MacDorman-Chattopadhyay-2016-Supplementary-Material

DATASET · OCTOBER 2015

2 AUTHORS:

Karl F. MacDorman
Indiana University

Debaleena Chattopadhyay
Indiana University-Purdue University Indiana…

Supplementary Material

Reducing consistency in human realism increases the uncanny valley effect; increasing category uncertainty does not

Karl F. MacDorman[a] and Debaleena Chattopadhyay[a]

[a]Indiana University School of Informatics and Computing, 535 Michigan St., Indianapolis, Indiana 46202 USA

Corresponding author: Karl F. MacDorman (kmacdorm@indiana.edu)

1. Supplementary data: Linear mixed-effects modeling

In our primary data analysis, we collapsed across each entity and investigated the three transitions: diagonal, lower right, and upper left. In a preliminary analysis, we investigated whether using a subset of entities in our experiments caused any significant random effects. We modeled our data in each transition using a linear mixed-effects model with fraction of real as a fixed factor and entity as a random factor. The following model was fitted by maximum likelihood for the four dependent variables: eeriness, warmth, response time (RT), and percentage categorized as real:

$$outcome_{i,j} = b_0 + u_{0,j} + b_1 fraction\ of\ real_{i,j} + b_2\,(entity\ X\ fraction\ of\ real)_{i,j} + \varepsilon_{i,j},$$

where $outcome_{i,j}$ was observed for the i^{th} fraction of the j^{th} entity.

We used the *lmer* package in R for our analysis (Bates, 2013; Bates, Maechler, & Bolker, 2012) and the *lmerTest* package (Kuznetsova, Brockhoff, & Christensen, 2013) to report the *F*-statistic using type III ANOVA with Satterthwaite approximation of degrees of freedom (Satterthwaite, 1946). The effect size of the linear mixed-effect models were analyzed using Ω_0^2—an extension of R^2 that accounts for the additional random effects (Xu, 2003). Effect sizes for Ω_0^2 were interpreted as follows: .01 as a small effect, .06 as a medium effect, and .14 as a large effect (Cohen, 1992). The prediction intervals for the random effect of entity on the four dependent variables are available in the archive. (Refer to the README for file details.)

1.1. Different human entities

Six human models—Zlakto, Ingrid, Clint, Emelie, Juliana, and Simona—were used in our experiments. Tables S1–S3 show the effect of each fixed-effect predictor (different levels of fraction of real) on eeriness ratings in three different transitions (diagonal, lower right, and upper left). Eeriness ratings were significantly affected by fraction of real in all three transitions: diagonal, $F(6, 36.90) = 92.96$, $MSE = 247.01$, $p < .001$; lower right, $F(6, 36.84) = 66.81$, $MSE = 185.84$, $p < .001$; and upper left $F(6, 35.75) = 41.17$, $MSE = 109.64$, $p < .001$. The fitted model showed that the variance explained by random effects of entity compared with the total variance of random effects was negligible (I^2, Higgins, Thompson, Deeks, & Altman, 2003): In the diagonal transition, entity caused 3.19%, and entity × fraction of real caused 1.31% variance; in the lower-right transition, entity caused 3.40%, and entity × fraction of real caused 2.06% variance; and in the upper-left transition, entity caused 3.00%, and entity × fraction of real caused 2.67% variance. However, the overall effect sizes of the fitted model in all three transitions were large, diagonal, Ω_0^2 = .23, lower right, Ω_0^2 = .24, and upper left, Ω_0^2 = .21, which can be attributed to the fixed factor, fraction of real.

Table S1: Parameters for Fixed Effects of Fraction of Real on Eeriness for Humans, Diagonal Transition

Predictor	Co-efficient (Slope)	SE	95% CI		*t* value
0–0 (Intercept)	0.99	.15	0.66,	1.32	6.49
⅙–⅙	–0.24	.13	–0.50,	0.02	–1.84
⅓–⅓	–0.58	.13	–0.84,	–0.32	–4.45
½–½	–1.24	.13	–1.50,	–0.98	–9.56
⅔–⅔	–1.78	.13	–2.04,	–1.52	–13.79
⅚–⅚	–2.06	.13	–2.32,	–1.80	–15.92
1–1	–2.12	.13	–2.38,	–1.86	–16.41

Table S2: Parameters for Fixed Effects of Fraction of Real on Eeriness for Humans, Lower-Right Transition

Predictor	Co-efficient (Slope)	SE	95% CI		*t* value
0–0 (Intercept)	0.99	.17	0.62,	1.35	5.78
0–⅓	–0.12	.16	–0.44,	0.20	–0.75
0–⅔	–0.25	.16	–0.57,	0.06	–1.61
0–1	–0.15	.16	–0.46,	0.17	–0.92
⅓–1	–1.01	.16	–1.33,	–0.69	–6.37
⅔–1	–1.98	.16	–2.30,	–1.66	–12.52
1–1	–2.12	.16	–2.44,	–1.80	–13.42

Table S3: Parameters for Fixed Effects of Fraction of Real on Eeriness for Humans, Upper-Left Transition

Predictor	Co-efficient (Slope)	SE	95% CI		*t* value
0–0 (Intercept)	0.99	.17	0.63,	1.34	5.80
⅓–0	–0.30	.17	–0.65,	0.04	–1.76
⅔–0	–0.71	.17	–1.06,	–0.37	–4.14
1–0	–0.71	.17	–1.06,	–0.36	–4.12
1–⅓	–1.13	.17	–1.48,	–0.78	–6.56
1–⅔	–1.86	.17	–2.21,	–1.52	–10.82
1–1	–2.12	.17	–2.47,	–1.77	–12.31

Similarly, warmth ratings were significantly affected by fraction of real in all three transitions: diagonal, $F(6, 36.21) = 20.81$, $MSE = 35.06$, $p < .001$; lower right, $F(6, 36.24) = 18.45$, $MSE = 33.14$, $p < .001$; and upper left $F(6, 36.29) = 19.30$, $MSE = 31.94$, $p < .001$. Tables S4–S6 show the effect of each fixed effect predictor on warmth ratings for the three transitions. The fitted model showed that the variance explained by random effects of entity compared with the total variance of random effects was small (I^2): diagonal, entity caused 19.32%, and entity × fraction of real caused 3.92%; lower right, entity caused 13.41%, and entity × fraction of real caused 4.36%; and upper left, entity caused

21.34%, and entity × fraction of real caused 3.27% variance. However, the overall effect sizes of the fitted model in all three transitions were large, diagonal, Ω_0^2 = .32, lower right, Ω_0^2 = .27, and upper left, Ω_0^2 = .31, which can be attributed to the fixed factor, fraction of real.

Table S4: Parameters for Fixed Effects of Fraction of Real on Warmth for Humans, Diagonal Transition

Predictor	Co-efficient (Slope)	SE	95% CI		*t* value
0–0 (Intercept)	–0.70	.29	–1.36,	–0.04	–2.37
⅙–⅙	0.12	.18	–0.23,	0.48	0.70
⅓–⅓	0.39	.18	0.03,	0.75	2.20
½–½	0.82	.18	0.47,	1.18	4.63
⅔–⅔	1.18	.18	0.83,	1.54	6.65
⅚–⅚	1.32	.18	0.97,	1.68	7.44
1–1	1.36	.18	1.00,	1.72	7.63

Table S5: Parameters for Fixed Effects of Fraction of Real on Warmth for Humans, Lower-Right Transition

Predictor	Co-efficient (Slope)	SE	95% CI		*t* value
0–0 (Intercept)	–0.70	.26	–1.26,	–0.13	–2.71
0–⅓	0.10	.19	–0.27,	0.48	0.55
0–⅔	0.15	.19	–0.22,	0.53	0.83
0–1	0.16	.19	–0.21,	0.54	0.87
⅓–1	0.67	.19	0.29,	1.04	3.57
⅔–1	1.23	.19	0.85,	1.60	6.57
1–1	–0.70	.26	0.98,	1.73	–2.71

Table S6: Parameters for Fixed Effects of Fraction of Real on Warmth for Humans, Upper-Left Transition

Predictor	Co-efficient (Slope)	SE	95% CI		*t* value
0–0 (Intercept)	–0.70	.30	–0.14	0.52	–2.31
⅓–0	0.19	.16	0.19,	0.85	1.17
⅔–0	0.52	.16	0.33,	0.99	3.17
1–0	0.66	.16	0.56,	1.21	4.04
1–⅓	0.89	.16	0.92,	1.58	5.41
1–⅔	1.25	.16	1.03,	1.69	7.62
1–1	1.36	.16	–0.14,	0.52	8.30

Similar to eeriness and warmth ratings, entity and entity × fraction of real explained negligible percentages of the total variance due to random effects on $\log_{10}$RT: diagonal, entity caused 0.80%, and entity × fraction of real caused 1.90% variance; lower right, entity caused 0.69%, and entity × fraction of real caused 2.80% variance; and upper left, entity caused 0.70%, and entity × fraction of real caused 1.41% variance. Similar results were found for category classification: diagonal, entity caused 4.64%, and entity × fraction of real caused 4.63% variance; lower right, entity caused 5.49%, and entity × fraction of real caused 6.27% variance; and upper left, entity caused 7.35%, and entity × fraction of real caused 7.05% variance.

Overall, the prediction intervals of the random effects confirmed that the conditional distribution of the random effects of entity had little overall variability (figures provided in the archive). To summarize, in our data the random effects of human entities explained little overall variance caused by chance (I^2 < 25%, Higgins et al., 2003). Hence, we used general linear modeling in our final analysis.

1.2. Different animal entities

Two animal models—dog and parrot—were used in our experiments. Tables S7–S9 show the effect of each fixed effect predictor on eeriness ratings in three different transitions. Eeriness ratings were significantly affected by fraction of real in all three transitions: diagonal, $F(6, 3127) = 138.91$, $MSE = 357.19$, $p < .001$; lower right, $F(6, 11.98) = 56.40$, $MSE = 153.02$, $p < .001$; and upper left $F(6, 3099) = 116.44$, $MSE = 325.82$, $p < .001$. The fitted model showed that variance explained by random effects of entity compared with the total variance of random effects was negligible: diagonal, entity caused 1.90%, and entity × fraction of real caused 0.00%; lower right, entity caused 4.92%, and entity × fraction of real caused 0.40%; and upper left, entity caused 0.40%, and entity × fraction of real caused 0.00%. However, the overall effect sizes of the fitted model in all three transitions were large, diagonal, $\Omega_0^2 = .22$, lower right, $\Omega_0^2 = .21$, and upper left, $\Omega_0^2 = .19$, which can be attributed to the fixed factor, fraction of real.

Table S7: Parameters for Fixed Effects of Fraction of Real on Eeriness for Animals, Diagonal Transition

Predictor	Co-efficient (Slope)	SE	95% CI		*t* value
0–0 (Intercept)	0.79	.18	0.23,	1.34	4.49
⅙–⅙	–0.34	.11	–0.55,	–0.13	–3.17
⅓–⅓	–0.80	.11	–1.01,	–0.59	–7.46
½–½	–1.47	.11	–1.68,	–1.26	–13.71
⅔–⅔	–1.92	.11	–2.13,	–1.71	–17.94
⅚–⅚	–2.17	.11	–2.38,	–1.96	–20.25
1–1	–2.17	.11	–2.38,	–1.96	–20.25

Table S8: Parameters for Fixed Effects of Fraction of Real on Eeriness for Animals, Lower-Right Transition

Predictor	Co–efficient (Slope)	SE	95% CI		*t* value
0–0 (Intercept)	0.79	.29	–0.14,	1.71	2.74
0–⅓	–0.41	.15	–0.73,	–0.08	–2.65
0–⅔	–0.70	.15	–1.02,	–0.37	–4.54
0–1	–0.85	.15	–1.17,	–0.52	–5.51
⅓–1	–1.48	.15	–1.81,	–1.16	–9.67
⅔–1	–1.98	.15	–2.31,	–1.66	–12.91
1–1	–2.17	.15	–2.50,	–1.85	–14.14

Table S9: Parameters for Fixed Effects of Fraction of Real on Eeriness for Animals, Upper-Left Transition

Predictor	Co–efficient (Slope)	SE	95% CI		*t* value
0–0 (Intercept)	0.79	.11	0.49,	1.08	7.24
⅓–0	–0.26	.11	–0.50,	–0.03	–2.35
⅔–0	–0.54	.11	–0.78,	–0.31	–4.87
1–0	–0.55	.11	–0.79,	–0.32	–4.94
1–⅓	–1.25	.11	–1.49,	–1.02	–11.21
1–⅔	–2.00	.11	–2.23,	–1.76	–17.85
1–1	–2.17	.11	–2.41,	–1.94	–19.41

Similarly, warmth ratings were significantly affected by fraction of real in all three transitions: diagonal, $F(6, 11.98) = 33.35$, $MSE = 68.81$, $p < .001$; lower right, $F(6, 11.99) = 52.55$, $MSE = 107.86$, $p < .001$; and upper left $F(6, 11.98) = 36.33$, $MSE = 75.79$, $p < .001$. Tables S10–S12 show the effect of each fixed effect predictor on warmth ratings for the three transitions. The fitted model showed that the variance explained by random effects of entity compared with the total variance of random effects was small (I^2): diagonal, entity caused 13.56%, and entity × fraction of real caused 5.06%; lower right, entity caused 16.24%, and entity × fraction of real caused 0.27%; upper left, entity caused 9.29%, and entity × fraction of real caused 0.70%. However, the overall effect sizes of the fitted model in all three transitions were large, diagonal, $\Omega_0^2 = .26$, lower right, $\Omega_0^2 = .27$; and upper left, $\Omega_0^2 = .23$, which can be attributed to the fixed factor, fraction of real.

Table S10: Parameters for Fixed Effects of Fraction of Real on Warmth for Animals, Diagonal Transition

Predictor	Co–efficient (Slope)	SE	95% CI		*t* value
0–0 (Intercept)	–0.52	.43	–1.95,	0.90	–1.22
⅙–⅙	0.28	.16	–0.06,	0.62	1.76
⅓–⅓	0.56	.16	0.21,	0.90	3.47
½–½	1.06	.16	0.72,	1.40	6.60
⅔–⅔	1.37	.16	1.03,	1.71	8.57
⅚–⅚	1.54	.16	1.20,	1.88	9.60
1–1	1.68	.16	1.34,	2.02	10.48

Table S11: Parameters for Fixed Effects of Fraction of Real on Warmth for Animals, Lower-Right Transition

Predictor	Co–efficient (Slope)	SE	95% CI		*t* value
0–0 (Intercept)	–0.52	.46	–2.06,	1.01	–1.15
0–⅓	0.22	.13	–0.04,	0.49	1.78
0–⅔	0.67	.13	0.40,	0.94	5.35
0–1	0.75	.13	0.48,	1.01	5.96
⅓–1	1.29	.13	1.02,	1.56	10.28
⅔–1	1.52	.13	1.25,	1.79	12.11
1–1	1.68	.13	1.41,	1.95	13.38

Table S12: Parameters for Fixed Effects of Fraction of Real on Warmth for Animals, Upper-Left Transition

Predictor	Co–efficient (Slope)	SE	95% CI		*t* value
0–0 (Intercept)	–0.52	.35	–1.66,	0.61	–1.51
⅓–0	0.12	.16	–0.22,	0.46	0.73
⅔–0	0.32	.16	–0.02,	0.66	2.01
1–0	0.33	.16	–0.01,	0.67	2.04
1–⅓	0.87	.16	0.53,	1.21	5.44
1–⅔	1.53	.16	1.19,	1.87	9.56
1–1	1.68	.16	1.34,	2.02	10.50

Similar to eeriness and warmth ratings, entity and entity × fraction of real explained negligible percentages of the total variance due to random effects on $\log_{10}$RT: diagonal, entity caused 1.60%, and entity × fraction of real caused 0.00% variance; lower right, entity caused 1.63%, and entity × fraction of real caused 0.00% variance; and upper left, entity caused 0.30%, and entity × fraction of real caused 0.50% variance. Similar results were found for category classification: diagonal, entity caused 0.06%, and entity × fraction of real caused 0.00% variance; lower right, entity caused 0.07%, and entity × fraction of real caused 0.19% variance; and upper left, entity caused 0.52%, and entity × fraction of real caused 0.58% variance.

To summarize, in our data the random effects of animal entities explained little overall variability caused by chance (I^2 < 25%, Higgins et al., 2003). Hence, we used general linear modeling in our final analysis.

1.3. Different object entities

Four object models—Ferrari, camera, water lily, and washer—were used in our experiments. Tables S13–S15 show the effect of each fixed effect predictor on eeriness ratings in three different transitions. Eeriness ratings were significantly affected by fraction of real in all three transitions: diagonal, $F(6, 4258) = 5.77$, $MSE = 10.50$, $p < .001$; lower right, $F(6, 4262) = 6.02$, $MSE = 11.31$, $p < .001$; and upper left $F(6, 4263) = 4.46$, $MSE = 8.54$, $p < .001$. The fitted model showed that the variance explained by random effects of entity compared with the total variance of random effects was negligible: diagonal, entity caused 3.84%, and entity × fraction of real caused 0.00%; lower right, entity caused 3.02%, and entity × fraction of real caused 0.00%; upper left, entity caused 3.58%, and entity × fraction of real caused 0.00%. The overall effect sizes of the fitted model in all three transitions were also small, diagonal, $\Omega_0^2 = .05$, lower right, $\Omega_0^2 = .04$, and upper left, $\Omega_0^2 = .05$.

Table S13: Parameters for Fixed Effects of Fraction of Real on Eeriness for Objects, Diagonal Transition

Predictor	Co–efficient (Slope)	SE	95% CI	t value
0–0 (Intercept)	–0.95	.15	–1.30, –0.59	–6.51
⅙–⅙	–0.12	.08	–0.28, 0.03	–1.61
⅓–⅓	–0.13	.08	–0.28, 0.03	–1.62
½–½	–0.22	.08	–0.37, –0.06	–2.78
⅔–⅔	–0.26	.08	–0.41, –0.11	–3.39
⅚–⅚	–0.38	.08	–0.54, –0.23	–4.97
1–1	–0.32	.08	–0.47, –0.17	–4.13

Table S14: Parameters for Fixed Effects of Fraction of Real on Eeriness for Objects, Lower-Right Transition

Predictor	Co–efficient (Slope)	SE	95% CI	t value
0–0 (Intercept)	–0.94	.13	–1.27, –0.62	–7.09
0–⅓	–0.06	.08	–0.21, 0.10	–0.71
0–⅔	–0.16	.08	–0.31, 0.00	–1.99
0–1	–0.20	.08	–0.36, –0.05	–2.56
⅓–1	–0.31	.08	–0.47, –0.16	–4.00
⅔–1	–0.35	.08	–0.50, –0.19	–4.40
1–1	–0.32	.08	–0.47, –0.17	–4.07

Table S15: Parameters for Fixed Effects of Fraction of Real on Eeriness for Objects, Upper-Left Transition

Predictor	Co–efficient (Slope)	SE	95% CI	t value
0–0 (Intercept)	–0.95	.14	–1.30, –0.59	–6.54
⅓–0	–0.08	.08	–0.24, 0.07	–1.05
⅔–0	–0.11	.08	–0.27, 0.04	–1.40
1–0	–0.15	.08	–0.31, 0.00	–1.94
1–⅓	–0.25	.08	–0.41, –0.10	–3.16
1–⅔	–0.29	.08	–0.45, –0.14	–3.70
1–1	–0.32	.08	–0.47, –0.16	–4.03

Similarly, warmth ratings were significantly affected by fraction of real in all three transitions: diagonal, $F(6, 4259) = 8.42$, $MSE = 7.98$, $p < .001$; lower right, $F(6, 4263) = 8.52$, $MSE = 8.51$, $p < .001$; and upper left $F(6, 4264) = 8.94$, $MSE = 8.26$, $p < .001$. Tables S16–S18 show the effect of each fixed effect predictor on warmth ratings for the three transitions. The fitted model showed that the variance explained by random effects of entity compared with the total variance of random effects was small (I^2): diagonal, entity caused 13.45%, and entity × fraction of real caused 0.00%; lower right, entity caused 14.25%, and entity × fraction of real caused 0.00%; upper left, entity caused 13.69%, and entity × fraction of real caused 0.00%. However, the overall effect sizes of the fitted model in all three transitions were large, diagonal, $\Omega_0^2 = .14$, lower right, $\Omega_0^2 = .14$, and upper left, $\Omega_0^2 = .14$, which can be attributed to the fixed factor, fraction of real.

Table S16: Parameters for Fixed Effects of Fraction of Real on Warmth for Objects, Diagonal Transition

Predictor	Co–efficient (Slope)	SE	95% CI		*t* value
0–0 (Intercept)	0.09	.20	–0.41,	0.58	0.44
⅙–⅙	0.06	.06	–0.05,	0.17	1.00
⅓–⅓	0.13	.06	0.02,	0.24	2.28
½–½	0.14	.06	0.03,	0.25	2.56
⅔–⅔	0.25	.06	0.14,	0.36	4.47
⅚–⅚	0.24	.06	0.13,	0.35	4.27
1–1	0.32	.06	0.21,	0.43	5.80

Table S17: Parameters for Fixed Effects of Fraction of Real on Warmth for Objects, Lower-Right Transition

Predictor	Co–efficient (Slope)	SE	95% CI		*t* value
0–0 (Intercept)	0.09	.21	–0.44,	0.61	0.41
0–⅓	0.07	.06	–0.04,	0.18	1.21
0–⅔	0.17	.06	0.06,	0.29	3.02
0–1	0.21	.06	0.09,	0.32	3.61
⅓–1	0.26	.06	0.15,	0.37	4.59
⅔–1	0.29	.06	0.17,	0.40	5.02
1–1	0.32	.06	0.21,	0.44	5.65

Table S18: Parameters for Fixed Effects of Fraction of Real on Warmth for Objects, Upper-Left Transition

Predictor	Co–efficient (Slope)	SE	95% CI		*t* value
0–0 (Intercept)	0.09	.20	–0.40,	0.58	0.45
⅓–0	0.04	.06	–0.07,	0.15	0.69
⅔–0	0.08	.06	–0.02,	0.19	1.53
1–0	0.11	.06	0.01,	0.22	2.06
1–⅓	0.19	.06	0.08,	0.30	3.46
1–⅔	0.25	.06	0.14,	0.35	4.47
1–1	0.32	.06	0.22,	0.43	5.87

Similar to eeriness and warmth ratings, entity and entity × fraction of real explained negligible percentages of the total variance due to random effects on $\log_{10}$RT: diagonal, entity caused 0.15%, and entity × fraction of real caused 0.49% variance; lower right, entity caused 0.75%, and entity × fraction of real caused 0.17% variance; and upper left, entity caused 0.83%, and entity × fraction of real caused 0.07% variance. Similar results were found for category classification: diagonal, entity caused 4.91%, and entity × fraction of real caused 1.40% variance; lower right, entity caused 2.74%, and entity × fraction of real caused 2.45% variance; and upper left, entity caused 7.36%, and entity × fraction of real caused 2.49% variance.

To summarize, in our data the random effects of object entities explained little overall variance caused by chance ($I^2 < 25\%$, Higgins et al., 2003). Hence, we used general linear modeling in our final analysis.

2. Supplementary data: Investigating order effects of the experimental design

2.1. Participants and procedure

We recruited 74 additional participants (Mdn_{age} = 19, IQR_{age} = 5.75, 72% female) for this round of the experiment. Each participant was presented with 17 representations of four different entities: Clint, Ingrid, dog, and camera.

These 17 representations were the 2 representations at the endpoints of all transitions and the 15 representations that were unique to one of the three transitions: 5 from the diagonal, 5 from the lower right, and 5 from the upper left. The order of this round was reversed from the previous rounds: Each participant first rated the task stimuli and then performed the categorization tasks. The order was reversed to determine whether order influenced our previous findings.

2.2. Order effect of task stimuli ratings and categorization tasks

To investigate the effect of order, we conducted a mixed ANOVA with *fraction of real* as a within-group factor, and *order* as between-group factor. From previous rounds of the experiment (where participants performed the categorization tasks prior to the task stimuli ratings), we had 224 participants who were presented with Ingrid and dog, 181 participants who were presented with Clint, and 143 participants who were presented with camera. (We did not record realism ratings for Clint in the previous round.) The objective of our analysis was to determine whether the order influenced the effect of the independent variable (fraction of real) on the dependent variables (subjective ratings on eeriness, warmth, and realism indices, percentage categorized as real, and response time). We found that the interaction effect of fraction of real × order on the dependent variables was either not significant or significant with a negligible effect size (maximum η_p^2 = .015). Significant interaction effects can be attributed to the large number of data points which ranged from 3686 to 11288. Nevertheless, we found at most a negligible effect size.

Fraction of real × order significantly affected eeriness ratings with a negligible effect size for Clint, $F(7.93, 1958) = 2.00$, $MSE = 3.23$, $p = .043$, $\eta_p^2 = .008$, Ingrid, $F(6.36, 1852) = 2.49$, $MSE = 4.84$, $p = .019$, $\eta_p^2 = .008$, and dog, $F(6.97, 2000) = 2.25$, $MSE = 3.91$, $p = .028$, $\eta_p^2 = .008$, but did not affect ratings for camera. Fraction of real × order significantly affected warmth ratings with a negligible effect size for Clint, $F(8.66, 2140) = 2.15$, $MSE = 1.53$, $p = .025$, $\eta_p^2 = .009$, but did not affect ratings for Ingrid, dog, or camera. Fraction of real × order significantly affected realism ratings with a small effect size: Ingrid, $F(8.29, 2412) = 3.55$, $MSE = 2.21$, $p < .001$, $\eta_p^2 = .01$, dog, $F(10.33, 2965) = 1.87$, $MSE = 2.44$, $p = .042$, $\eta_p^2 = .006$; and camera, $F(7.39, 1567) = 2.06$, $MSE = 4.09$, $p = .042$, $\eta_p^2 = .01$. Fraction of real × order significantly affected percentage categorized as real with a negligible effect size for Clint, $F(10.76, 7125) = 1.95$, $MSE = 0.16$, $p = .031$, $\eta_p^2 = .003$, and camera, $F(10.75, 4644) = 6.73$, $MSE = 0.20$, $p < .001$, $\eta_p^2 = .015$, but not for Ingrid or Dog. Fraction of real × order significantly affected response time with a negligible effect size for Clint, $F(13.39, 8849) = 2.38$, $MSE = .03$, $p = .003$, $\eta_p^2 = .004$, Ingrid, $F(13.55, 8034) = 2.39$, $MSE = 0.02$, $p = .003$, $\eta_p^2 = .004$, and dog, $F(13.52, 8019) = 2.57$, $MSE = 0.02$, $p = .001$, $\eta_p^2 = .004$, but not for camera.

As an example, Figure 1 shows how eeriness ratings for Clint along the diagonal transition varied between the two orders of the experiments. Furthermore, fraction of real had similar effects as in previous rounds.

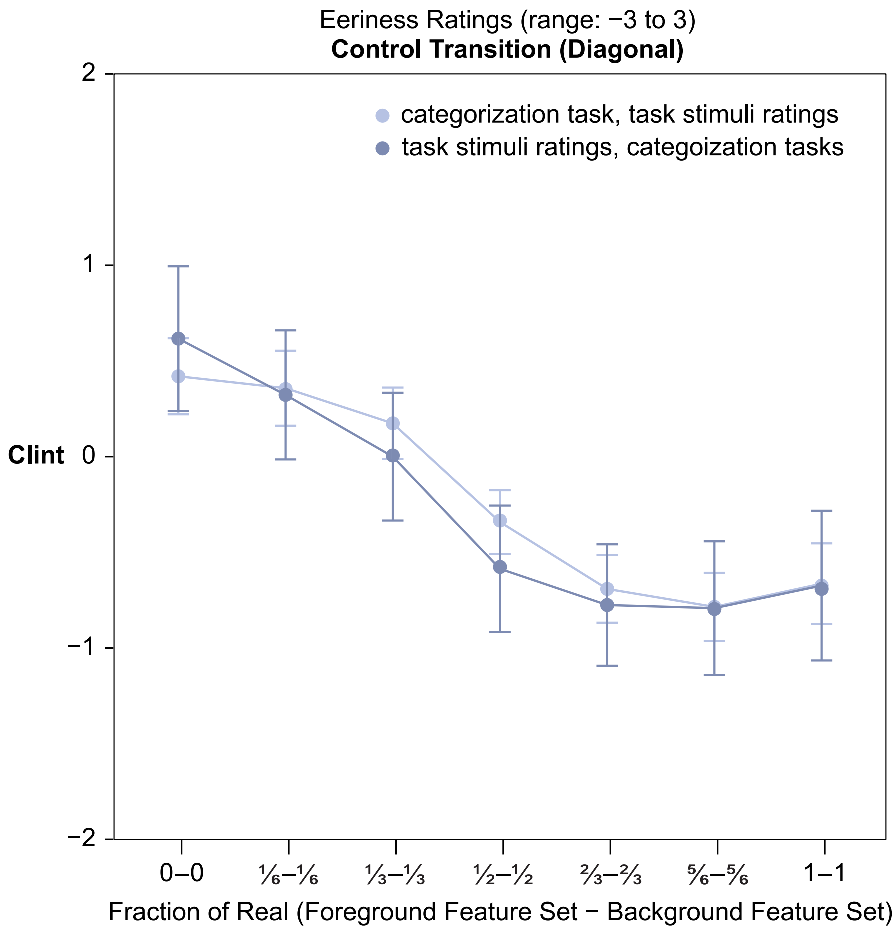

Fig. 1. The effect of fraction of real × order on eeriness ratings for Clint along the diagonal transition.

2.3. Effect of fraction of real on realism ratings

We conducted three within-group, repeated-measures ANOVAs to investigate the effect of fraction of real on realism ratings for each of the three transitions: diagonal, lower right, and upper left. For the two human models, fraction of real significantly affected realism ratings for all three transitions with a large effect size: diagonal, $F(4.12, 602) = 508$, $MSE = 2.02$, $p < .001$, $\eta_p^2 = .78$; lower right, $F(3.78, 548) = 453$, $MSE = 2.22$, $p < .001$, $\eta_p^2 = .76$; and upper left, $F(3.97, 584) = 1015$, $MSE = 1.59$, $p < .001$, $\eta_p^2 = .81$. Similar results were found for the animal model: diagonal, $F(4.16, 304) = 203$, $MSE = 2.03$, $p < .001$, $\eta_p^2 = .74$; lower right, $F(4.85, 354) = 141$, $MSE = 1.89$, $p < .001$, $\eta_p^2 = .66$; and upper left, $F(3.07, 221) = 266$, $MSE = 2.15$, $p < .001$, $\eta_p^2 = .79$; and for the object model: diagonal, $F(4.87, 355) = 55.27$, $MSE = 2.63$, $p < .001$, $\eta_p^2 = .43$; lower right, $F(6, 432) = 49.27$, $MSE = 2.12$, $p < .001$, $\eta_p^2 = .41$; and upper left, $F(4.06, 296) = 82.46$, $MSE = 3.03$, $p < .001$, $\eta_p^2 = .53$. Realism sensitivity increased with anthropomorphism. These results confirm that participants perceived the fraction-of-real manipulation similar to the previous rounds of experiments where the categorization tasks preceded the task stimuli ratings.

2.4. Effect of fraction of real on eeriness ratings

For the two human models in the high anthropomorphism group (n = 148), three within-group, repeated-measures ANOVAs confirmed that fraction of real significantly affected eeriness ratings for all three transitions of the human models with a large effect size: diagonal, $F(4.55, 664) = 105$, $MSE = 2.41$, $p < .001$, $\eta_p^2 = .42$; lower right, $F(4.57, 663) = 118$, $MSE = 2.41$, $p < .001$, $\eta_p^2 = .45$; and upper left, $F(4.86, 714) = 97.07$, $MSE = 2.22$, $p < .001$, $\eta_p^2 = .40$. Fraction of real also significantly affected eeriness ratings for all three transitions of the animal model with a large effect size: diagonal, $F(3.58, 261) = 53.83$, $MSE = 2.87$, $p < .001$, $\eta_p^2 = .42$; lower right, $F(4.14, 302) = 47.26$, $MSE = 2.45$, $p < .001$, $\eta_p^2 = .39$; and upper left, $F(4.31, 310) = 63.95$, $MSE = 2.51$, $p < .001$, $\eta_p^2 = .47$. However, for the object model, fraction of real significantly affected eeriness ratings with a small effect size only for the lower right transition, $F(4.78, 344) = 2.88$, $MSE = 2.57$, $p = .016$, $\eta_p^2 = .04$, but not for the diagonal and upper-left transitions.

2.5. Effect of fraction of real on warmth ratings

For the two human models in the high anthropomorphism group, three within-group, repeated-measures ANOVAs confirmed that fraction of real significantly affected warmth ratings for all three transitions of the human models with a large effect size: diagonal, $F(3.49, 510) = 56.34$, $MSE = 1.86$, $p < .001$, $\eta_p^2 = .28$; lower right, $F(3.82, 554) = 64.24$, $MSE = 1.75$, $p < .001$, $\eta_p^2 = .31$; and upper left, $F(4.01, 589) = 53.95$, $MSE = 1.45$, $p < .001$, $\eta_p^2 = .27$. Fraction of real significantly affected warmth ratings for all three transitions of the animal model with a large effect size: diagonal, $F(3.05, 223) = 40.45$, $MSE = 2.00$, $p < .001$, $\eta_p^2 = .36$; lower right, $F(3.86, 282) = 35.81$, $MSE = 1.59$, $p < .001$, $\eta_p^2 = .33$; and upper left, $F(3.37, 243) = 44.50$, $MSE = 2.23$, $p < .001$, $\eta_p^2 = .38$. However, for the object model, fraction of real significantly affected warmth ratings with a small effect size only for the diagonal transition, $F(3.77, 275) = 3.54$, $MSE = 0.46$, $p < .001$, $\eta_p^2 = .05$, but not for the lower-right and upper-left transitions.

The overall effects of the fraction of real on eeriness and warmth ratings were similar to the previous round of experiments where the categorization tasks preceded the task stimuli ratings. However, we did not find a significant effect of fraction of real on eeriness ratings for an object in the diagonal and upper-left transitions, or on warmth ratings for an object in the upper-left and lower-right transitions, which we found in the previous round of experiments. This lack of significance might be because of the sample size (n = 610) and the use of four different object models in the previous round as compared with only one of those four models in the current round of experiment and a smaller sample size (n = 74).

2.6. Effect of fraction of real on response time in the categorization task

For the two human models in the high anthropomorphism group, three within-group, repeated-measures ANOVAs confirmed that fraction of real significantly affected log-RTs for all three transitions of the human model with a large effect size: diagonal, $F(5.07, 1496) = 62.86$, $MSE = 0.02$,

p < .001, η_p^2 = .18; lower right, F(5.03, 1482) = 50.04, MSE = 0.02, p < .001, η_p^2 = .15; and upper left, F(5.18, 1528) = 66.23, MSE = 0.02, p < .001, η_p^2 = .18. Fraction of real also significantly affected log-RTs for all three transitions of the animal model with a medium or large effect size: diagonal, F(5.26, 774) = 28.59, MSE = 0.02, p < .001, η_p^2 = .16; lower right, F(5.52, 812) = 22.84, MSE = 0.02, p < .001, η_p^2 = .13; and upper left, F(4.74, 697) = 41.34, MSE = 0.02, p < .001, η_p^2 = .22; and all three transitions of the object model with a small or medium effect size: diagonal, F(6, 882) = 10.24, MSE = 0.02, p < .001, η_p^2 = .07; lower right, F(4.94, 726) = 5.59, MSE = 0.02, p < .001, η_p^2 = .04; and upper left, F(5.38, 791) = 12.09, MSE = 0.02, p < .001, η_p^2 = .08.

In line with previous literature on implicit association test (IAT) studies (Nosek, Greenwald, & Banaji, 2005; Nosek, Greenwald, & Banaji, 2007) that reported no order effect of administering implicit and explicit measures on the subjects' performance (Hofmann, Gawronski, Gschwendner, Le, & Schmidt, 2005), we found that our results were either not significantly affected by the order in the experiment, or were significantly affected by the order with a negligible effect size.

3. Research design rationale

Human likeness and realism have been identified as important continua for understanding the uncanny valley phenomenon. Human likeness corresponds to the x-axis in Mori's original graph. Unfortunately, human likeness is not amenable to rigorous experimental control, because it is difficult to align features between humans and nonhuman objects and morphing between dissimilar features can create unintended and sometimes disturbing image artifacts.

Animacy is also a dimension important to understanding the uncanny. Although we engaged participants in categorizing and rating the animacy of two humans and two animals, these results were similar to those for realism and would not have led to a different interpretation with respect to the hypotheses. In addition, it would not have made sense to apply animacy categorizations to inanimate objects. Thus, our manipulation and analyses focused on realism. In the interest of experimental control, all stimuli were created by placing an entity's photograph on a layer above a render of its precisely aligned 3D computer model and varying the opacity of its feature sets.

This study attempted to reduce fatigue and learning effects by only using seven levels of objective realism for two sets of features. This number seemed justified given that past studies with more levels found no sharp discontinuities in their dependent variables. The number of stimuli per entity was further reduced from 49 to 17 by using only three transitions, which cut the length of the categorization task by nearly two thirds. The results were in accord with these design choices.

Stimuli on the control transition (diagonal) were paired with stimuli on the transitions with reduced consistency in feature realism (lower right and upper left) with the following justification: Each control stimulus can be recreated simply by averaging the two consistency-reduced stimuli with which it is paired.

The maximally ambiguous stimulus is by definition the stimulus that elicits the most uncertainty. It is operationalized in a two-alternative forced-choice categorization task as the stimulus that is placed in each category 50% of the time. Because this study used discrete levels of objective realism, the analyses instead used the most ambiguous stimulus among those seven levels.

The analyses did not use the slowest response time, because factors other than uncertainty, such as perceived attractiveness, youthfulness, inconsistency, and novelty, could cause participants to look at a stimulus longer (Faw, 1970; Greenberg, Uzgiris, & Hunt, 1970; Langlois, Roggman, and Rieser-Danner, 1990; Quinsey, Ketsetzis, Earls, & Karamanoukian, 1996). For example, in a two-alternative categorization task, participants' responses were significantly slower when viewing headshots of their sexually preferred targets (Imhoff et al., 2010). Nevertheless, using response time as a measure of ambiguity would not have altered the conclusions of this study because, for each group and transition, the stimulus with the slowest response time and with the most ambiguity were either the same stimulus or stimuli that were not significantly different in their response times.

It was initially planned to use stimuli derived from only two men and two women in this study. However, the 3D computer models were rated considerably eerier and less warm than the photographs of the actual humans. In an effort to explore the shape of the curves for other cases, two additional women were used. These young and attractive women were professionally modeled by commercial 3D artists with makeup added manually to enhance their attractiveness. Nevertheless, they remained eerier and less warm than their real human counterparts.

Although categorization tasks typically use contrastive target concepts, *computer animated* was used as the alternative to *real* for two reasons: (a) given the study's focus on the uncanny valley in computer animation in films and videogames, *computer animated* has ecological validity; and (b) alternative concepts like *unreal, fake,* or *artificial* lend themselves to misinterpretation. For example, a computer-modeled bird is a real, albeit artificial, representation of an entity that is itself real, authentic, and natural. Human artifacts and fantasy creatures are artificial in a completely different sense.

Throughout this study, participants rated humans, animals, and objects on evaluative indices of realism, warmth, and eeriness. The warmth index was included because warmth is the primary dimension of interpersonal perception. However, a limitation in applying this index to inanimate objects is a possible attenuation in the response variance owing to the use of anchors that presuppose sociality (e.g., a washing machine is not typically described as *grumpy* or *cheerful*). An alternative would be to use a pleasantness or attractiveness index. The eeriness index, however, is not subjected to this limitation, because attributions of eeriness are made both with respect to low anthropomorphism objects, such as dark forests, ominous clouds, and brooding music, as well as human beings and other animals.

Another concern with the warmth index is its inclusion of polysemes. Specifically, the semantic differential item *warm-hearted–cold-hearted* can be interpreted in terms of physical objects and their properties (i.e., a heart's temperature) or psychological traits (i.e., good natured or uncaring). The related meanings of polysemous items could cause them to load differently on humans, animals, and objects because psychological traits are salient only at higher levels of anthropomorphism. Alternatively, the participant may try to infer how the experimenter expects the psychological trait to be applied to an inanimate object, drawing an ad-hoc conclusion that would vary across participants. (Barsalou, 1983). An area for future investigation is whether each evaluative index measures a single concept regardless of an entity's level of anthropomorphism.

For the categorization task and the task stimuli ratings, 17 versions of each entity were presented in random order. The stimuli corresponding to each transition were not segregated into their own blocks. Block segregation by transition would decrease sensitization to stimuli in other transitions at the risk of increasing habituation in each block from exposure to fewer, more homogeneous stimuli. This kind of repeated exposure to relatively homogenous stimuli should be avoided because it could result in temporary distortions in the rating of faces after seeing long sequences of similar faces (Seyama & Nagayama, 2009). Presenting stimuli in a more varied context may also have greater ecological validity because in real life people are seldom exposed to a sequence of highly similar faces.

References

Barsalou, L. W. (1983). Ad hoc categories. *Memory & Cognition, 11*(3), 211–227.

Bates, D., (2013). Linear mixed model implementation in lme4. *University of Wisconsin*. [PDF Document]. Retrieved from: http://www.icesi.edu.co/CRAN/web/packages/lme4/vignettes/Implementation.pdf

Bates, D., Maechler, M., & Bolker, B. (2012). lme4: Linear mixed–effects models using S4 classes. Retrieved from: http://cran.r-project.org/web/packages/lme4/index.html

Cohen, J. (1992). Statistical power analysis. *Current directions in psychological science, 1(3)*, 98–101. doi:10.1111/1467-8721.ep10768783

Faw, T. T., (1970). The effects of stimulus incongruity on the free looking time of adults and children. *Psychonomic Science, 19*(6), 355–357. doi:10.3758/BF03328857

Greenberg, D., Uzgiris, I. C., & Hunt, J. McV. (1970). Attentional preference and experience: III. Visual familiarity and looking time. *Genetic Psychology, 117*(1), 123–135.

Higgins, J., Thompson, S. G., Deeks, J. J., & Altman, D. G. (2003). Measuring inconsistency in meta–analyses. *BMJ*, *327*(7414), 557–560. doi:10.1136/bmj.327.7414.557

Hofmann, W., Gawronski, B., Gschwendner, T., Le, H., & Schmitt, M. (2005). A meta-analysis on the correlation between the Implicit Association Test and explicit self-report measures. *Personality and Social Psychology Bulletin, 31(10)*, 1369–1385. doi:10.1177/0146167205275613

Imhoff, R., Schmidt, A. F., Nordsiek, U., Luzar, C., Young, A. W., & Banse, R. (2010). Viewing time effects revisited: Prolonged response latencies for sexually attractive targets under restricted task conditions. *Archives of Sexual Behavior, 39*(6), 1275–1288. doi:10.1007/s10508-009-9595-2

Langlois, J. H., Roggman, L. A., Rieser-Danner, L. A. (1990). Infants' differential social responses to attractive and unattractive faces. *Developmental Psychology, 26*(1), 153–159. doi:10.1037/0012-1649.26.1.153

Kuznetsova, A., Brockhoff, P. B., & Christensen, R. H. B. (2013). lmerTest: Tests for random and fixed effects for linear mixed effect models (lmer objects of lme4 package). *R package version*, 2–0. Retrieved from: http://cran.r-project.org/web/packages/lmerTest/lmerTest.pdf

Nosek, B. A., Greenwald, A. G., & Banaji, M. R. (2007). The Implicit Association Test at age 7: A methodological and conceptual review. In J. A.Bargh (Ed.), *Automatic processes in social thinking and behavior*, 265–292, New York: Psychology Press.

Nosek, B. A., Greenwald, A. G., & Banaji, M. R. (2005). Understanding and using the Implicit Association Test: II. Method variables and construct validity. *Personality and Social Psychology Bulletin, 31(2)*, 166–180. doi:10.1177/0146167204271418

Quinsey, V. L., Ketsetzis, M., Earls, C., & Karamanoukian, A. (1996). Viewing time as a measure of sexual interest. *Ethology and Sociobiology, 17*(5), 341–354. doi:10.1016/S0162-3095(96)00060-X

Satterthwaite, F. E. (1946). An approximate distribution of estimates of variance components. *Biometrics Bulletin, 2*(6), 110–114.

Seyama, J. I., & Nagayama, R. (2009). Probing the uncanny valley with the eye size aftereffect. *Presence: Teleoperators and Virtual Environments, 18*(5), 321-339. doi:10.1162/pres.18.5.321

Xu, R. (2003). Measuring explained variation in linear mixed effects models. *Statistics in medicine, 22(22)*, 3527–3541. doi: 10.1002/sim.1572