideal generic model, we aimed at predicting individual % first fixations (and % cumulative fixation time) for a set of test images (Fig. 3, Fig S2). We pooled fixation data across the 117 observers of the *Lon*, *Gi* and *Xu* samples and split the data into training and test sets of 350 images each (the procedure was repeated for 1000 random splits and prediction errors averaged across splits). First, we probed the prediction error of a (theoretical) ideal generic model, predicting the group mean exactly (i.e. the generic 'noise ceiling', or individual deviation from the group mean for the set of test images). We calculated this absolute deviation from the mean of the remaining group for each observer and fixation dimension. We also calculated the cumulative prediction errors across the six reliable dimensions (i.e. the sum of absolute errors across these dimensions). Next, we probed whether individual predictions could improve on this generic noise ceiling. For each individual, we calculated their deviation from the group mean for the training set in units of standard deviations (the individual z-value). We then predicted the individual's % first fixations (or % cumulative fixation time) for the test images to correspond to the same *z*-value, which was determined based on the mean and standard deviation for the remaining group and test images. That is, we adjusted the prediction of the ideal generic model based on the individual group deviation seen for the training data. Note that this individual prediction was strictly blind to the to-be predicted individual's fixation data for the test set. Also note that the individual prediction should only improve on the generic one if an individual's group deviation for the training set are predictive of that seen for the independent test images. This procedure resulted in a set of individual and generic prediction errors for each observer. We compared the mean of individual and generic prediction errors across observers and tested the statistical significance of their difference using paired *t*-tests. We also probed which proportion of generic prediction errors could be explained using by the individual predictions. This was defined as one minus the ratio of SMSEs for the individual and generic prediction, with SMSEs referring to the sum of mean squared errors across the six reliable fixation dimensions.

**Covariance patterns between dimensions and correlations with other measures.** To investigate the covariance pattern between the dimensions of consistent individual differences in fixation behavior, we inspected pair-wise Pearson correlation matrices (Fig. 4*B*, Fig. S3 *A* and *B*). We further used metric multidimensional scaling to project the pair-wise dissimilarities between dimensions (defined as $(1\text{-}r)^2$) onto distances in a two-dimensional space (Fig. S3 *C* and *D*). To further test the stability of covariance patterns between datasets we calculated pair-wise Pearson correlations between Fisher Z-transformed correlation matrices from different samples.

To test the perceptual implications of salience differences, we concentrated on the example of faces (Fig. S4). Specifically, we probed a correlation between individual face salience as indicated by the proportion of cumulative dwell time or *first* fixations landing on faces and total scores in the Cambridge Face Memory Test (6). This standard test of individual face recognition skills was administered online to participants from the *Gi* sample, after the first eye tracking session.

To explore the relationship between personality and individual gaze behavior, we computed all pairwise correlations between reliable dimensions of salience differences and personality (Fig.

S5). Specifically we correlated individual salience differences for *Faces*, *Emotion*, *Text*, *Taste*, *Touched* and *Motion* with the Big Five as determined by the IPIP-NEO 120 (2) *Neuroticism* (N), *Extraversion* (E), *Openness* (O), *Assertiveness* (A), *Conscientiousness* (C), with high sensitivity (HS) as determined by the Highly Sensitive Person scale (4), and with sensation seeking (SS) as determined by the Brief Sensation Seeking Scale (5). The resulting 6x7 correlation matrix was computed separately for the proportion of cumulative fixation time and for that of *first* fixations; accompanying *p*-values were adjusted for multiple testing using the Holm-Bonferroni correction for family-wise errors (10).

## Supplementary Results and Discussion

**Consistency of covariance pattern across datasets.** Fixation tendencies in the *Lon* sample showed a characteristic covariance pattern, for which multidimensional scaling revealed two clusters (*Faces* and *Motion* on one side, *Text*, *Touched* and *Taste* on the other, Fig. 4). To test the generalizability of this pattern, we repeated this analysis for all four data samples (Lon, Gi_1, Gi_2 and Xu et al.) and found it was highly similar across datasets (Fig. S3). All pairwise correlations between sample-specific (and Fisher z-transformed) correlation matrices were >.68 for cumulative fixation durations and >.90 for first fixations.

**Personality correlations.** Having established a correlation of semantic salience differences with perception (Fig. S4), we then explored potential relationships with personality variables. Observers in the *Lon* sample completed questionnaires for seven personality dimensions, including the Big Five (2), Sensation Seeking (5) and High Sensitivity (4) (see SI Methods above). We tested all 7x6 pairwise correlations between personality traits and individual salience differences, applying family-wise error correction for multiple comparisons (10). Results showed no significant relationship between personality variables and cumulative fixation times (all $r < .39$, *n.s.*; Fig. S5*A*), or *first* fixations (all $r < .23$, *n.s.*; Fig. S5*B*).

However, given the large number of tests and control for multiple testing, we cannot rule out the existence of small or medium effects. Either way, the salience differences we found should inform and enrich the science of individual differences. They have unusually high magnitudes (up to factor 3) and reliability (up to and greater than .9) for objective psychological traits and appear to document fundamental differences in visual attention and perception, which are main filters of incoming information about our surroundings.

**Control analysis for visual field biases.** Different types of objects tend to appear at different parts of the visual field and recent findings suggest that observers are attuned to these contingencies (11–13). To test the relationship between individual salience and visual field biases, we first explored the distribution of objects corresponding to dimensions of individual salience across image space (Fig. S6*A*; neutral and emotional faces collapsed into Faces). The most prominent spatial bias in the scene stimuli was a strong tendency for faces to appear in the upper visual field (~75% of faces).

Therefore, we tested whether individual face salience (individual % of first fixations landing on faces) correlated with a general upper visual field bias. We defined the latter as the median elevation of first fixations towards images not containing a face (relative to central fixation and expressed in % image height). This was indeed the case ($r = .49$-$.78$ across samples, all $P < .05$; Fig. S6*B*).

Crucially, however, individual differences in face salience persisted independent of this spatial bias. To test whether individual salience preferences depended on visual field biases, we tested whether individual differences in face salience persisted for the lower visual field, correlating the individual percentage of first fixations landing on faces in the upper visual field (UVF) with that landing on faces in the lower visual field (LVF). For this analysis, we defined UVF and LVF faces as those for which the median height of the pixel mask was in the upper and lower image half, respectively. Importantly, individual face salience was stable across the UVF and LVF, showing that it persisted independently of the UVF bias ($r$ = .61-.87 across samples, all $P < .05$; Fig. S6*C*).

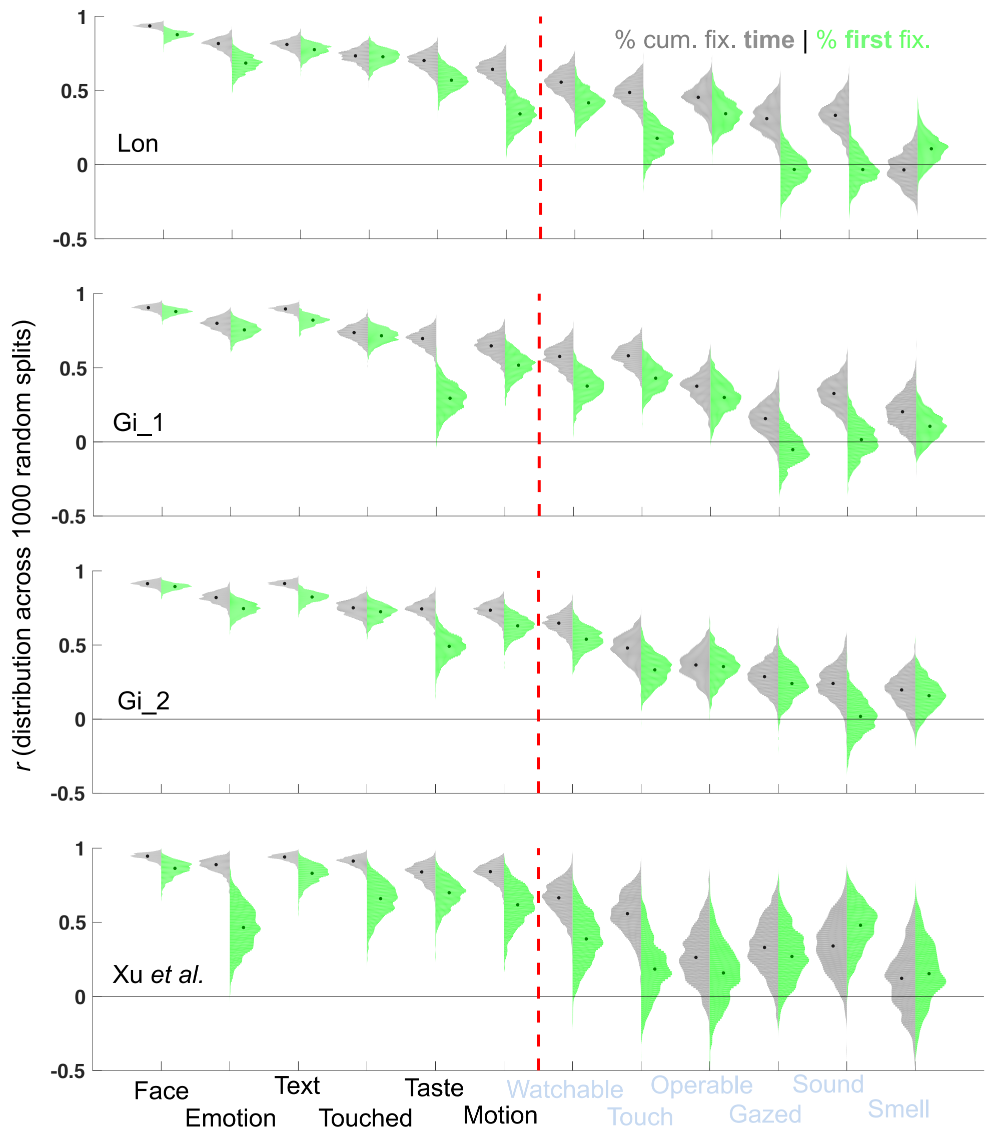


**Figure S1. Consistency of results across datasets.** Distribution of bootstrapped split-half correlations for each of the twelve semantic dimensions tested (as indicated by the labels on the lowermost x-axis). Results are shown separately for the four observer samples tested (as indicated by the row labels). Gi_1 and Gi_2 refer to the first and second appointment of the Gi sample. The grey left-hand leaf of each distribution plot shows a histogram of split-half correlations for 1000 random splits of the image set, the green right hand leaf shows the corresponding histogram for *first* fixations after image onset. Overlaid dots indicate the median consistency correlation for each distribution. High split-half correlations indicate consistent individual differences in fixation across images for a given dimension. The dashed red line separates the six attributes found to be consistent dimensions of individual differences in the *Lon* sample. Note the similarity of results across datasets.

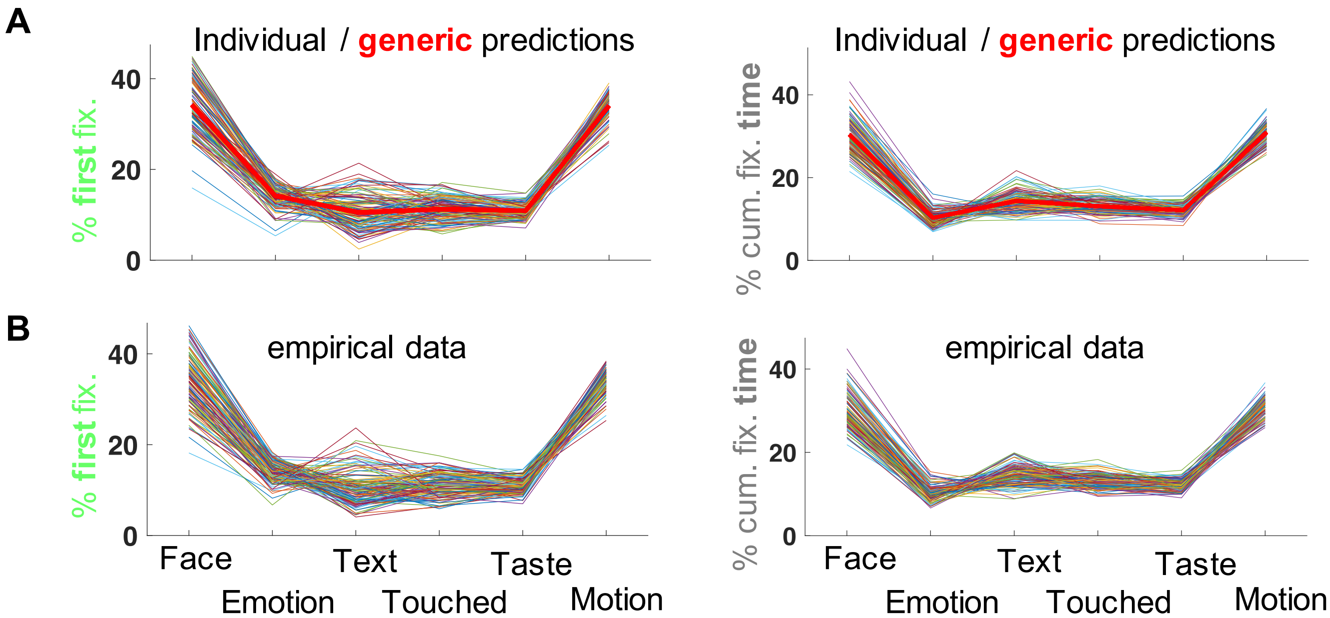


**Figure S2. Individual and generic predictions of fixation behavior.** (***A***) Predicted proportions of fixations along the six semantic dimensions of individual salience. Thin lines show individual predictions based on deviations from the group for an independent training set of images. The thicker red lines show the ideal generic prediction. (***B***) Empirical fixation data for the same individuals and along the same dimensions. Both panels show first fixation data on the left-hand side and cumulative dwell time on the right, as indicated by the axis labels.

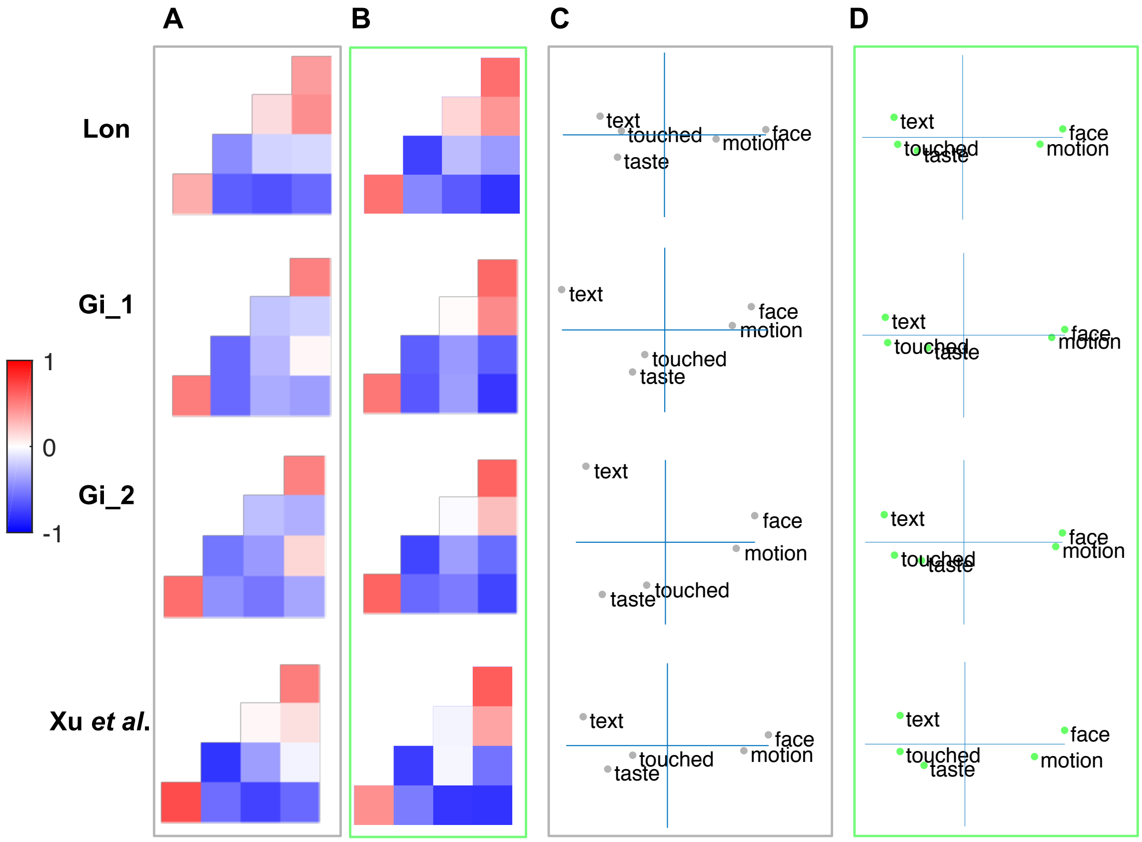


**Fig. S3. Consistency of covariance pattern across datasets.** (*A*) shows covariance patterns for dimensions of individual differences in cumulative fixation durations and (*B*) those for individual differences in the proportion of first fixations. Each row shows the results for one dataset as indicated (Lon, Gi_1, Gi_2 and Xu et al.). Colors of the left hand correlation matrices indicate pairwise Pearson correlation coefficients between dimensions as indicated by the bar. Please refer to Fig. 4 for dimension labels (please note that due to space constraints the diagonal of identity values has been dropped; from top to bottom: taste, text, motion, face; from left to right: motion, text, taste, touched). Note the similarity of covariance patterns between datasets. All pairwise correlations between (Fisher z-transformed) correlation matrices were >.68 for cumulative fixation durations and >.90 for first fixations. The right hand side scatter plots show the results of metric multidimensional scaling onto two dimensions for cumulative fixation duration (*C*) and first fixations (*D*). This analysis yielded a distinct cluster for Faces and Motion, as well as a cluster for Text, Touched Taste for first fixations in all datasets. This structure was very similar for cumulative dwell time, with the exception of Text separating from Touched and Taste in the Gi_1 and Gi_2 data.

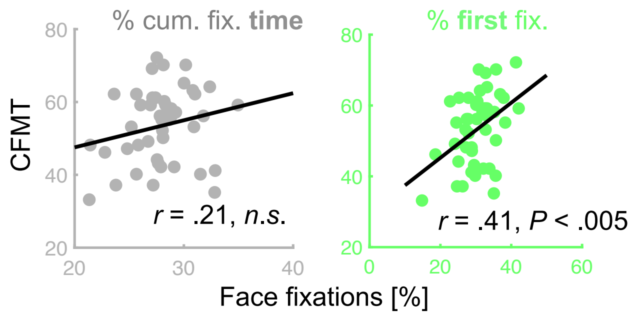


**Fig. S4. Correlation between fixation behavior and perceptual skills.** Performance on the Cambridge Face Memory Test (CMFT) correlated significantly with the individual proportion of first fixations landing on faces when freely viewing complex scenes (green, right hand side). This correlation was not significant for cumulative fixation time across the viewing time of three seconds (grey, left hand side). All data from the Gi_1 sample.

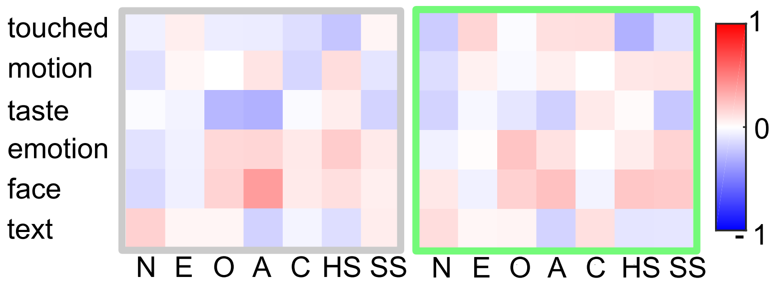


**Fig. S5. Fixation behavior and personality.** Neither cumulative fixation time (grey frame, left hand side), nor the proportion of first fixations (green frame, right hand side) towards any of the six dimensions of individual gaze behavior correlated significantly with any of the tested dimensions of personality (N: Neuroticism, E: Extraversion, O: Openness, A: Assertiveness, C: Conscientiousness, HS: High Sensitivity, SS: Sensation Seeking). All data from the Gi_1 sample.

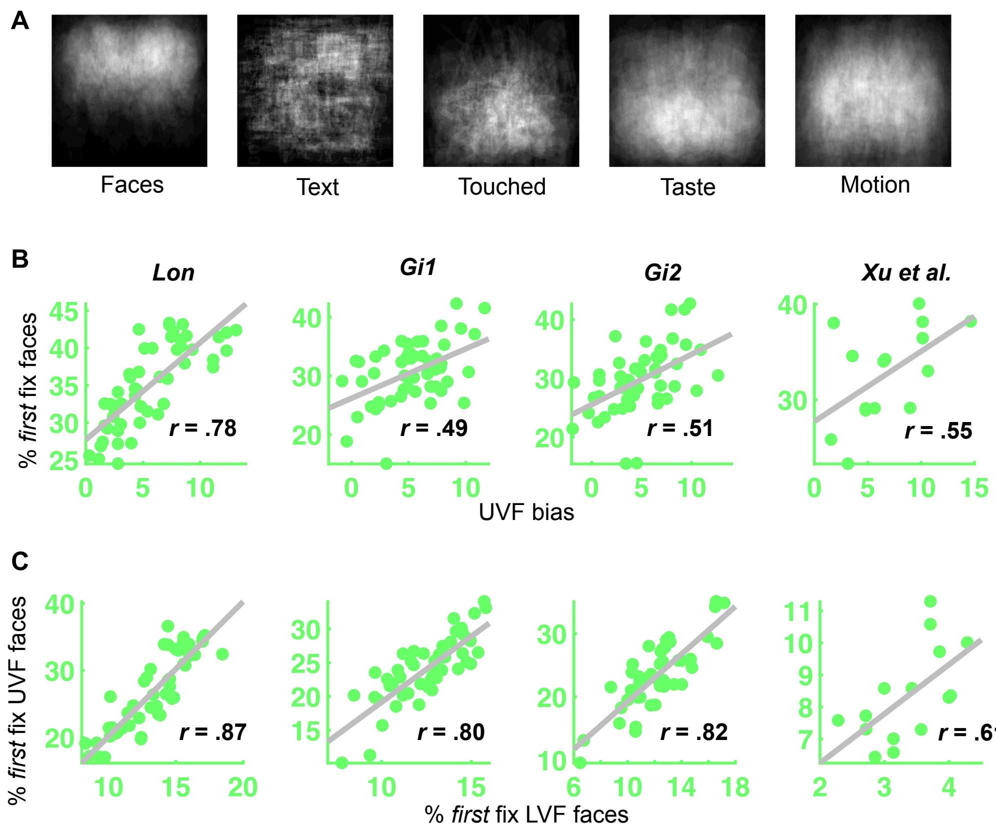


**Fig. S6. Individual salience and visual field biases.** (*A*) Distribution of different types of objects in image space across scenes. Notice the upwards bias of Faces. (*B*) Individual face salience significantly correlated with a general upper visual field bias in all four samples (i.e. with the elevation of first fixations towards images without a face; see Suppelemtary Results above for details). (*C*). Nevertheless, individual face salience persisted independent of this spatial bias. The individual proportion of first fixations landing in the upper and lower visual field (UVF and LVF) were highly correlated with each other.

**Table S1. Range and median consistency of individual differences in fixation behavior towards six semantic dimensions.** The left hand side of the table shows data for individual differences in the proportion of cumulative fixation time (across three seconds) spent on objects with the respective semantic attributes. The right hand side shows data on individual differences in the proportion of first fixations after image onset landing on objects with those attributes. For each semantic attribute, the data from different samples (*Lon*, *Gi_1, Gi_2* and *Xu et al.*) is presented in separate rows. The range across participants is given in % fixation time or % of first fixations and the max/min ratio indicates the relative difference between observers attracted the most or least by a given attribute. Pearson correlations (*r*) indicate the median split-half correlation of individual differences across 1000 random image splits and the corresponding *P*-value (Bonferroni corrected for 12 semantic attributes in the *Lon* sample, as indicated by the *). Consistency correlations failing to reach statistical significance are highlighted in red. The final row for each attribute shows the corresponding re-test reliability across several weeks.

| | **Ind. % fixation time** | | | | **Ind. % first fix** | | | |
|---|---|---|---|---|---|---|---|---|
| | ***r*** | ***P*** | **range[%]** | **max/min** | ***r*** | ***P*** | **range[%]** | **max/min** |
| **Faces - Lon** | .94 | <.001* | 24-43 | 1.80 | .88 | <.001* | 24-43 | 1.77 |
| **- Gi_1** | .91 | <.001 | 21-35 | 1.64 | .88 | <.001 | 15-42 | 2.82 |
| **– Gi_2** | .91 | <.001 | 17-34 | 1.99 | .89 | <.001 | 15-43 | 2.76 |
| **– Xu *et al.*** | .95 | <.001 | 23-35 | 1.50 | .86 | <.001 | 24-41 | 1.69 |
| **- Re-test** (Gi_1-2) | .80 | <.001 | - | - | .86 | <.001 | - | - |
| **Emotion - Lon** | .82 | <.001* | 8-15 | 1.93 | .69 | <.001* | 9-18 | 1.88 |
| **– Gi_1** | .80 | <.001 | 8-13 | 1.68 | .76 | <.001 | 8-17 | 2.20 |
| **– Gi_2** | .82 | <.001 | 7-13 | 1.79 | .75 | <.001 | 8-17 | 2.22 |
| **- Xu *et al.*** | .89 | <.001 | 8-12 | 1.56 | .48 | .07 | 13-17 | 1.31 |
| **- Re-test** (Gi_1-2) | .85 | <.001 | - | - | .79 | <.001 | - | - |
| **Text - Lon** | .81 | <.001* | 9-16 | 1.76 | .77 | <.001* | 6-17 | 2.96 |
| **– Gi_1** | .90 | <.001 | 9-19 | 1.97 | .82 | <.001 | 5-16 | 3.11 |
| **– Gi_2** | .91 | <.001 | 9-20 | 2.21 | .82 | <.001 | 4-17 | 3.91 |
| **- Xu *et al.*** | .94 | <.001 | 8-18 | 2.16 | .83 | <.001 | 4-13 | 3.25 |
| **- Re-test** (Gi_1-2) | .84 | <.001 | - | - | .89 | <.001 | - | - |
| **Touched - Lon** | .73 | <.001* | 11-16 | 1.52 | .73 | <.001* | 6-16 | 2.48 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **– Gi_1** | .74 | <.001 | 9-15 | 1.63 | .71 | <.001 | 6-15 | 2.65 |
| **– Gi_2** | .75 | <.001 | 9-16 | 1.67 | .72 | <.001 | 6-16 | 2.74 |
| **- Xu *et al.*** | .91 | <.001 | 9-16 | 1.85 | .65 | .008 | 7-13 | 1.81 |
| **- Re-test** (Gi_1-2) | .70 | <.001 | - | - | .78 | <.001 | - | - |
| **Taste - Lon** | .70 | <.001* | 10-16 | 1.58 | .57 | <.001* | 10-16 | 1.67 |
| **– Gi_1** | .70 | <.001 | 11-15 | 1.38 | .29 | .04 | 10-14 | 1.36 |
| **– Gi_2** | .74 | <.001 | 10-17 | 1.67 | .50 | <.001 | 9-16 | 1.75 |
| **- Xu *et al.*** | .84 | <.001 | 11-16 | 1.44 | .69 | .004 | 9-15 | 1.72 |
| **- Re-test** (Gi_1-2) | .78 | <.001 | - | - | .62 | <.001 | - | - |
| **Motion - Lon** | .64 | <.001* | 28-36 | 1.31 | .35 | .15* | 31-39 | 1.25 |
| **– Gi_1** | .65 | <.001 | 28-34 | 1.22 | .52 | <.001 | 30-38 | 1.29 |
| **– Gi_2** | .73 | <.001 | 26-33 | 1.29 | .52 | <.001 | 28-37 | 1.32 |
| **- Xu *et al.*** | .85 | <.001 | 28-33 | 1.19 | .62 | .01 | 33-40 | 1.22 |
| **- Re-test** (Gi_1-2) | .68 | <.001 | - | - | .78 | <.001 | - | - |

**Table S2. Correlations between individual salience and visual exploration.** The left hand side of the table shows correlations between visual explorations and individual differences in the proportion of cumulative fixation time (across three seconds) spent on objects with the respective semantic attributes. The right hand side shows correlations between visual explorations and individual differences in the proportion of first fixations after image onset landing on objects with those attributes. For each semantic attribute, the data from different samples (*Lon*, *Gi_1, Gi_2* and *Xu et al*.) is presented in separate columns. Pearson correlations (*r*) are printed in bold and marked with asterisks when crossing statistical significance (Holm-Bonferroni corrected for 6 dimensions of interest; *P < .05, **P< .01, ***P < .001).

| | Ind. % fixation time | | | | Ind. % first fix | | | |
|---|---|---|---|---|---|---|---|---|
| | **Lon** | **Gi1** | **Gi2** | **Xu *et al.*** | **Lon** | **Gi1** | **Gi2** | **Xu *et al.*** |
| **Faces** | -.21 | -.32 | -.26 | -.37 | .14 | -.14 | -.02 | -.40 |
| **Emotion** | **-.63*** ** | **-.55*** ** | **-.62*** ** | -.43 | .14 | -.17 | -.06 | -.51 |
| **Text** | .30 | .04 | .07 | .11 | .23 | .08 | .13 | .17 |
| **Touched** | .22 | .19 | -.03 | -.37 | -.04 | .09 | -.12 | .29 |
| **Taste** | .10 | .25 | .29 | .28 | -.24 | .02 | -.21 | .31 |
| **Motion** | **-.42** ** | -.35 | -.32 | -.56 | .-.10 | .01 | -.01 | -.26 |

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