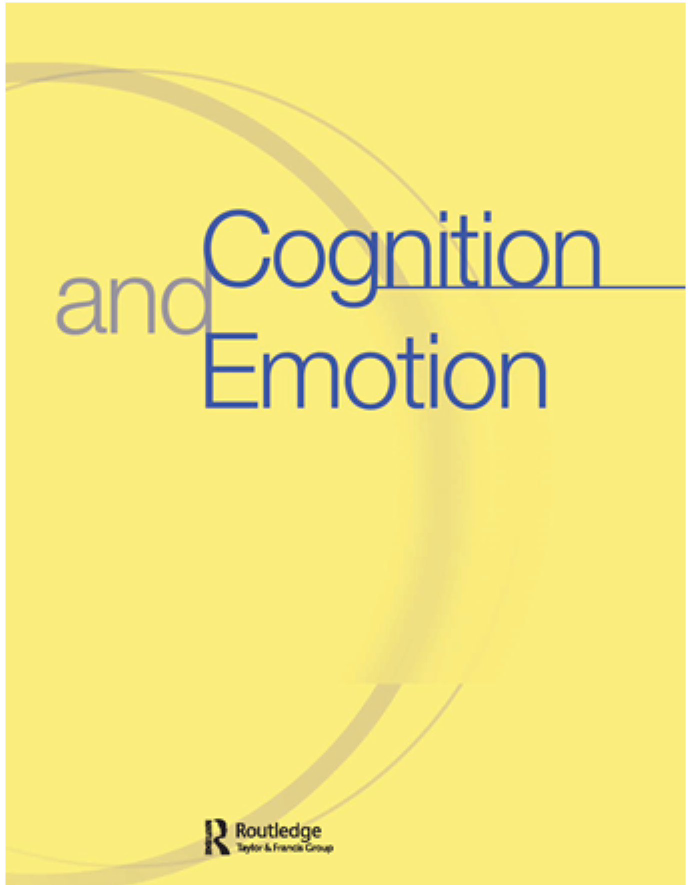

Self-generated cognitive fluency: Consequences on evaluative judgments

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SUPPLEMENT: Appendix A: Insignificant experiment (6)

One more experiment was conducted, yielding an insignificant target effect of pair distance overall, but still showing a tendency in one condition (i.e., means in the expected direction of greater liking for pairs of wide than narrow pair distances when oriented towards the maximum). The SDE was replicated. Following the arguments of Rosenthal (1979), and, more recently, Lakens and Etz (2017), we argue that mixed levels of significance in a series of studies which form a line of research often are more likely to occur than a series of exclusively significant studies, and can provide evidence for the target hypothesis if statistical power is sufficient and Type I error rates are adequately controlled (see Overview section above). We describe this experiment in short terms.

Six sets of six ideographs, from six languages unfamiliar to our student population, were chosen as stimuli. We expected the SDE to replicate and further predicted more positive evaluative judgments for elements from wider pairs, as compared to elements from narrower pairs. The same methodology was used as in Experiment 1 except using two more fictitious languages (6 instead of 4), and using a shorter chain of six ideographs per language (instead of eight). No participant was excluded. For accuracies and response latencies see Table 6.

Table 6 **Experiment 6**, Accuracies and Response latencies by Pair distance.

	Pair 3/4		Pair 2/5		Pair 1/6	
Accuracy	.736	(.357)	.856	(.268)	.895	(.235)
Latency	1409	(571)	1354	(535)	1223	(499)

Note. Accuracies are given in proportion of correct responses. Response latencies are given in milliseconds. Standard deviations are presented in brackets.

Using the same type of statistical modelling as in Experiment 1, and with significant SDE's for accuracy and latency, liking was compared between elements as part of trained stimulus pairs of type 1/6 (pair distance = 5, M_{16} = 3.53, SD = 1.53) and 4/5 (pair distance = 1, M_{45} = 3.41, SD = 1.44), F(1, 40) = 2.00; p = .16, dz = .10. As the interaction between pair distance and orientation was significant, F(1,1664) = 4.91; p = .03, Bonferroni-Holm corrected simple effects were calculated revealing that the outer-inner difference was significant when stimuli were oriented towards the maximum (M_{outer} = 3.69, M_{inner} = 3.43; $t(94.5)$ = -2.45; p < .03), whereas the difference was not significant for stimuli oriented towards the minimum (M_{outer} = 3.37, M_{inner} = 3.38; $t(94.5)$ = .177; p = .86). The blending hypothesis was confirmed for outer pairs as stimuli closer to the maximum were preferred to those closer to the minimum (p < .001), but not for inner pairs (p = .57).

In a separately calculated model, predicting preferences for the stimuli involved in inner and outer pairs by the response times to these same stimuli, and participants as random factor, we found that response times for a stimulus significantly predicted the preference for it, F(1,50.73) = 5.61; p = .02, β = -.14. That is, the shorter the response time, the more a stimulus was liked.

SUPPLEMENT: Appendix B: Artificial words from Bailey & Hahn (2001)

Four blocks:

1) Binth, Clemp, Dresp, Flesk, Misp, Nulp, Shrept, Shrust

2) Blesk, Clenth, Dolf, Finth, Resp, Slon, Smiss, Zint

3) Breltch, Crupt, Druss, Frondge, Gesht, Sesk, Swess, Wust

4) Brunth, Crusp, Drup, Freltch, Kwesk, Smist, Swuft, Thrindge

SUPPLEMENT: Appendix C: Modelling of effects

In order to determine which random effect structure to assume, we used generalized linear mixed models with random effects for *participants* for accuracy data, and linear mixed models with random effects for *participants* for latency and preference data. Non-minimal models were compared with the corresponding minimal model for each experiment (see below). If there was a significant difference in fit, the particular type of random slope as specified in the non-minimal model under comparison was then retained for the final model, afinal, resp., tfinal, resp., pfinal. In a second step, these final models were assembled and run in order to evaluate the respective fixed effect structure from those models (see Jaeger, 2008). This strategy thus considers random intercepts and random slopes for the main effects of the experimental design. The analyses employed the statistical programming language R (R Core Team, 2013), using the package lme4 (Bates, Maechler, Bolker, & Walker, 2015) and afex (Singmann, Bolker, Westfall, & Aust, 2018).

Experiment 1

Model comparisons were performed in a two-steps procedure: In the first step, we fitted three or four models for each data type (a1, a2, a3 for accuracy data, tm1, tm2, tm3 for latency data, and p1, p2, p3, p4 for preference data). Models of type a and tm had the same fixed effect structure, that is, pair distance and ideograph style, as well as their interaction. Models of type p had, additionally, orientation (towards minimum or maximum of the dimension) as a fixed effect. All models had a random intercept for participants. Models a3, tm3 and p4 had only this intercept, so these models are minimal. Models a1 / tm1 / p1 also had a random slope for pair distance as function of participant. Models a2 and tm2 had a random slope for ideograph style instead, whereas model p2 had a random slope for orientation. Finally, model p3 had a random slope for ideograph style. These models were then compared using the Chi square difference statistic $\Delta\chi^2$.

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Accuracies

Model	*df*	*AIC*	*BIC*	*loglik*	*deviance*	$\Delta\chi^2$	Δdf	*p*
a3	17	1987.8	2085.8	-976.88	1953.8			
a1	26	1960.8	2110.8	-954.37	1908.8	45.014	9	9.17e-07 ***
a2	26	1889.2	2039.3	-918.62	1837.2	116.51	9	< 2.2e-16 ***

afinal = random slopes for pair distance and ideograph style, as a function of participants, are kept.

Latencies

Model	*df*	*AIC*	*BIC*	*loglik*	*deviance*	$\Delta\chi^2$	Δdf	*p*
tm3	18	29311	29410	-14637	29275			
tm1	27	29263	29411	-14604	29209	65.624	9	1.091e-10 ***
tm2	27	29284	29432	-14615	29230	44.641	9	1.075e-06 ***

tfinal = random slopes for pair distance and ideograph style, as a function of participants, are kept.

Preferences

Model	*df*	*AIC*	*BIC*	*loglik*	*deviance*	$\Delta\chi^2$	Δdf	*p*
p4	18	4486.1	4577.5	-2225.1	4450.1			
p1	20	4487.0	4588.5	-2223.5	4447.0	3.16	2	0.206
p2	27	4480.2	4581.8	-2220.1	4440.2	9.9093	2	0.007051 **
p3	20	4444.9	4581.9	-2195.4	4390.9	59.276	9	1.848e-09***

pfinal = random slopes for ideograph style and orientation, as a function of participants, are kept.

Experiment 2

Model comparisons were performed in a two-steps procedure: In the first step, we fitted three models for accuracy and latency data (a1, a2, a3 for accuracy, tm1, tm2, tm3 for latency), and five models for preference data (p1, p2, p3, p4, p5). Models pertaining to accuracy and latency had pair distance and nonword list, as well as their interaction, as fixed factors. Models pertaining to preference had these, and additionally, orientation (towards minimum or maximum of the dimension) and comparator as fixed factors, along with all possible interactions. All models had a random intercept for participants. Models a3, tm3 and p5 had only this intercept, so these models are minimal. Models a1 / tm1 / p1 also had a random slope for pair distance as function of participant, whereas a2 / tm2 / p2 had a random slope for nonword list. Model p3 had a random slope for orientation, and model p4 had a random slope for comparator. These models were then compared using the Chi square difference statistic $\Delta\chi^2$.

Accuracies

Model	*df*	*AIC*	*BIC*	*loglik*	*deviance*	$\Delta\chi^2$	Δdf	*p*
a3	17	2946.7	3046.9	-1456.3	2912.7			
a1	26	2909.1	3062.4	-1428.6	2857.1	55.582	9	9.434e-09 ***
a2	26	2859.3	3012.6	-1403.7	2807.3	105.39	9	< 2.2e-16 ***

afinal = random slopes for pair distance and nonword list, as a function of participants, are kept.

Latencies

Model	*df*	*AIC*	*BIC*	*loglik*	*deviance*	$\Delta\chi^2$	Δdf	*p*
tm3	18	29240	29339	-14602	29204			

tm1	27	29221	29370	-14584	29167	36.447	9	3.303e-05	***
tm2	27	29171	29319	-14558	29117	87.192	9	5.948e-15	***

tfinal = random slopes for pair distance and nonword list, as a function of participants, are kept.

Preferences

Model	*df*	*AIC*	*BIC*	*loglik*	*deviance*	$\Delta\chi^2$	Δdf	*p*	
p5	43	4662.2	4886.0	-2288.1	4576.2	53.605	9	2.244e-08	***
p1	36	4670.6	4858.0	-2299.3	4598.6	31.181	2	1.694e-07	***
p2	43	4662.2	4886.0	-2288.1	4576.2	53.605	9	2.244e-08	***
p3	36	4671.8	4859.1	-2299.9	4599.8	30.004	2	3.053e-07	***
p4	36	4684.1	4871.4	-2306.1	4612.1	17.717	2	0.0001422	***

pfinal = random slopes for pair distance, nonword list, orientation and comparator, as a function of participants, are kept.

Experiment 3

Model comparisons were performed in a two-steps procedure: In the first step, we fitted three or four models for each data type (a1, a2, a3 for accuracy data, tm1, tm2, tm3 for latency data, and p1, p2, p3, p4 for preference data). Models of type a and tm had the same fixed effect structure, that is, pair distance, ideograph style and number of learning cycles, as well as their interactions. Models of type p had, additionally, orientation (towards minimum or maximum of the dimension) as a fixed effect. All models had a random intercept for participants. Models a3, tm3 and p4 had only this intercept, so these models are minimal. Models a1 / tm1 / p1 also had a random slope for pair distance as function of participant. Models a2 and tm2 had a random slope for ideograph style instead, whereas model p2 had a random slope for orientation. Finally, model p3 had a random slope for ideograph style. These models were then compared using the Chi square difference statistic $\Delta\chi^2$.

Experiment 3a

Accuracies

Model	*df*	*AIC*	*BIC*	*loglik*	*deviance*	$\Delta\chi^2$	Δdf	*p*
a3	37	1962.1	2198.8	-944.06	1888.1			
a1	42	1929.7	2198.3	-922.82	1845.7	42.465	5	4.742e-08***

a2	46	1941.1	2235.3	-924.55	1849.1	39.014	9	1.145e-05

afinal = random slopes for pair distance and ideograph style as a function of participants are kept.

Latencies

Model	*df*	*AIC*	*BIC*	*loglik*	*deviance*	$\Delta\chi^2$	Δdf	*p*
tm3	38	12605	12845	-6264.5	12529			
tm1	43	12541	12813	-6227.4	12455	74.137	5	1.408e-14***
tm2	47	12560	12858	-6233.1	12466	62.751	9	3.942e-10***

tfinal = random slopes for pair distance and ideograph style as a function of participants are kept.

Preferences

Model	*df*	*AIC*	*BIC*	*loglik*	*deviance*	$\Delta\chi^2$	Δdf	*p*
p4	50	5687.3	5952.2	-2793.7	5587.3			
p1	52	5682.0	5957.4	-2789.0	5578.0	9.3361	2	0.009391**
p2	52	5673.3	5948.7	-2784.6	5569.3	18.056	2	0.00012***
p3	59	5751.5	6064.0	-2816.7	633.5	0	9	1

pfinal = random slopes for pair distance and orientation, as a function of participants, are kept.

Experiment 3b

Accuracies

Model	*df*	*AIC*	*BIC*	*loglik*	*deviance*	$\Delta\chi^2$	Δdf	*p*
a3	37	1187.0	1421.5	-556.49	1113.0			
a1	42	1191.7	1457.9	-553.87	1107.7	5.2413	5	0.3871
a2	46	1201.4	1492.9	-554.70	1109.4	3.5791	9	0.9369

afinal = no random slopes as a function of participants are kept.

Latencies

Model	*df*	*AIC*	*BIC*	*loglik*	*deviance*	$\Delta\chi^2$	Δdf	*p*
tm3	38	12521	12761	-6222.5	12445			
tm1	43	12460	12731	-6186.8	12374	71.451	5	5.111e-14***
tm2	47	12477	12773	-6191.4	12383	62.185	9	5.075e-10***

tfinal = random slopes for pair distance and ideograph style as a function of participants are kept.

Preferences

Model	*df*	*AIC*	*BIC*	*loglik*	*deviance*	$\Delta\chi^2$	Δdf	*p*
p4	50	5402.3	5664.3	-2651.2	5302.3			
p1	52	5402.2	5674.6	-2649.1	5298.2	4.1457	2	0.1258
p2	52	5406.0	5678.4	-2651.0	5302.0	0.3673	2	0.8322
p3	59	5405.1	5714.1	-2643.5	5287.1	15.286	9	0.08338

pfinal = no random slopes as a function of participants are kept.

Experiment 4

In this experiment, type of comparator ("older", or "more frequently used", see Methods section in Experiment 1) did make a difference for accuracies and latencies, but not for preference. Therefore, the reported models for preference do not have comparator as a fixed factor, whereas the remaining models do.

For accuracy and latency models, four models each were fitted (a1, a2, a3, a4 for accuracy, tm1, tm2, tm3, tm4 for latency). These had pair distance, type of ideograph, and comparator, as well as their interactions, as fixed factors. The five models pertaining to preference (p1, p2, p3, p4, p5) had pair distance, type of ideograph, comparator and orientation (towards minimum or maximum of the dimension) as fixed factors, along with all possible interactions. All models had a random intercept for participants. Models a4, tm4 and p5 had only this intercept, so these models are minimal. Models a1 / tm1 / p1 also had a random slope for pair distance as function of participant, whereas a2 / tm2 / p2 had a random slope for type of ideograph. Models a3 /tm3 / p3 had a random slope for comparator, and p4 had a random slope for orientation. These models were then compared using the Chi square difference statistic $\Delta\chi^2$.

Accuracies

Model	*df*	*AIC*	*BIC*	*loglik*	*deviance*	$\Delta\chi^2$	Δdf	*p*
a4	33	10947	11194	-5440.7	10881			
a1	42	10525	10839	-5220.6	10441	440.12	9	< 2.2e-16 ***

a2	42	10556	10869	-5235.8	10472	409.76	9	< 2.2e-16 ***
a3	35	10937	11199	-5433.6	10867	14.219	2	0.0008172 ***

afinal = random slopes for pair distance, type of ideograph, and comparator, as a function of participants, are kept.

Latencies

Model	*df*	*AIC*	*BIC*	*loglik*	*deviance*	$\Delta\chi^2$	Δdf	*p*
tm4	10	157867	157939	-78923	157847			
tm1	12	157807	157894	-78892	157783	63.37	2	1.735e-14 ***
tm2	12	157703	157789	-78839	157679	167.98	2	< 2.2e-16 ***
tm3	12	157862	157948	-78919	157838	8.6139	2	0.01347 *

tfinal = random slopes for pair distance, type of ideograph, and comparator, as a function of participants, are kept.

Preferences

Model	*df*	*AIC*	*BIC*	*loglik*	*deviance*	$\Delta\chi^2$	Δdf	*p*
p5	34	25781	26011	-12856	25713			
p1	36	25759	26003	-12844	25687	25.517	2	2.878e-06 ***
p2	43	25626	25917	-12770	25540	172.83	9	< 2.2e-16 ***
p3	36	25727	25971	-12828	25655	57.146	2	3.899e-13 ***
p4	36	25736	25980	-12832	25664	48.858	2	2.458e-11 ***

pfinal = random slopes for pair distance, type of ideograph and orientation, as a function of participants, are kept.

Experiment 5

Model structure and comparisons were the same as in Experiment 2.

Accuracies

Model	*df*	*AIC*	*BIC*	*loglik*	*deviance*	$\Delta\chi^2$	Δdf	*p*
a3	33	2375.9	2563.5	-1154.9	2309.9			

a1	42	2353.9	2592.7	-1135.0	2269.9	39.931	9	7.822e-06 ***
a2	42	2376.8	2615.6	-1146.4	2292.8	17.057	9	0.04784 *

afinal = random slopes were kept for pair distance and nonword list, as a function of participants.

Latencies

Model	*df*	*AIC*	*BIC*	*loglik*	*deviance*	$\Delta\chi^2$	Δdf	*p*
tm3	34	2828.9	3009.1	-1380.5	2760.9			
tm1	43	2776.9	3004.8	-1345.5	2690.9	69.972	9	1.542e-11 **
tm2	43	2809.6	3037.4	-1361.8	2723.6	37.335	9	2.293e-05 ***

tfinal = random slopes for pair distance and nonword list, as a function of participants, are kept.

Preferences

Model	*df*	*AIC*	*BIC*	*loglik*	*deviance*	$\Delta\chi^2$	Δdf	*p*
p2	10	1896.1	1939.1	-938.05	1876.1			
p0	12	1899.0	1950.6	-937.49	1875.0	1.114	2	0.5729
p1	12	1887.8	1939.3	-931.87	1863.8	12.35	2	0.002081 **

pfinal = random slopes for orientation as a function of participants, are kept.

Experiment 6

Model comparisons were performed in the same way as in Experiment 1.

Accuracies

Model	*df*	*AIC*	*BIC*	*loglik*	*deviance*	$\Delta\chi^2$	Δdf	*p*
a3	33	1999.6	2190	-966.80	1933.6			
a1	42	1972.7	2215	-944.35	1888.7	44.912	9	9.581e-07
a2	42	1902.2	2144.6	-909.12	1818.2	115.36	9	2.2e-16

afinal = random slopes for pair distance and ideograph style as a function of participants are kept.

Latencies

Model	*df*	*AIC*	*BIC*	*loglik*	*deviance*	$\Delta\chi^2$	Δdf	*p*
tm3	34	29326	29513	-14629	29258			
tm1	43	29280	29516	-14597	29194	64.101	9	2.157e-10***
tm2	43	29298	29534	-14606	29212	46.182	9	5.572e-07***

tfinal = random slopes for pair distance and ideograph style as a function of participants are kept.

Preferences

Model	*df*	*AIC*	*BIC*	*loglik*	*deviance*	$\Delta\chi^2$	Δdf	*p*
p4	26	7170.7	7315.9	-3559.3	7118.7			
p1	28	7170.8	7327.2	-3557.4	7114.8	3.8215	2	0.148
p2	28	7167.9	7324.3	-3556.0	7111.9	6.7188	2	0.03476 *
p3	46	7145.3	7402.2	-3526.7	7053.3	65.324	20	1.036e-06 ***

pfinal = random slopes for ideograph style and orientation, as a function of participants, are kept.

SUPPLEMENT: Appendix D: Model estimates for effects

```
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Experiment 1

Accuracies, fixed effects:

```
Fixed effects:
              Estimate Std. Error z value Pr(>|z|)    
(Intercept)    2.63295    0.24644  10.684  < 2e-16 ***
dist1         -1.54619    0.21328  -7.250 4.18e-13 ***
dist2          0.06476    0.20907   0.310  0.75674    
dist3          0.27689    0.24126   1.148  0.25110    
block1        -0.42041    0.22262  -1.888  0.05896 .  
block2        -0.12663    0.27819  -0.455  0.64898    
block3         0.71211    0.36054   1.975  0.04825 *  
dist1:block1   0.43260    0.19378   2.232  0.02559 *  
dist2:block1  -0.48045    0.20196  -2.379  0.01736 *  
dist3:block1  -0.08144    0.22315  -0.365  0.71514    
dist1:block2   0.52009    0.19740   2.635  0.00842 ** 
dist2:block2   0.39904    0.21683   1.840  0.06572 .  
dist3:block2  -0.69873    0.21960  -3.182  0.00146 ** 
dist1:block3  -0.94003    0.23802  -3.949 7.84e-05 ***
dist2:block3   0.34092    0.24957   1.366  0.17193    
dist3:block3   0.57871    0.27421   2.110  0.03482 *  
---
```

Accuracies, random effects:

```
 Groups Name        Variance Std.Dev. Corr                               
 Part.  (Intercept) 1.4824   1.2175                                      
        dist1       0.9402   0.9696   -0.51                              
        dist2       0.4969   0.7049    0.58 -0.67                        
        dist3       0.8783   0.9372   -0.06 -0.26 -0.44                  
        block1      0.7390   0.8597   -0.36  0.45 -0.55 -0.13            
        block2      1.4017   1.1839    0.20  0.13  0.07 -0.56  0.50      
        block3      2.4419   1.5627    0.17 -0.03 -0.02  0.25 -0.72 -0.50
```

Latencies, fixed effects:

	Estimate	Std. Error	df	t value	Pr(>|t|)	
(Intercept)	1526.901	101.301	36.151	15.073	< 2e-16	***
dist1	127.252	35.661	195.908	3.568	0.000452	***
dist2	97.813	50.798	37.385	1.926	0.061794	.
dist3	-46.931	35.234	57.513	-1.332	0.188122	
block1	119.273	48.154	35.456	2.477	0.018163	*
block2	-30.006	45.905	35.810	-0.654	0.517512	
block3	-51.325	44.149	39.533	-1.163	0.251982	
dist1:block1	8.519	59.471	1654.926	0.143	0.886112	
dist2:block1	-48.223	55.526	1666.344	-0.868	0.385262	
dist3:block1	78.582	53.783	1676.294	1.461	0.144181	
dist1:block2	42.059	59.098	1594.652	0.712	0.476769	
dist2:block2	-19.157	55.264	1679.683	-0.347	0.728894	
dist3:block2	-84.788	54.042	1684.890	-1.569	0.116855	
dist1:block3	47.136	60.553	1628.298	0.778	0.436426	
dist2:block3	-93.145	53.616	1698.662	-1.737	0.082521	.
dist3:block3	92.243	52.291	1672.674	1.764	0.077909	.

Latencies, random effects:

Groups	Name	Variance	Std.Dev.	Corr					
Part.	(Intercept)	367153	605.93						
	dist1	2945	54.27	0.63					
	dist2	58037	240.91	0.61	0.41				
	dist3	10665	103.27	0.30	-0.06	-0.52			
	block1	47968	219.02	0.66	-0.10	0.16	0.63		
	block2	40003	200.01	0.14	0.82	-0.04	-0.05	-0.53	
	block3	35350	188.02	-0.61	-0.43	0.21	-0.79	-0.63	-0.22
Residual		576967	759.58						

Preferences, fixed effects:

	Estimate	Std. Error	df	t value	Pr(>|t|)	
(Intercept)	3.46791	0.12110	36.00065	28.636	<2e-16	***
block1	0.16047	0.13460	36.05218	1.192	0.2410	
block2	0.08615	0.10075	36.08062	0.855	0.3981	
block3	-0.04223	0.10817	37.61538	-0.390	0.6984	
dist1	-0.10135	0.04154	1024.00003	-2.440	0.0149	*
direct1	-0.07095	0.06243	36.69587	-1.136	0.2631	
block1:dist1	-0.13514	0.07195	1024.00003	-1.878	0.0606	.
block2:dist1	0.02703	0.07195	1024.00003	0.376	0.7073	
block3:dist1	-0.03378	0.07195	1024.00003	-0.470	0.6388	
block1:direct1	0.03716	0.07195	1024.00003	0.517	0.6056	
block2:direct1	0.10473	0.07195	1024.00003	1.456	0.1458	
block3:direct1	-0.05743	0.07195	1024.00003	-0.798	0.4249	
dist1:direct1	0.07939	0.04154	1024.00003	1.911	0.0563	.
block1:dist1:direct1	-0.11318	0.07195	1024.00003	-1.573	0.1160	
block2:dist1:direct1	0.13682	0.07195	1024.00003	1.902	0.0575	.
block3:dist1:direct1	0.02872	0.07195	1024.00003	0.399	0.6899	

Preferences, random effects:

Groups	Name	Variance	Std.Dev.	Corr
Part.	(Intercept)	0.47881	0.6920	
	block1	0.47876	0.6919	-0.39

```
        block2      0.18402  0.4290    0.14 -0.59
        block3      0.24140  0.4913    0.59 -0.87  0.44
        direct1     0.08034  0.2834    0.07  0.05  0.37  0.30
 Residual           2.04311  1.4294
```

Experiment 2

Accuracies, fixed effects:

```
             Estimate   Std. Error z value  Pr(>|z|)
(Intercept)  1.41994    0.18587   7.639 2.18e-14 ***
dist1       -1.11965    0.15919  -7.034 2.01e-12 ***
dist2       -0.09876    0.13295  -0.743   0.4576
dist3        0.31192    0.14790   2.109   0.0349 *
list1        0.07208    0.18415   0.391   0.6955
list2       -0.06987    0.20693  -0.338   0.7356
list3        0.19113    0.15664   1.220   0.2224
dist1:list1  0.28611    0.14639   1.954   0.0507 .
dist2:list1 -0.27098    0.14984  -1.808   0.0705 .
dist3:list1 -0.22075    0.15741  -1.402   0.1608
dist1:list2 -0.33527    0.14992  -2.236   0.0253 *
dist2:list2  0.03662    0.15182   0.241   0.8094
dist3:list2  0.31638    0.16017   1.975   0.0482 *
dist1:list3  0.02398    0.14559   0.165   0.8692
dist2:list3 -0.13247    0.15171  -0.873   0.3825
dist3:list3  0.16373    0.16196   1.011   0.3120
```

Accuracies, random effects:

```
Groups Name        Variance Std.Dev. Corr
 Part.  (Intercept) 1.2378   1.1126
        dist1       0.7075   0.8411   -0.75
        dist2       0.3296   0.5741   -0.22  0.05
        dist3       0.4014   0.6336    0.64 -0.80 -0.34
        list1       0.9539   0.9767   -0.21  0.26 -0.34 -0.20
        list2       1.2971   1.1389    0.38 -0.39  0.00  0.47 -0.89
        list3       0.5507   0.7421   -0.14  0.13  0.01  0.13 -0.10 -0.10
```

Latencies, fixed effects:

```
              Estimate Std. Error       df t value Pr(>|t|)
(Intercept) 1655.123    104.704   40.972  15.808   <2e-16 ***
dist1         35.797     49.607   44.596   0.722   0.4743
dist2         90.014     38.355   42.852   2.347   0.0236 *
dist3        -26.597     44.625   43.866  -0.596   0.5542
list1         30.359     52.573   38.581   0.577   0.5670
list2         -5.873     57.003   40.888  -0.103   0.9184
list3         70.585     46.777   42.762   1.509   0.1387
dist1:list1    3.386     59.953 1479.539   0.056   0.9550
dist2:list1    8.415     55.874 1603.311   0.151   0.8803
dist3:list1   38.097     53.874 1597.097   0.707   0.4796
dist1:list2    2.419     65.899 1433.024   0.037   0.9707
dist2:list2   52.668     57.003 1557.384   0.924   0.3556
dist3:list2  -28.607     55.194 1606.034  -0.518   0.6043
dist1:list3  -21.803     59.557 1254.731  -0.366   0.7144
```

```
dist2:list3   11.712     53.614 1593.953   0.218   0.8271
dist3:list3  -50.882     52.804 1606.282  -0.964   0.3354
```

Latencies, random effects:

```
Groups   Name        Variance Std.Dev. Corr
 Part.    (Intercept) 445196   667.2
          dist1        48848   221.0    -0.23
          dist2        18918   137.5    -0.07 -0.61
          dist3        42206   205.4     0.19 -0.59  0.45
          list1        72124   268.6     0.27 -0.23  0.39  0.15
          list2        86919   294.8    -0.46  0.19 -0.26  0.23 -0.53
          list3        50014   223.6     0.65 -0.59  0.01  0.35 -0.21 -
0.32
 Residual             569831   754.9
```

Preferences, fixed effects:

```
                           Estimate Std. Error        df t value Pr(>|t|)
(Intercept)              3.548e+00  9.476e-02  4.132e+01  37.442  < 2e-16
***
list1                    2.107e-01  6.512e-02  6.912e+02   3.236 0.001272 **
list2                    2.732e-02  6.567e-02  7.041e+02   0.416 0.677544
list3                   -2.135e-01  6.692e-02  6.385e+02  -3.191 0.001490 **
comp1                    9.125e-04  5.359e-02  4.146e+01   0.017 0.986496
dist1                   -1.699e-01  6.058e-02  4.158e+01  -2.804 0.007636 **
direct1                 -6.555e-02  6.042e-02  4.135e+01  -1.085 0.284193
list1:comp1              5.522e-02  6.999e-02  1.173e+03   0.789 0.430332
list2:comp1             -8.531e-02  7.042e-02  1.171e+03  -1.211 0.225978
list3:comp1              7.596e-02  7.146e-02  1.096e+03   1.063 0.288016
list1:dist1             -1.455e-01  5.863e-02  1.155e+03  -2.482 0.013222 *
list2:dist1              7.205e-02  5.904e-02  1.160e+03   1.220 0.222564
list3:dist1              7.023e-02  6.087e-02  1.167e+03   1.154 0.248838
comp1:dist1              7.830e-02  3.404e-02  1.149e+03   2.300 0.021621 *
list1:direct1           -4.052e-02  5.863e-02  1.155e+03  -0.691 0.489634
list2:direct1            5.633e-02  5.905e-02  1.159e+03   0.954 0.340281
list3:direct1            1.971e-03  6.089e-02  1.167e+03   0.032 0.974183
comp1:direct1           -4.791e-03  3.404e-02  1.149e+03  -0.141 0.888099
dist1:direct1            2.668e-02  3.403e-02  1.148e+03   0.784 0.433160
list1:comp1:dist1       -3.748e-02  6.634e-02  8.591e+02  -0.565 0.572262
list2:comp1:dist1       -2.522e-01  6.657e-02  8.686e+02  -3.789 0.000162
***
list3:comp1:dist1        1.674e-01  6.821e-02  8.856e+02   2.454 0.014300 *
list1:comp1:direct1     -2.696e-03  6.661e-02  8.815e+02  -0.040 0.967722
list2:comp1:direct1     -1.030e-01  6.684e-02  8.908e+02  -1.542 0.123496
list3:comp1:direct1      1.623e-01  6.847e-02  9.074e+02   2.370 0.018006 *
list1:dist1:direct1      7.170e-03  5.847e-02  1.148e+03   0.123 0.902435
list2:dist1:direct1     -3.639e-02  5.879e-02  1.148e+03  -0.619 0.536064
list3:dist1:direct1      3.805e-02  6.042e-02  1.148e+03   0.630 0.528971
comp1:dist1:direct1      2.325e-02  3.403e-02  1.148e+03   0.683 0.494670
list1:comp1:dist1:
direct1                  1.981e-01  5.847e-02  1.148e+03   3.388 0.000728
***
list2:comp1:dist1:
direct1                 -1.285e-01  5.879e-02  1.148e+03  -2.186 0.028989 *
list3:comp1:dist1:
direct1                  -1.416e-01  6.042e-02  1.148e+03  -2.343 0.019300 *
```

Preferences, random effects:

```
Groups   Name        Variance Std.Dev. Corr
 Part.    (Intercept) 0.32760  0.5724
          dist1       0.10490  0.3239   -0.06
          comp1       0.07149  0.2674   -0.32  0.49
          direct1     0.10404  0.3226   -0.03  0.24  0.27
 Residual             1.48842  1.2200
```

Experiment 3 a

Accuracies, fixed effects:

```
                          Estimate Std. Error z value Pr(>|z|)
(Intercept)               4.293944   0.232165  18.495  < 2e-16 ***
step1                    -1.054184   0.217272  -4.852 1.22e-06 ***
step2                     0.183479   0.242895   0.755 0.450019
block1                   -0.049737   0.311540  -0.160 0.873157
block2                   -0.099881   0.286441  -0.349 0.727317
block3                   -0.036297   0.296876  -0.122 0.902689
repetition1              -0.207722   0.202782  -1.024 0.305666
repetition2               0.477172   0.216423   2.205 0.027467 *
step1:block1             -0.120893   0.271796  -0.445 0.656470
step2:block1              0.708900   0.296873   2.388 0.016946 *
step1:block2             -0.038608   0.252778  -0.153 0.878606
step2:block2              0.181330   0.284875   0.637 0.524435
step1:block3              0.459219   0.274426   1.673 0.094253 .
step2:block3             -1.069223   0.289957  -3.688 0.000226 ***
step1:repetition1        -0.048743   0.241243  -0.202 0.839878
step2:repetition1         0.187482   0.259863   0.721 0.470622
step1:repetition2         0.003215   0.257473   0.012 0.990039
step2:repetition2        -0.136498   0.265301  -0.515 0.606901
block1:repetition1        0.246787   0.324754   0.760 0.447302
block2:repetition1        0.090177   0.290361   0.311 0.756128
block3:repetition1       -0.110958   0.311637  -0.356 0.721803
block1:repetition2       -0.181326   0.337272  -0.538 0.590835
block2:repetition2        0.123538   0.317773   0.389 0.697452
block3:repetition2        0.280613   0.344473   0.815 0.415293
step1:block1:repetition1 -0.262922   0.286749  -0.917 0.359191
step2:block1:repetition1 -0.408547   0.339272  -1.204 0.228517
step1:block2:repetition1  0.416527   0.271286   1.535 0.124690
step2:block2:repetition1 -0.339780   0.318207  -1.068 0.285613
step1:block3:repetition1  0.299748   0.296862   1.010 0.312627
step2:block3:repetition1 -0.904686   0.308758  -2.930 0.003389 **
step1:block1:repetition2 -0.425040   0.313526  -1.356 0.175202
step2:block1:repetition2  0.497231   0.361240   1.376 0.168680
step1:block2:repetition2 -0.355756   0.308177  -1.154 0.248340
step2:block2:repetition2  0.452458   0.368805   1.227 0.219889
step1:block3:repetition2  0.301906   0.353919   0.853 0.393639
step2:block3:repetition2 -0.165652   0.351057  -0.472 0.637022
```

Accuracies, random effects:

```
Groups Name        Variance Std.Dev. Corr
 Part.  (Intercept) 0.7215   0.8494
        step1       1.4571   1.2071   -0.50
        step2       1.1119   1.0545    0.29 -0.39
        block1      1.9988   1.4138    0.02  0.04  0.68
        block2      1.4896   1.2205    0.05 -0.09 -0.11 -0.41
        block3      1.7822   1.3350   -0.05  0.12 -0.44 -0.32 -0.46
```

Latencies, fixed effects:

```
                          Estimate  Std. Error        df  t value Pr(>|t|)
(Intercept)              1.768e+00  4.533e-02  9.477e+01  39.003  < 2e-16
***
step1                    3.288e-01  3.461e-02  9.525e+01   9.498 1.91e-15
***
step2                   -2.598e-02  2.394e-02  2.736e+02  -1.086 0.278636
block1                   1.636e-01  4.342e-02  9.320e+01   3.768 0.000288
***
block2                  -8.638e-02  3.473e-02  9.708e+01  -2.487 0.014586 *
block3                  -1.784e-02  3.696e-02  9.784e+01  -0.483 0.630370
repetition1              4.699e-02  6.421e-02  9.486e+01   0.732 0.466111
repetition2              4.327e-02  6.473e-02  9.471e+01   0.669 0.505422
step1:block1             1.010e-01  4.042e-02  3.777e+03   2.499 0.012512 *
step2:block1            -3.636e-02  3.939e-02  3.720e+03  -0.923 0.356077
step1:block2             6.838e-02  3.969e-02  3.787e+03   1.723 0.085046 .
step2:block2            -1.717e-02  3.886e-02  3.733e+03  -0.442 0.658645
step1:block3            -5.988e-02  3.935e-02  3.785e+03  -1.522 0.128204
step2:block3             3.223e-02  3.905e-02  3.737e+03   0.825 0.409298
step1:repetition1       -5.113e-02  4.914e-02  9.635e+01  -1.040 0.300721
step2:repetition1        2.381e-03  3.407e-02  2.771e+02   0.070 0.944320
step1:repetition2        4.345e-02  4.935e-02  9.441e+01   0.880 0.380912
step2:repetition2        6.676e-04  3.407e-02  2.714e+02   0.020 0.984379
block1:repetition1       3.648e-02  6.164e-02  9.413e+01   0.592 0.555419
block2:repetition1      -6.665e-02  4.924e-02  9.743e+01  -1.354 0.178948
block3:repetition1       6.339e-02  5.245e-02  9.918e+01   1.208 0.229740
block1:repetition2      -8.127e-02  6.202e-02  9.276e+01  -1.310 0.193299
block2:repetition2       3.013e-02  4.935e-02  9.684e+01   0.611 0.542911
block3:repetition2      -4.442e-03  5.266e-02  9.616e+01  -0.084 0.932953
step1:block1:repetition1
                         1.254e-01  5.758e-02  3.793e+03   2.178 0.029458 *
step2:block1:repetition1
                        -4.890e-02  5.589e-02  3.726e+03  -0.875 0.381707
step1:block2:repetition1
                        -8.599e-02  5.623e-02  3.789e+03  -1.529 0.126239
step2:block2:repetition1
                         8.101e-02  5.517e-02  3.737e+03   1.469 0.142048
step1:block3:repetition1
                        -1.748e-02  5.597e-02  3.801e+03  -0.312 0.754834
step2:block3:repetition1
                         2.442e-02  5.596e-02  3.761e+03   0.436 0.662512
step1:block1:repetition2
                         2.033e-02  5.773e-02  3.771e+03   0.352 0.724744
step2:block1:repetition2
                        -1.297e-01  5.613e-02  3.710e+03  -2.310 0.020947 *
step1:block2:repetition2
                         1.418e-02  5.619e-02  3.789e+03   0.252 0.800702
step2:block2:repetition2
                         7.371e-03  5.493e-02  3.724e+03   0.134 0.893258
step1:block3:repetition2
                        -4.660e-02  5.574e-02  3.762e+03  -0.836 0.403227
step2:block3:repetition2
                         3.420e-02  5.543e-02  3.715e+03   0.617 0.537213
```

Latencies, random effects:

```
Groups   Name        Variance Std.Dev. Corr
 Part.    (Intercept) 0.175381 0.41878
          step1       0.065564 0.25605   0.73
          step2       0.005807 0.07621  -0.37 -0.54
          block1      0.099725 0.31579   0.24  0.59 -0.92
          block2      0.039238 0.19809   0.14  0.40  0.14 -0.10
          block3      0.056339 0.23736  -0.28 -0.32  0.69 -0.52 -0.38
 Residual             1.055531 1.02739
```

Preferences, fixed effects:

	Estimate	Std. Error	df	t value	Pr(>|t|)
(Intercept)	4.433e+00	8.027e-02	9.688e+01	55.227	< 2e-16***
step1	-1.506e-01	4.300e-02	9.739e+01	-3.502	0.000699***
dominance1	1.119e-01	4.930e-02	9.819e+01	2.270	0.025392*
block1	-5.124e-02	6.957e-02	1.170e+03	-0.736	0.461605
block2	1.630e-01	6.884e-02	1.173e+03	2.368	0.018040*
block3	-4.668e-02	6.827e-02	1.169e+03	-0.684	0.494257
repetition1	-4.051e-02	1.136e-01	9.674e+01	-0.356	0.722266
repetition2	-8.346e-02	1.148e-01	9.717e+01	-0.727	0.468894
step1:dominance1	-1.989e-02	3.968e-02	1.152e+03	-0.501	0.616271
step1:block1	2.170e-02	6.905e-02	1.184e+03	0.314	0.753309
step1:block2	-1.039e-01	6.827e-02	1.183e+03	-1.522	0.128171
step1:block3	-9.045e-02	6.784e-02	1.175e+03	-1.333	0.182709
dominance1:block1	7.096e-02	6.919e-02	1.181e+03	1.026	0.305331
dominance1:block2	-9.109e-03	6.842e-02	1.182e+03	-0.133	0.894107
dominance1:block3	-4.432e-02	6.795e-02	1.175e+03	-0.652	0.514341
step1:repetition1	6.615e-02	6.090e-02	9.776e+01	1.086	0.280090
step1:repetition2	-4.566e-02	6.156e-02	9.784e+01	-0.742	0.460005
dominance1:repetition1	7.272e-02	6.980e-02	9.842e+01	1.042	0.300029
dominance1:repetition2	-1.793e-02	7.055e-02	9.859e+01	-0.254	0.799940
block1:repetition1	1.572e-01	9.874e-02	1.173e+03	1.592	0.111748
block2:repetition1	-2.454e-01	9.745e-02	1.170e+03	-2.518	0.011929*
block3:repetition1	1.799e-01	9.652e-02	1.167e+03	1.863	0.062662.
block1:repetition2	3.208e-02	9.951e-02	1.170e+03	0.322	0.747250
block2:repetition2	8.458e-02	9.812e-02	1.178e+03	0.862	0.388863
block3:repetition2	-8.533e-02	9.789e-02	1.166e+03	-0.872	0.383530
step1:dominance1:block1	-3.971e-03	6.900e-02	1.152e+03	-0.058	0.954115
step1:dominance1:block2	-2.866e-02	6.823e-02	1.152e+03	-0.420	0.674480
step1:dominance1:block3	5.577e-02	6.781e-02	1.152e+03	0.822	0.411014
step1:dominance1:repetition1	-8.729e-02	5.620e-02	1.152e+03	-1.553	0.120662
step1:dominance1:repetition2	2.602e-03	5.682e-02	1.152e+03	0.046	0.963483
step1:block1:repetition1	-1.001e-01	9.786e-02	1.190e+03	-1.023	0.306742
step1:block2:repetition1	-1.715e-01	9.676e-02	1.179e+03	-1.773	0.076556.
step1:block3:repetition1	7.254e-02	9.595e-02	1.175e+03	0.756	0.449833
step1:block1:repetition2	1.106e-01	9.877e-02	1.183e+03	1.119	0.263235
step1:block2:repetition2	6.984e-02	9.714e-02	1.188e+03	0.719	0.472320
step1:block3:repetition2	-5.950e-02	9.735e-02	1.173e+03	-0.611	0.541194
dominance1:block1:repetition1	7.223e-02	9.811e-02	1.186e+03	0.736	0.461745
dominance1:block2:repetition1	-6.068e-03	9.694e-02	1.178e+03	-0.063	0.950100
dominance1:block3:repetition1	-1.155e-01	9.610e-02	1.174e+03	-1.202	0.229701
dominance1:block1:repetition2	-9.808e-03	9.897e-02	1.180e+03	-0.099	0.921073
dominance1:block2:repetition2	2.158e-02	9.739e-02	1.187e+03	0.222	0.824693
dominance1:block3:repetition2	4.453e-02	9.749e-02	1.172e+03	0.457	0.647934
step1:dominance1:block1:repetition1	-4.718e-02	9.779e-02	1.152e+03	-0.482	0.629559
step1:dominance1:block2:repetition1	-2.544e-02	9.671e-02	1.152e+03	-0.263	0.792517
step1:dominance1:block3:repetition1	1.061e-01	9.591e-02	1.152e+03	1.106	0.268823

```
step1:dominance1:block1:repetition2
                          2.988e-02  9.871e-02  1.152e+03   0.303 0.762151
step1:dominance1:block2:repetition2
                          4.595e-02  9.707e-02  1.152e+03   0.473 0.636007
step1:dominance1:block3:repetition2
                         -8.848e-02  9.731e-02  1.152e+03  -0.909 0.363404
```

Preferences, random effects:

```
Groups   Name        Variance Std.Dev. Corr
 Part.    (Intercept) 0.47917  0.6922
          step1       0.02693  0.1641   -0.86
          dominance1  0.08337  0.2887    0.56 -0.73
 Residual             2.31606  1.5219
```

Experiment 3 b

Accuracies, fixed effects:

```
                         Estimate Std. Error z value Pr(>|z|)
(Intercept)               3.76413    0.14250  26.415  < 2e-16 ***
step1                    -0.64180    0.13143  -4.883 1.04e-06 ***
step2                     0.35060    0.16181   2.167   0.0303 *
block1                   -0.10630    0.18215  -0.584   0.5595
block2                   -0.02321    0.17658  -0.131   0.8954
block3                    0.08832    0.19424   0.455   0.6493
repetition1              -0.23691    0.17294  -1.370   0.1707
repetition2               0.04720    0.18075   0.261   0.7940
step1:block1              0.12229    0.22311   0.548   0.5836
step2:block1             -0.21049    0.26391  -0.798   0.4251
step1:block2              0.04412    0.21575   0.205   0.8380
step2:block2              0.18675    0.27165   0.687   0.4918
step1:block3             -0.14895    0.23370  -0.637   0.5239
step2:block3             -0.02470    0.28910  -0.085   0.9319
step1:repetition1         0.21318    0.17978   1.186   0.2357
step2:repetition1        -0.24143    0.21264  -1.135   0.2562
step1:repetition2        -0.35072    0.18378  -1.908   0.0563 .
step2:repetition2         0.25008    0.23722   1.054   0.2918
block1:repetition1       -0.20244    0.23707  -0.854   0.3931
block2:repetition1        0.23527    0.24343   0.966   0.3338
block3:repetition1       -0.10573    0.25215  -0.419   0.6750
block1:repetition2       -0.09793    0.25345  -0.386   0.6992
block2:repetition2        0.10635    0.25730   0.413   0.6794
block3:repetition2        0.16030    0.29967   0.535   0.5927
step1:block1:repetition1  0.44996    0.30411   1.480   0.1390
step2:block1:repetition1 -0.18595    0.33422  -0.556   0.5780
step1:block2:repetition1 -0.01007    0.30256  -0.033   0.9734
step2:block2:repetition1  0.25895    0.37340   0.693   0.4880
step1:block3:repetition1  0.09061    0.30943   0.293   0.7697
step2:block3:repetition1  0.15900    0.37140   0.428   0.6686
step1:block1:repetition2  0.03660    0.30386   0.120   0.9041
step2:block1:repetition2  0.23535    0.38288   0.615   0.5388
step1:block2:repetition2  0.18486    0.30857   0.599   0.5491
step2:block2:repetition2 -0.40567    0.39315  -1.032   0.3022
```

```
step1:block3:repetition2 -0.60487    0.34017  -1.778   0.0754 .
step2:block3:repetition2  0.29719    0.45735   0.650   0.5158
```

Accuracies, random effects:

```
Groups Name        Variance Std.Dev.
 Part.  (Intercept) 0.3754   0.6127
```

Latencies, fixed effects:

```
                            Estimate Std. Error         df t value Pr(>|t|)
(Intercept)               1.761e+00  5.068e-02  9.510e+01  34.745  < 2e-16
***
step1                     2.933e-01  3.338e-02  9.926e+01   8.786 4.74e-14
***
step2                     3.880e-02  3.340e-02  1.008e+02   1.162  0.24813
block1                    8.290e-02  4.321e-02  8.221e+01   1.918  0.05854 .
block2                   -9.139e-02  3.356e-02  1.453e+02  -2.723  0.00726 **
block3                    5.735e-02  4.067e-02  8.825e+01   1.410  0.16198
repetition1               7.656e-02  7.195e-02  9.625e+01   1.064  0.28994
repetition2              -8.284e-03  7.112e-02  9.504e+01  -0.116  0.90752
step1:block1              2.929e-02  4.130e-02  3.728e+03   0.709  0.47828
step2:block1             -1.451e-02  4.105e-02  3.723e+03  -0.353  0.72375
step1:block2             -4.899e-02  4.056e-02  3.729e+03  -1.208  0.22713
step2:block2              3.688e-02  4.018e-02  3.721e+03   0.918  0.35871
step1:block3              5.096e-02  4.116e-02  3.724e+03   1.238  0.21570
step2:block3             -4.205e-02  4.073e-02  3.718e+03  -1.033  0.30190
step1:repetition1         4.756e-02  4.759e-02  1.013e+02   0.999  0.32002
step2:repetition1        -2.917e-03  4.766e-02  1.032e+02  -0.061  0.95131
step1:repetition2        -2.110e-02  4.687e-02  9.944e+01  -0.450  0.65357
step2:repetition2        -1.508e-02  4.681e-02  1.005e+02  -0.322  0.74797
block1:repetition1       -1.835e-02  6.229e-02  8.296e+01  -0.295  0.76906
block2:repetition1        9.522e-03  4.792e-02  1.474e+02   0.199  0.84275
block3:repetition1       -8.949e-03  5.823e-02  8.901e+01  -0.154  0.87820
block1:repetition2        4.775e-02  6.049e-02  8.182e+01   0.789  0.43214
block2:repetition2        4.752e-03  4.722e-02  1.460e+02   0.101  0.91998
block3:repetition2       -4.795e-03  5.721e-02  8.850e+01  -0.084  0.93339
step1:block1:repetition1
                          1.301e-02  5.940e-02  3.727e+03   0.219  0.82668
step2:block1:repetition1
                          3.202e-02  5.928e-02  3.723e+03   0.540  0.58909
step1:block2:repetition1
                          7.248e-03  5.753e-02  3.720e+03   0.126  0.89976
step2:block2:repetition1
                         -3.509e-02  5.709e-02  3.716e+03  -0.615  0.53886
step1:block3:repetition1
                         -1.139e-01  5.888e-02  3.727e+03  -1.934  0.05323 .
step2:block3:repetition1
                          1.300e-01  5.838e-02  3.721e+03   2.228  0.02597 *
step1:block1:repetition2
                         -1.027e-01  5.795e-02  3.725e+03  -1.772  0.07642 .
step2:block1:repetition2
                          4.196e-02  5.739e-02  3.719e+03   0.731  0.46479
step1:block2:repetition2
                          3.273e-02  5.711e-02  3.726e+03   0.573  0.56655
step2:block2:repetition2
                          1.281e-02  5.653e-02  3.718e+03   0.227  0.82080
step1:block3:repetition2
                          9.991e-02  5.812e-02  3.727e+03   1.719  0.08570 .
step2:block3:repetition2
                         -3.805e-02  5.718e-02  3.719e+03  -0.666  0.50573
```

Latencies, random effects:

```
Groups   Name        Variance Std.Dev. Corr
 ps       (Intercept) 0.22011  0.4692
          step1       0.05252  0.2292    0.23
          step2       0.05384  0.2320    0.48 -0.73
          block1      0.08602  0.2933    0.30  0.12  0.02
          block2      0.02522  0.1588   -0.66  0.18 -0.65 -0.59
          block3      0.07018  0.2649    0.18 -0.36  0.42 -0.63  0.33
 Residual             1.11616  1.0565
```

Preferences, fixed effects:

```
                        Estimate   Std. Error  df        t value
Pr(>|t|)
(Intercept)             4.346e+00  8.901e-02  9.355e+01  48.821  < 2e-16
***
step1                  -1.455e-01  4.218e-02  1.247e+03  -3.450 0.000579
***
dominance1              2.452e-01  4.218e-02  1.247e+03   5.814 7.72e-09
***
block1                  1.053e-01  7.408e-02  1.278e+03   1.422 0.155414
block2                  4.895e-02  7.295e-02  1.288e+03   0.671 0.502335
block3                 -1.618e-01  7.352e-02  1.270e+03  -2.201 0.027920 *
repetition1             3.738e-02  1.265e-01  9.490e+01   0.296 0.768155
repetition2             1.298e-01  1.248e-01  9.335e+01   1.040 0.301008
step1:dominance1        6.975e-03  4.218e-02  1.247e+03   0.165 0.868684
step1:block1           -6.683e-02  7.302e-02  1.247e+03  -0.915 0.360236
step1:block2            8.835e-02  7.163e-02  1.247e+03   1.233 0.217649
step1:block3            1.456e-02  7.271e-02  1.247e+03   0.200 0.841249
dominance1:block1      -4.091e-02  7.302e-02  1.247e+03  -0.560 0.575364
dominance1:block2       1.261e-01  7.163e-02  1.247e+03   1.760 0.078592 .
dominance1:block3      -7.063e-02  7.271e-02  1.247e+03  -0.971 0.331508
step1:repetition1       4.573e-02  6.035e-02  1.247e+03   0.758 0.448692
step1:repetition2      -8.380e-03  5.910e-02  1.247e+03  -0.142 0.887263
dominance1:repetition1  5.057e-02  6.035e-02  1.247e+03   0.838 0.402162
dominance1:repetition2-4.414e-03  5.910e-02  1.247e+03  -0.075 0.940469
block1:repetition1      5.802e-02  1.067e-01  1.283e+03   0.544 0.586765
block2:repetition1     -4.804e-02  1.038e-01  1.298e+03  -0.463 0.643589
block3:repetition1     -6.457e-02  1.053e-01  1.273e+03  -0.613 0.539741
block1:repetition2     -1.299e-01  1.036e-01  1.274e+03  -1.254 0.210019
block2:repetition2      9.413e-02  1.028e-01  1.290e+03   0.916 0.359946
block3:repetition2      9.979e-02  1.033e-01  1.272e+03   0.966 0.334390
step1:dominance1:block1
                       -1.267e-01  7.302e-02  1.247e+03  -1.736 0.082877 .
step1:dominance1:block2
                        7.183e-03  7.163e-02  1.247e+03   0.100 0.920137
step1:dominance1:block3
                       -3.158e-02  7.271e-02  1.247e+03  -0.434 0.664124
step1:dominance1:repetition1
                        1.438e-02  6.035e-02  1.247e+03   0.238 0.811670
step1:dominance1:repetition2
                        3.704e-03  5.910e-02  1.247e+03   0.063 0.950037
step1:block1:repetition1
                       -3.709e-02  1.049e-01  1.247e+03  -0.354 0.723667
step1:block2:repetition1
                       -6.114e-02  1.015e-01  1.247e+03  -0.602 0.547131
step1:block3:repetition1
                       -5.764e-02  1.040e-01  1.247e+03  -0.554 0.579589
step1:block1:repetition2
```

```
                          -6.261e-02  1.023e-01  1.247e+03  -0.612 0.540749
step1:block2:repetition2
                           3.329e-02  1.008e-01  1.247e+03   0.330 0.741243
step1:block3:repetition2
                           8.933e-02  1.021e-01  1.247e+03   0.875 0.381787
dominance1:block1:repetition1
                          -1.253e-01  1.049e-01  1.247e+03  -1.194 0.232571
dominance1:block2:repetition1
                           1.346e-01  1.015e-01  1.247e+03   1.325 0.185335
dominance1:block3:repetition1
                           1.320e-01  1.040e-01  1.247e+03   1.269 0.204771
dominance1:block1:repetition2
                           5.009e-02  1.023e-01  1.247e+03   0.490 0.624539
dominance1:block2:repetition2
                          -9.272e-02  1.008e-01  1.247e+03  -0.920 0.357814
dominance1:block3:repetition2
                          -1.535e-01  1.021e-01  1.247e+03  -1.504 0.132940
step1:dominance1:block1:repetition1
                           1.278e-02  1.049e-01  1.247e+03   0.122 0.903046
step1:dominance1:block2:repetition1
                          -1.334e-01  1.015e-01  1.247e+03  -1.314 0.189197
step1:dominance1:block3:repetition1
                           1.531e-01  1.040e-01  1.247e+03   1.472 0.141351
step1:dominance1:block1:repetition2
                           1.160e-01  1.023e-01  1.247e+03   1.134 0.256962
step1:dominance1:block2:repetition2
                           6.278e-02  1.008e-01  1.247e+03   0.623 0.533471
step1:dominance1:block3:repetition2
                          -1.291e-01  1.021e-01  1.247e+03  -1.264 0.206320
```

Preferences, random effects:

```
Groups   Name        Variance Std.Dev.
 ps       (Intercept) 0.5947   0.7711
 Residual             2.4664   1.5705
```

Experiment 4

Accuracies, fixed effects:

```
                       Estimate Std. Error z value Pr(>|z|)
(Intercept)            2.738357   0.126679  21.616  < 2e-16 ***
dist1                 -1.676532   0.117178 -14.308  < 2e-16 ***
dist2                 -0.575291   0.104866  -5.486 4.11e-08 ***
dist3                  0.688374   0.130369   5.280 1.29e-07 ***
block1                -0.120501   0.105867  -1.138 0.255024
block2                 0.174799   0.119452   1.463 0.143375
block3                -0.148505   0.108950  -1.363 0.172863
Compare1               0.196517   0.041218   4.768 1.86e-06 ***
dist1:block1          -0.052340   0.086257  -0.607 0.543987
dist2:block1           0.104023   0.091302   1.139 0.254563
dist3:block1          -0.059105   0.102959  -0.574 0.565924
dist1:block2           0.219526   0.090350   2.430 0.015110 *
dist2:block2          -0.152376   0.093637  -1.627 0.103672
dist3:block2           0.033039   0.107743   0.307 0.759111
dist1:block3           0.008815   0.084956   0.104 0.917360
dist2:block3           0.332591   0.092140   3.610 0.000307 ***
dist3:block3          -0.033598   0.101350  -0.332 0.740263
dist1:Compare1        -0.014371   0.047949  -0.300 0.764397
dist2:Compare1        -0.026147   0.050682  -0.516 0.605924
dist3:Compare1         0.001264   0.057844   0.022 0.982564
block1:Compare1        0.094837   0.054673   1.735 0.082806 .
```

```
block2:Compare1       -0.016744   0.056661  -0.296 0.767604
block3:Compare1       -0.007113   0.054015  -0.132 0.895228
dist1:block1:Compare1 -0.168497   0.076914  -2.191 0.028472 *
dist2:block1:Compare1  0.079146   0.084008   0.942 0.346130
dist3:block1:Compare1  0.203442   0.095025   2.141 0.032279 *
dist1:block2:Compare1  0.062463   0.079591   0.785 0.432572
dist2:block2:Compare1 -0.029946   0.084904  -0.353 0.724308
dist3:block2:Compare1 -0.082454   0.097988  -0.841 0.400082
dist1:block3:Compare1  0.045831   0.075069   0.611 0.541522
dist2:block3:Compare1  0.032531   0.084117   0.387 0.698956
dist3:block3:Compare1 -0.134246   0.093100  -1.442 0.149314
```

Accuracies, random effects:

```
Groups Name        Variance Std.Dev. Corr
Pt. (Intercept) 2.08512  1.4440
    dist1        1.58626  1.2595   -0.68
dist2       0.87429  0.9350   -0.40  0.07
    dist3        0.86547  0.9303    0.60 -0.58 -0.48
    block1       1.07921  1.0388   -0.02  0.18 -0.18 -0.10
    block2       1.42849  1.1952   -0.06  0.15  0.06 -0.07 -0.36
    block3       1.22305  1.1059   -0.09 -0.16  0.20  0.18 -0.35 -0.42
    Compare1     0.05911  0.2431   -0.35  0.37  0.04 -0.23  0.04 -0.30
0.22
```

Latencies, fixed effects:

```
                       Estimate Std. Error        df t value Pr(>|t|)
(Intercept)           1623.2319    34.3905  200.8205  47.200  < 2e-16 ***
dist1                  155.1745    17.1855  184.4779   9.029 2.28e-16 ***
dist2                   49.7165    13.7309  283.0102   3.621 0.000348 ***
dist3                  -48.3644    13.6357  202.0599  -3.547 0.000485 ***
block1                 147.6690    24.6739  203.2047   5.985 9.66e-09 ***
block2                 -59.9040    22.5666  194.8752  -2.655 0.008598 **
block3                 -33.1447    22.6775  200.1547  -1.462 0.145426
Compare1                41.3594     7.5705  285.0324   5.463 1.02e-07 ***
dist1:block1           -54.1733    24.5066 7826.5775  -2.211 0.027095 *
dist2:block1            22.2221    21.9141 8695.2696   1.014 0.310585
dist3:block1            31.9609    21.1019 8829.6987   1.515 0.129909
dist1:block2            12.8960    23.0882 8197.2518   0.559 0.576482
dist2:block2            -1.5667    21.4467 8712.5131  -0.073 0.941766
dist3:block2           -34.6069    20.6377 8802.6013  -1.677 0.093602 .
dist1:block3             9.7803    23.7505 8105.2846   0.412 0.680501
dist2:block3           -17.3616    21.4687 8679.7807  -0.809 0.418714
dist3:block3            32.6975    20.9948 8813.1499   1.557 0.119410
dist1:Compare1          26.6225    13.4749 8774.8542   1.976 0.048220 *
dist2:Compare1         -17.2145    12.4066 8689.5938  -1.388 0.165318
dist3:Compare1         -11.1901    12.0196 8735.8057  -0.931 0.351883
block1:Compare1         -1.2902    12.6005 8773.1877  -0.102 0.918447
block2:Compare1          6.0386    12.2342 8777.9951   0.494 0.621614
block3:Compare1          0.8958    12.3604 8752.7495   0.072 0.942225
dist1:block1:Compare1   25.9076    23.9166 8716.8247   1.083 0.278729
dist2:block1:Compare1   14.1993    21.7434 8622.8533   0.653 0.513749
dist3:block1:Compare1  -44.9762    21.0010 8712.3093  -2.142 0.032251 *
dist1:block2:Compare1  -18.3138    22.8068 8649.9671  -0.803 0.421998
dist2:block2:Compare1  -15.1899    21.3421 8661.0752  -0.712 0.476648
dist3:block2:Compare1   10.1411    20.6244 8705.4171   0.492 0.622940
dist1:block3:Compare1   -3.9886    23.2618 8702.4837  -0.171 0.863860
```

```
dist2:block3:Compare1   -5.9614    21.2677 8648.7817  -0.280 0.779252
dist3:block3:Compare1    3.9877    20.9031 8713.0925   0.191 0.848711
```

Latencies, random effects:

```
Groups   Name        Variance Std.Dev. Corr
Pt. (Intercept) 229149   478.69
    dist1         21412   146.33    0.42
    dist2          6473    80.46    0.30  0.48
    dist3          8143    90.24   -0.37 -0.38 -0.52
    block1        89567   299.28    0.18  0.08 -0.40  0.19
    block2        71791   267.94   -0.01 -0.14  0.56 -0.48 -0.36
block3       72021   268.37   -0.20  0.04 -0.01  0.13 -0.61 -0.14
    Compare1       1230    35.07    0.57 -0.02  0.28 -0.16  0.05 -0.24 -
0.16
    Residual    476470   690.27
```

Preferences, fixed effects:

```
                           Estimate Std. Error         df t value Pr(>|t|)
(Intercept)              4.204e+00  5.307e-02  2.067e+02  79.222  < 2e-16
***
block1                  -9.384e-02  5.312e-02  1.883e+02  -1.766   0.0789 .
block2                  -7.371e-02  5.134e-02  1.876e+02  -1.436   0.1528
block3                   1.200e-01  5.133e-02  1.717e+02   2.338   0.0205 *
comp1                    4.365e-02  2.959e-02  4.369e+02   1.475   0.1409
distance1                6.641e-02  2.691e-02  2.085e+02   2.468   0.0144 *
direct1                  1.717e-01  2.901e-02  2.086e+02   5.918 1.32e-08
***
block1:comp1            -5.449e-02  5.833e-02  3.169e+02  -0.934   0.3509
block2:comp1            -2.879e-02  5.630e-02  3.241e+02  -0.511   0.6094
block3:comp1             4.486e-02  5.801e-02  3.145e+02   0.773   0.4399
block1:distance1        -8.386e-02  3.412e-02  5.306e+03  -2.458   0.0140 *
block2:distance1         2.922e-02  3.461e-02  5.316e+03   0.844   0.3985
block3:distance1        -5.739e-03  3.518e-02  5.352e+03  -0.163   0.8704
comp1:distance1          1.522e-02  1.987e-02  5.260e+03   0.766   0.4436
block1:direct1          -8.193e-02  3.413e-02  5.303e+03  -2.400   0.0164 *
block2:direct1           2.611e-02  3.462e-02  5.311e+03   0.754   0.4508
block3:direct1           1.865e-02  3.520e-02  5.346e+03   0.530   0.5962
comp1:direct1           -1.431e-02  1.987e-02  5.259e+03  -0.720   0.4714
distance1:direct1       -1.290e-01  1.986e-02  5.257e+03  -6.493 9.20e-11
***
block1:comp1:distance1 1.996e-02  3.693e-02  2.799e+03   0.540   0.5889
block2:comp1:distance1-6.607e-02  3.748e-02  2.826e+03  -1.763   0.0780 .
block3:comp1:distance1-1.823e-02  3.799e-02  2.899e+03  -0.480   0.6313
block1:comp1:direct1   6.210e-02  3.751e-02  3.199e+03   1.656   0.0979 .
block2:comp1:direct1   2.491e-02  3.802e-02  3.181e+03   0.655   0.5124
block3:comp1:direct1  -6.545e-02  3.850e-02  3.239e+03  -1.700   0.0892 .
block1:distance1:direct1
                         3.313e-02  3.406e-02  5.257e+03   0.973   0.3307
block2:distance1:direct1
                        -2.192e-02  3.454e-02  5.257e+03  -0.635   0.5256
block3:distance1:direct1
                         2.443e-03  3.505e-02  5.257e+03   0.070   0.9444
comp1:distance1:direct11.627e-02  1.986e-02  5.257e+03   0.819   0.4127
block1:comp1:distance1:direct1
                        -2.516e-02  3.406e-02  5.257e+03  -0.739   0.4601
block2:comp1:distance1:direct1
                         5.499e-04  3.454e-02  5.257e+03   0.016   0.9873
block3:comp1:distance1:direct1
                         2.575e-02  3.505e-02  5.257e+03   0.735   0.4626
```

Preferences, random effects:

```
Groups   Name        Variance Std.Dev. Corr
 Part.    (Intercept) 0.48628  0.69734
          block1      0.32097  0.56654   0.01
          block2      0.27688  0.52619  -0.09 -0.43
          block3      0.25227  0.50227   0.03 -0.28 -0.37
          comp1       0.00643  0.08019  -0.34 -0.39  0.43  0.18
          distance1   0.06635  0.25758  -0.08  0.18 -0.22 -0.22  0.49
        direct1     0.09001  0.30001  -0.10  0.08  0.22  0.05  0.51  0.05
 Residual             2.46474  1.56995
```

Experiment 5

Accuracies, fixed effects:

```
Estimate Std. Error z value Pr(>|z|)
(Intercept)             -1.43315    0.21033  -6.814 9.51e-12 ***
sequence1                0.09906    0.20622   0.480  0.63096
block1                  -0.11903    0.17426  -0.683  0.49459
block2                  -0.14985    0.17340  -0.864  0.38749
block3                  -0.04971    0.18085  -0.275  0.78343
dist1                    0.58823    0.14843   3.963 7.40e-05 ***
dist2                    0.11770    0.14625   0.805  0.42093
dist3                   -0.03995    0.13746  -0.291  0.77134
sequence1:block1        -0.06606    0.16614  -0.398  0.69089
sequence1:block2         0.03957    0.16166   0.245  0.80662
sequence1:block3        -0.01296    0.17272  -0.075  0.94018
sequence1:dist1         -0.09478    0.14296  -0.663  0.50735
sequence1:dist2          0.22024    0.13467   1.635  0.10196
sequence1:dist3         -0.20581    0.12489  -1.648  0.09938 .
block1:dist1            -0.01875    0.16057  -0.117  0.90707
block2:dist1             0.23369    0.16271   1.436  0.15095
block3:dist1            -0.20817    0.16485  -1.263  0.20666
block1:dist2            -0.06583    0.16732  -0.393  0.69399
block2:dist2            -0.46049    0.17428  -2.642  0.00824 **
block3:dist2             0.32324    0.16807   1.923  0.05445 .
block1:dist3            -0.10378    0.17154  -0.605  0.54519
block2:dist3             0.39386    0.16621   2.370  0.01780 *
block3:dist3             0.01053    0.16921   0.062  0.95039
sequence1:block1:dist1 -0.20521    0.15711  -1.306  0.19150
sequence1:block2:dist1 -0.09865    0.15961  -0.618  0.53652
sequence1:block3:dist1  0.52306    0.16119   3.245  0.00117 **
sequence1:block1:dist2  0.20116    0.16463   1.222  0.22177
sequence1:block2:dist2  0.46238    0.17288   2.675  0.00748 **
sequence1:block3:dist2 -0.70057    0.16512  -4.243 2.21e-05 ***
sequence1:block1:dist3 -0.01892    0.16867  -0.112  0.91068
sequence1:block2:dist3 -0.27270    0.16451  -1.658  0.09738 .
sequence1:block3:dist3 -0.01453    0.16565  -0.088  0.93012
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Accuracies, random effects:

```
Groups      Name        Variance Std.Dev. Corr
 participant (Intercept) 1.2929   1.1370
             block1      0.5815   0.7625   -0.41
             block2      0.4755   0.6896    0.60 -0.46
```

```
            block3      0.6245   0.7902   -0.25 -0.51 -0.42
            dist1       0.3793   0.6159   -0.59 -0.06 -0.31  0.46
            dist2       0.2547   0.5047    0.43 -0.29  0.96 -0.46 -0.23
            dist3       0.1956   0.4423   -0.27  0.72 -0.85  0.06  0.01 -
0.79
Number of obs: 2176, groups:  participant, 34
```

Latencies, fixed effects:

```
                                  Estimate Std. Error  df t value Pr(>|t|)
(Intercept)            1.236e+00  8.303e-02  3.203e+01  14.886 6.05e-16
***
sequence1             -1.985e-01  8.303e-02  3.203e+01  -2.391 0.022873 *
block1                -3.683e-02  4.046e-02  3.306e+01  -0.910 0.369166
block2                -1.007e-01  3.557e-02  3.809e+01  -2.832 0.007356
**
block3                 1.714e-01  4.232e-02  3.172e+01   4.050 0.000308
***
dist1                  8.515e-02  3.730e-02  3.288e+01   2.283 0.029031 *
dist2                  6.622e-02  3.008e-02  5.661e+01   2.201 0.031810 *
dist3                 -6.638e-02  3.127e-02  3.504e+01  -2.123 0.040934 *
sequence1:block1      -3.145e-02  4.046e-02  3.306e+01  -0.777 0.442432
sequence1:block2      -1.220e-02  3.557e-02  3.809e+01  -0.343 0.733444
sequence1:block3      -5.162e-02  4.232e-02  3.172e+01  -1.220 0.231583
sequence1:dist1        7.959e-02  3.730e-02  3.288e+01   2.134 0.040416 *
sequence1:dist2       -7.501e-02  3.008e-02  5.661e+01  -2.493 0.015601 *
sequence1:dist3       -2.336e-02  3.127e-02  3.504e+01  -0.747 0.460114
block1:dist1          -2.542e-02  4.807e-02  1.331e+03  -0.529 0.597002
block2:dist1          -3.546e-02  4.617e-02  1.340e+03  -0.768 0.442558
block3:dist1           1.663e-02  4.568e-02  1.270e+03   0.364 0.715922
block1:dist2          -2.828e-02  4.507e-02  1.312e+03  -0.627 0.530466
block2:dist2          -9.487e-02  4.490e-02  1.320e+03  -2.113 0.034773 *
block3:dist2           6.840e-02  4.521e-02  1.321e+03   1.513 0.130521
block1:dist3           7.153e-03  4.275e-02  1.324e+03   0.167 0.867130
block2:dist3           8.567e-02  4.364e-02  1.335e+03   1.963 0.049818 *
block3:dist3           1.615e-02  4.315e-02  1.325e+03   0.374 0.708181
sequence1:block1:dist1 -6.197e-03  4.807e-02  1.331e+03  -0.129 0.897438
sequence1:block2:dist1  1.799e-03  4.617e-02  1.340e+03   0.039 0.968925
sequence1:block3:dist1  5.597e-02  4.568e-02  1.270e+03   1.225 0.220752
sequence1:block1:dist2  8.724e-02  4.507e-02  1.312e+03   1.936 0.053105 .
sequence1:block2:dist2  7.130e-02  4.490e-02  1.320e+03   1.588 0.112500
sequence1:block3:dist2 -8.834e-02  4.521e-02  1.321e+03  -1.954 0.050906 .
sequence1:block1:dist3 -1.406e-02  4.275e-02  1.324e+03  -0.329 0.742287
sequence1:block2:dist3 -3.490e-02  4.364e-02  1.335e+03  -0.800 0.423911
sequence1:block3:dist3 -1.473e-02  4.315e-02  1.325e+03  -0.341 0.732842
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Latencies, random effects:

```
 Groups      Name        Variance Std.Dev. Corr
 participant (Intercept) 0.226699 0.47613
             block1      0.032744 0.18095   0.53
             block2      0.020816 0.14428  -0.11  0.30
             block3      0.038559 0.19636  -0.62 -0.77  0.26
             dist1       0.021910 0.14802   0.74  0.43 -0.63 -0.73
             dist2       0.007316 0.08554  -0.02  0.08  0.80  0.53 -0.46
             dist3       0.011915 0.10915   0.52  0.36  0.36 -0.45  0.01 -
0.05
 Residual                0.307287 0.55433
Number of obs: 1479, groups:  participant, 34
```

Preferences, fixed effects:

```
                         Estimate Std. Error        df t value Pr(>|t|)
```

```
(Intercept)               3.96875    0.17712  31.99999  22.407  < 2e-16
***
sequence1                -0.06801    0.17712  31.99999  -0.384  0.70352
ring1                    -0.11949    0.05245 472.00000  -2.278  0.02317 *
direct1                   0.17096    0.07829  32.00000   2.184  0.03643 *
sequence1:ring1          -0.02390    0.05245 472.00000  -0.456  0.64889
sequence1:direct1         0.11213    0.07829  32.00000   1.432  0.16176
ring1:direct1            -0.16728    0.05245 472.00000  -3.189  0.00152 **
sequence1:ring1:direct1  -0.03493    0.05245 472.00000  -0.666  0.50581
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Preferences, random effects:

```
 Groups      Name        Variance Std.Dev. Corr
 participant (Intercept) 0.9731   0.9865
             direct1     0.1149   0.3389   0.27
 Residual                1.4966   1.2234
Number of obs: 544, groups:  participant, 34
```

Experiment 6

Accuracies, fixed effects:

```
                 Estimate Std. Error z value Pr(>|z|)
(Intercept)       2.99156    0.30937   9.670  < 2e-16 ***
distance1        -1.20215    0.22586  -5.323 1.02e-07 ***
distance2         0.08249    0.17300   0.477 0.633479
style1            0.31220    0.29425   1.061 0.288694
style2            0.71060    0.36372   1.954 0.050736 .
style3           -0.20029    0.26121  -0.767 0.443203
style4           -0.20822    0.26347  -0.790 0.429357
style5            0.19881    0.29647   0.671 0.502474
distance1:style1 -0.33691    0.20015  -1.683 0.092324 .
distance2:style1  0.46250    0.22148   2.088 0.036778 *
distance1:style2 -0.55078    0.22905  -2.405 0.016187 *
distance2:style2  0.87994    0.25794   3.411 0.000646 ***
distance1:style3 -0.14627    0.19475  -0.751 0.452626
distance2:style3 -0.31365    0.19624  -1.598 0.109980
distance1:style4  0.34705    0.19268   1.801 0.071680 .
distance2:style4 -0.32652    0.19549  -1.670 0.094863 .
distance1:style5  0.62844    0.20292   3.097 0.001955 **
distance2:style5 -0.62379    0.19797  -3.151 0.001628 **
---
```

Accuracies, random effects:

```
Groups Name        Variance Std.Dev. Corr
Part.(Intercept)3.1283   1.7687
    distance1   1.3472   1.1607   -0.41
    distance2   0.3581   0.5984   -0.18 -0.47
    style1      1.1869   1.0894    0.09 -0.67  0.24
    style2      2.1844   1.4780    0.30  0.24 -0.23 -0.21
    style3      1.0906   1.0443   -0.05  0.00  0.18 -0.17 -0.24
    style4      1.1040   1.0507   -0.24  0.49 -0.51 -0.25 -0.11 -0.47
    style5      1.3481   1.1611    0.18 -0.29  0.22 -0.46  0.09 0.13 -0.37
```

Latencies, fixed effects:

	Estimate	Std. Error	t value
(Intercept)	1304.82	57.78	22.583
distance1	78.70	22.98	3.424
distance2	24.95	15.28	1.634
style1	-28.70	41.90	-0.685
style2	-51.27	36.89	-1.390
style3	124.55	39.98	3.116
style4	-51.19	30.39	-1.684
style5	2.12	45.93	0.046
distance1:style1	46.72	31.62	1.478
distance2:style1	-15.57	29.87	-0.521
distance1:style2	-21.61	32.48	-0.665
distance2:style2	-40.13	29.94	-1.340
distance1:style3	-16.87	33.82	-0.499
distance2:style3	62.86	31.91	1.970
distance1:style4	-10.82	31.67	-0.342
distance2:style4	37.50	29.93	1.253
distance1:style5	-46.14	31.14	-1.482
distance2:style5	13.69	30.71	0.446

Latencies, random effects:

Groups	Name	Variance	Std.Dev.	Corr						
Part.	(Intercept)	132676	364.25							
	distance1	12736	112.86	0.24						
	distance2	1794	42.35	0.17	-0.12					
	style1	52967	230.15	0.10	-0.52	0.59				
	style2	35207	187.64	-0.16	-0.13	-0.80	-0.16			
	style3	44198	210.23	0.30	0.22	0.24	-0.09	-0.54		
	style4	18699	136.74	-0.39	-0.16	-0.46	-0.23	0.18	-0.43	
	style5	66464	257.81	0.45	0.36	0.14	-0.31	-0.26	-0.11	0.01
Residual		206724	454.67							

Preferences, fixed effects:

	Estimate	Std. Error	t value
(Intercept)	3.471545	0.137056	25.329
style1	-0.008130	0.094285	-0.086
style2	-0.291667	0.087335	-3.340
style3	0.110772	0.104710	1.058
style4	0.202236	0.101447	1.994
style5	-0.114837	0.097273	-1.181
dist1	-0.092480	0.030736	-3.009
direct1	-0.058943	0.041716	-1.413
style1:dist1	-0.005081	0.068728	-0.074
style2:dist1	0.065041	0.068728	0.946
style3:dist1	0.022358	0.068728	0.325
style4:dist1	-0.130081	0.068728	-1.893
style5:dist1	0.022358	0.068728	0.325
style1:direct1	-0.008130	0.068728	-0.118
style2:direct1	0.147358	0.068728	2.144
style3:direct1	-0.035569	0.068728	-0.518
style4:direct1	-0.035569	0.068728	-0.518
style5:direct1	0.001016	0.068728	0.015
dist1:direct1	0.068089	0.030736	2.215
style1:dist1:direct1	-0.122967	0.068728	-1.789
style2:dist1:direct1	-0.150407	0.068728	-2.188
style3:dist1:direct1	0.038618	0.068728	0.562
style4:dist1:direct1	0.002033	0.068728	0.030
style5:dist1:direct1	0.166667	0.068728	2.425

Preferences, random effects:

```
Groups   Name        Variance Std.Dev. Corr
 Part.    (Intercept) 0.73143  0.8552
          direct1     0.03262  0.1806   -0.21
          style1      0.17081  0.4133    0.30  0.05
          style2      0.11906  0.3450   -0.04 -0.01 -0.32
          style3      0.25586  0.5058   -0.03  0.75  0.14  0.24
          style4      0.22828  0.4778   -0.18 -0.23 -0.44 -0.55 -0.60
          style5      0.19427  0.4408    0.22 -0.31 -0.61  0.21 -0.18
0.01
          Residual    1.85921  1.3635
```


SUPPLEMENT: Appendix E: General approach to data analysis and results concerning the SDE effect as found in all experiments.

Overview of data analysis

For accuracy, latency, and preference data, we estimated linear mixed models (or generalized linear mixed models with logistic link function) with *participants* as random factors, to determine the best-fitting random structure. The final model with appropriate random effects was used to evaluate fixed effects (Jaeger, 2008; Judd, Westfall, & Kenny, 2012, see Appendix C). Appendix D contains estimates for fixed and random effects. Effect sizes are reported as Cohen's *dz*. Independent variables used orthogonal sum-to-zero contrasts (deviation or effects coding) where the last factor level of each variable is mapped onto all contrast variables with -1 and all other factor levels are mapped onto exactly one contrast variable with +1. Because by default, lmer-models do not use this coding, we explicitly set the contrasts for these types of models via afex::set_sum_contrasts().

Latencies (correct responses) are trimmed according to the Tukey criterion (outlier trials being values larger (smaller) than the upper (lower) quartile plus (minus) 1.5 times the interquartile range in an individual's distribution of latencies (see Clark-Carter, 2004, Chapter 9). If nothing else reported, type of comparator had no effect, therefore models without this factor are described.

Experiment 1:

1. Accuracy

The overall error level was 16.5%, across participants. The final model contained fixed effects for pair distance (pair 4/5, pair 3/6, pair 2/7, and pair 1/8), ideograph style (Chinese, Georgian, Konkani, Tigrinya), and their interaction. Pair distance was significant, $\chi^2(3) = 46.03$; $p < .001$, with more correct responses at wider pair distances ($M_{45} = .67$; $M_{36} = .82$; $M_{27} = .86$; $M_{18} = .93$, SDE-effect replicated), see Table 1. Responses to pair type 1/8 were more correct than to type 3/6 ($z = -3.24$; $p = .003$) and to type 4/5 ($z = -7.20$; $p < .001$), responses to pair type 2/7 were more correct than to type 4/5 ($z = -5.18$; $p < .001$), and responses to pair type 3/6 were more correct than to type 4/5 ($z = -4.65$; $p < .001$).

The interaction was also significant, $\chi^2(9) = 35.23$; $p < .001$. Bonferroni-Holm corrected contrasts showed the pair distance effect significant for each of the four ideograph styles alone ($p < .01$), but less pronounced in the Georgian style than in other styles.

2. *Response latencies*

The final model had the same fixed effect structure as above (see Appendix C). Only pair distance was significant, $F(3,33.15) = 6.19$; $p = .002$, showing quicker responding in trials of wider than narrower pairs, (SDE-effect, $M_{45} = 1715$ *ms*; $M_{36} = 1620$ *ms*; $M_{27} = 1512$ *ms*; $M_{18} = 1371$ *ms*), see Table 1. Responses to pair type 1/8 were faster than to type 3/6 ($t(35.9) = 3.02$; $p = .02$), and to type 4/5 ($t(35.2) = 4.34$; $p < .001$). Responses to pair type 2/7 were faster than to type 4/5 ($t(34.5) = 2.97$; $p = .02$).

Experiment 2:

1. *Accuracy*

The overall error level was 28.9%. The final model contained fixed effects for pair distance (pairs 4/5, 3/6, 2/7, 1/8), list (4 non-word-lists), and the interaction. A significant pair distance effect, $\chi^2(3) = 41.59$; $p < .001$, indicated more correct responses with wider pair distances (SDE, $M_{45} = .55$; $M_{36} = .72$; $M_{27} = .75$; $M_{18} = .82$), Table 2. Responses to pair type 1/8 were more correct than to types 4/5 ($z = -7.36$; $p < .001$), 3/6 ($z = -3.91$; $p < .001$), and 2/7 ($z = -2.57$; $p = .02$); responses to pair type 2/7 were more correct than type 4/5 ($z = -5.30$; $p < .001$), responses to pair type 3/6 were more correct than responses to type 4/5 ($z = -4.88$; $p < .001$). The significant interaction, $\chi^2(9) = 17.11$; $p < .05$, showed a significant SDE in each word list separately (Bonferroni-Holm corrected contrasts, $p < .001$ level), although less pronounced with lists 1 and 3.

2. *SDE-Effect: Response latencies*

The final model had the same fixed effect structure as above (see Appendix C). Only pair distance was significant, $F(3,45.65) = 3.20$; $p = .03$, showing quicker responding with wider than narrower pairs (SDE, $M_{45} = 1735$ *ms*; $M_{36} = 1800$ *ms*; $M_{27} = 1649$ *ms*; $M_{18} = 1591$ *ms*), see Table 2. Responses to pair type 1/8 were faster than to type 3/6 ($t(40.3) = 2.77$; $p < .05$), no other post hoc comparison was significant. This, together with the accuracy results, shows that participants presumably generated spatial representation amongst the eight stimuli, thereby determining the difficulty levels between wide and narrow pairs along the comparator dimension.

Experiment 3:

The Tukey criterion was applied for data trimming on a blockwise basis, such that across participants, blocks with extremly high average error rates would be excluded (average percentage correct per block smaller than the lower quartile minus 1.5 times the interquartile range in the sample's distribution of block averages, see Clark-Carter, 2004, Chapter 9).

1. SDE-Effect: Accuracy

Experiment 3a (spatial learning cues). Out of 408 blocks, 39 blocks were excluded, leaving 369 blocks left for analysis. The overall error level after exclusion was 6.39%. The final model used for analysis contained fixed effects for pair distance (pair 3/4, pair 2/5, and pair 1/6), ideograph style (Chinese, Georgian, Konkani, and Tigrinya), number of learning cycles (3, 5, and 8), and the three-way interaction of these factors. There was a significant fixed factor effect for pair distance, $\chi^2(2) = 23.98$; $p < .001$, indicating that responses were more correct with wider pair distances ($M_{34} = .89$; $M_{25} = .94$; $M_{16} = .96$), thus replicating the SDE, see Table 3. In particular, responses to pair type 1/6 were more correct than responses to pair type 3/4 ($z = -4.22$; $p <.001$) and responses to pair type 2/5 were more correct than responses to pair type 3/4 (z = -3.48; p < .001), but responses to pair type 1/6 were not significantly more correct than responses to pair type 2/5 (z = -1.39; p = .34).

The interaction between pair distance and ideograph style was also significant, $\chi^2(6) = 18.81$; p = .004, indicating that the pair distance effect was more pronounced in the Chinese ideograph block as compared to the other three styles. We also found a significant triple-interaction between pair distance, ideograph style, and number of learning cycles, $\chi^2(12) = 40.06$; p < .001, which was not interpreted.

Experiment 3b (temporal learning cues). Out of 404 blocks, 56 blocks were excluded, leaving 348 blocks left for analysis. The overall error level after exclusion was 3.16%. The final model used for analysis was of the same structure as the previous one for Experiment 8a. There was a significant fixed factor effect for pair distance, $\chi^2(2) = 23.94$; p < .001, indicating that responses were more correct with wider pair distances (M_{34} = .95; M_{25} = . 98; M_{16} = .98), thus replicating the SDE, see Table 3. In particular, responses to pair type 1/6 were more correct than responses to pair type 3/4 (z = -3.79; p <.001) and responses to pair type 2/5 were more correct than responses to pair type 3/4 (z = -4.02; p < .001), but responses to pair type 1/6 were not significantly more correct than responses to pair type 2/5 (z = .20; p = .97). No further significant effects were observed.

2. SDE-Effect: Response latencies

Experiment 3a (spatial learning cues). The final model used for analysis had the same fixed effect structure as the one reported for accuracy (for its random effect structure see Appendix C). In this model, pair distance had a significant effect, $F(2,92.78) = 50.96$; p < .001, replicating the SDE by showing quicker responding in trials of wider than narrower pair distance, (M_{34} = 2160 *ms*; M_{25} = 1748 *ms*; M_{16} = 1469 *ms*), see Table 3. In particular, responses to pair type 1/6 were faster than responses to pair type 3/4 (*t-ratio* = 10.14 (*df* = 95.5); p <.001), responses to pair type 1/6 were faster than responses to pair type 2/5 (*t-ratio*

= 6.19 (df = 93.0); $p < .001$), and responses to pair type 2/5 were faster than responses to pair type 3/4 (t-$ratio$ = 7.05 (df = 94.2); $p < .001$).

Ideograph style also had a significant main effect, $F(3,88.48) = 5.58$; $p < .001$, indicating that responses to Chinese ideographs were slowest as compared to the other three ideograph styles, ps < .04, with no other post hoc differences being significant. There was also a significant interaction of pair distance and ideograph style, $F(6,3709.17) = 2.50$; $p = .02$, with the SDE appearing more pronounced in Chinese and Georgian scripts as compared to Konkani and Tigrinya, ps < .05. No further effects were significant.

Experiment 3b (temporal learning cues). A similar model as above was fitted and statistically evaluated (for its random effect structure see Appendix C). In this model, pair distance had a significant effect, $F(2,92.19) = 72.58$; $p < .001$, replicating the SDE by showing quicker responding in trials of wider than narrower pair distance, (M_{34} = 2077 ms; M_{25} = 1808 ms; M_{16} = 1437 ms), see Table 3. In particular, responses to pair type 1/6 were faster than responses to pair type 3/4 (t-$ratio$ = 11.75 (df = 92.9); $p <.001$), responses to pair type 1/6 were faster than responses to pair type 2/5 (t-$ratio$ = 6.96 (df = 93.3); $p < .001$), and responses to pair type 2/5 were faster than responses to pair type 3/4 (t-$ratio$ = 4.23 (df = 93.5); $p < .001$). Ideograph style also had a significant main effect, $F(3,83.58) = 3.99$; $p < .01$, indicating that responses to Chinese ideographs were slower than those to Georgian, $p = .04$, as well as responses to Konkani ideographs being slower than those to Georgian, p = .04. No further effects were significant.

Experiment 4:

SDE-Effect: Accuracy

The overall error level was 18%. The final model contained fixed effects for pair distance (pair 3/4, pair 2/5, and pair 1/6), ideograph style (Chinese, Georgian, Konkani, and

Tigrinya), type of comparator, and their interaction. A significant effect for pair distance, $\chi^2(3) = 199.67$; $p < .001$, indicated more correct responses with wider pair distances (SDE, $M_{45} = .67$; $M_{36} = .80$; $M_{27} = .87$; $M_{18} = .92$), see Table 4. Responses to pair type 1/8 were more correct than to type 4/5 ($z = -12.66$; $p <.001$), responses to pair type 1/8 were more correct than responses to pair type 3/6 ($z = -8.80$; $p < .001$), responses to type 1/8 were more correct than to type 2/7 ($z = -3.55$; $p < .001$), responses to type 2/7 were more correct than to type 4/5 ($z = -11.66$; $p < .001$), responses to type 2/7 were more correct than to type 3/6 ($z = -6.59$; $p < .001$), and responses to type 3/6 were more correct than to type 4/5 ($z = -8.04$; $p < .001$).

The interaction showed, $\chi^2(9) = 30.57$; $p = .0004$, that the SDE was less pronounced for Georgian letters than for other types (*ps* < .01). Type of comparator was significant, $\chi^2(1) = 21.29$; $p < .001$, with accuracies higher for comparator "*old*" ($M = .84$) than for "*more frequently used*" ($M = .79$, $z = 4.76$; $p < .001$).

SDE-Effect: Response latencies

The final model had the same fixed effect structure as above (Appendix C). Pair distance had a significant effect, $F(3,229.18) = 37.72$; $p < .001$, showing quicker responding in trials of wider than narrower pair distance, (SDE, $M_{45} = 1790$ *ms*; $M_{36} = 1694$ *ms*; $M_{27} = 1601$ *ms*; $M_{18} = 1491$ *ms*), see Table 4. In particular, responses to pair type 1/8 were faster than to type 4/5 ($z = 10.28$; $p <.001$), to type 3/6 ($z = 8.13$; $p < .001$), and to type 2/7 ($z = 4.64$; $p < .001$). Responses to pair type 2/7 were faster than to type 4/5 ($z = 7.95$; $p < .001$) and to type 3/6 ($z = 4.37$; $p < .001$), and responses to pair type 3/6 were faster than responses to type 4/5 ($z = 4.44$; $p < .001$).

Type of ideograph, $F(3,218.32) = 13.29$; $p < .001$, showed that, as post-hoc tests revealed (*ps* < .001), participants needed on average longer to respond to Chinese ideographs ($M = 1819$ *ms*) as compared to Georgian ($M = 1595$ *ms*), Konkani ($M = 1626$ *ms*) or Tigrinya ideographs (M = 1501 *ms*). Lastly, type of comparator was significant, $F(1,226.18) = 29.75$; $p < .001$ with slower responding to "*older than*" items (M = 1673 *ms*) than to "*more frequently used*" items (M = 1592 *ms*; $z = 5.46$; $p < .001$).

Experiment 5:

SDE-Effect: Accuracy

The overall error level was 27%. The final model contained fixed effects for pair distance (pairs 4/5, 3/6, 2/7, 1/8), list (4 non-word-lists), and the interaction. A significant pair distance effect, $\chi^2(3) = 18.11$; $p < .001$, indicated more correct responses with wider pair distances (SDE, $M_{45} = .65$; $M_{36} = .69$; $M_{27} = .75$; $M_{18} = .81$), see Table 5. Responses to pair type 1/8 were more correct than to types 4/5 ($z = 4.32$; $p < .001$), 3/6 ($z = 3.00$; $p < .01$), and 2/7 ($z = 2.44$; $p = .04$); responses to pair type 2/7 were more correct than type 4/5 ($z = 2.96$; $p < .01$).

SDE-Effect: Response latencies

The final model had the same fixed effect structure as above (see Appendix C). Pair distance was significant, $F(3,38.23) = 5.63$; $p = .003$, showing a tendency to quicker responding with wider than narrower pairs (SDE, M_{45} = 1305 *ms*; M_{36} = 1329 *ms*; M_{27} = 1157 *ms*; M_{18} = 1187 *ms*), see Table 5. Responses to pair type 1/8 were faster than to types 4/5 ($z = 4.32$; $p < .001$), 3/6 ($z = 3.00$; $p < .01$) and 2/7 ($z = 2.44$; $p < .04$), as well as faster to type 2/7 than type 4/5 (z =2.96; $p < .01$). This, together with the accuracy results, shows that participants presumably generated spatial representation amongst the eight stimuli, thereby determining the difficulty levels between wide and narrow pairs along the comparator dimension.

Self-generated cognitive fluency: Consequences on evaluative judgments

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Running Head: Relational fluency

Abstract

People can support abstract reasoning by using mental models with spatial simulations. Such models are employed when people represent elements in terms of ordered dimensions (e.g., who is oldest, Tom, Dick, or Harry). We test and find that the process of forming and using such mental models can influence the liking of its elements (e.g., Tom, Dick, or Harry). The presumed internal structure of such models (linear-transitive array of elements), generates variations in processing ease (fluency) when using the model in working memory (see the Symbolic Distance Effect, SDE). Specifically, processing of pairs where elements have larger distances along the order should be easier compared to pairs with smaller distances. Elements from easier pairs should be liked more than elements from difficult pairs (fluency being hedonically positive). Experiment 1 shows that unfamiliar ideographs are liked more when at wider distances and therefore easier to process. Experiment 2 replicates this effect with non-words. Experiment 3 rules out a non-spatial explanation of the effect while Experiments 4 offers a high-powered replication. Experiment 5 shows that the spatial effect spontaneously emerges after learning, even without a task that explicitly focuses on fluency. Experiment 6 employed a shorter array, but yielded no significant results.

225 words

Key Words: symbolic distance effect (SDE), magnitude processing, linear orders, spatial processing, cognitive fluency

Word Count: 8491 (without references)

Running Head: Relational fluency

Self-generated cognitive fluency: Consequences on evaluative judgments

1. Introduction

1. 1. Background

Much evidence shows that perceptually or cognitively *fluent* stimuli elicit positive affective responses, as revealed by participants' favourability ratings, or their physiological reactions (Winkielman & Cacioppo, 2001, for a review: Winkielman, Schwarz, Fazendeiro, & Reber, 2003). Things are liked more if easier to perceive and cognize. More generally, participants draw on internal subjective experiences in their judgments of external stimuli (Schwarz & Clore, 1996; Strack, Martin, & Stepper, 1988). Importantly, such experiences may not derive from stimulus features (Anderson, 1981) but reflect the relative effort of stimulus processing, resulting in a cognitive feelings of fluency (Clore, 1992; Jost, Kruglanski, & Nelson, 1998, Schwarz, 1998). Fluency is assumed to be associated with pleasure and positive affective reactions (Winkielman et al., 2003, but see Unkelbach, 2006 for an argument against inherent pleasantness of fluency).

Fluency effects can be elicited by manipulating perceptual effort by variations in repetition, presentation time, or figure-to-ground contrast (e.g., Reber, Winkielman, and Schwarz, 1998, see the mere exposure effect, Zajonc, 1968). For example, in the mere exposure effect, neutral stimuli are liked more after frequent repetition (Bornstein, 1989; Zajonc, 1968), presumably due to greater neural processing efficiency with more repetitions, leading to greater judgments of clarity and distinctness (Desimone, Miller, Chelazzi, & Lueschow, 1995; Witherspoon & Allan, 1985). Fluency can also be manipulated at the conceptual level by placing the stimulus within a predictive or non-predictive semantic context making it easier or harder to derive the stimulus meaning (e.g., Fazendeiro, Winkielman, Luo, & Lorah, 2005; Whittlesea, 1993).

Critically, whether a specific stimulus elicits fluency/disfluency and liking/disliking depends on the exact task performed by the participant, for example, emotionally ambiguous faces being disfluently processed when categorized on emotion, but fluently when categorized on gender which was not ambiguous (see Winkielman, Olszanowski, & Gola (2015). Analog effects showing task dependence of fluency and preferences were observed with brain measures (EEG) of processing difficulty (Kaminska et al., 2020) and have been modelled computationally (Ryali et al, 2020).

1.2. Present Research

Previous studies on fluency have focused on either perceptual factors or on cognitive factors, see above. The present research investigates fluency phenomena during online processing of self-constructed mental models (Greeno, 1989; Hegarty, 2004). We provide evidence for fluency as internally generated, not to be described in terms of external (perceptual), individual stimulus features, or pre-existing semantic contexts. Unlike previous research on conceptual fluency, self-generated fluency does not rely on information or schemata in long-term memory. Rather, this fluency derives from the nature of the self-constructed relations *between* newly learned, individual stimuli. The degree of fluency associated with a stimulus, as we argue, derives from reasoning about the stimulus as it relates to other stimuli when constructing an overall mental representation of all stimuli simultaneously. Differences in fluency are to be expected just because the experimental task taps precisely into the characteristics of this overall representation.

1.3. The Paradigm

The present research involves learning elements on a continuum. For example, after learning a linear rank order of fictitious persons, such as *Tom (T) is older than Dick (D), Dick* *is older than Harry (H), Harry is older than Chris (C)*, … etc., participants respond to later test queries (e.g., *who is the older?*) about person pairs of wider distances on that T>D>H>C order (e.g., T-C) more quickly, and with greater accuracy, than about narrower distances (e.g., D-H, Potts, 1972, 1974; Smith & Foos, 1975; Pohl & Schumacher, 1991). This "symbolic distance effect" (SDE), suggests a spatial representation of the order T > D >H > C etc. constructed during learning (Leth-Steensen & Marley, 2000). Several authors have proposed that wider distances may be more discriminable than narrower distances (Holyoak & Patterson, 1981; Huttenlocher, 1968). Although tthe SDE may not necessarily rely on spatial representation (Hintzman, 1986; see also Leth-Steensen & Marley, 2000), research provides evidence of spatial involvement in such tasks (von Hecker et al., 2016, 2019; von Hecker & Klauer, 2021).

The faster speed and greater accuracy in processing elements from wider conceptual distances compared to narrower distances, can be taken as a proxy for subjectively experienced difficulty, therefore, as proxy for conceptual fluency (Wänke, 2013). As standard in the fluency literature, we assume that quicker responses indicate more subjective fluency (Winkielman et al., 2006; see Discussion). The involvement of fluency in SDE is suggested by brain imaging studies on transitive reasoning that found differences in activation in prefrontal and parietal cortex areas known to be involved in spatial processing (Acuna et al., 2002; Christoff et al.,2001; Hinton et al., 2010; van Opstal et al., 2009; Zalesak & Heckers, 2009): Test queries were easier on wider than narrower distances, and participants indicated they tried to form a mental chain to solve the task. In sum, research suggests that wider conceptual distances between pairs of matched items is associated with greater fluency than narrower distances.

1.4. Predictions

We assume that participants experience more fluency when processing information about order (e.g., in *age*, *frequency*, etc.) within a pair of wide than narrow distance, corresponding to more positive affect with wide distances, resulting in more liking for individual stimuli from wide than narrow pairs.

Notably, identifying the dominant (e.g., older, taller) element in a pair taps into the spatial order representation that generates the difficulty differential, which is therefore self-induced during reasoning. Thus, fluency does not stem from an isolated stimulus or any external context but is the experience of processing an order information about two mental elements, depending on all stimuli along the dimension. Given the above assumption, when learning and processing T>D>H>C order, participants should develop more positive responses towards T and C as compared to D and H.

As argued earlier, here we are interested in fluency and preferences that derive from the *configuration* between stimuli within a mental model, and not any other distinguishing attributes. Therefore we first test for SDE in all experiments to confirm that greater fluency corresponds with greater ordinal distance between comparison pairs. However, note that participants might also conflate preferences with "order dominance" (see von Hecker et al., 2016, 2019). For example, participants may prefer a dominant stimulus on the age dimension (oldest, or least old). This is especially possible with unfamiliar, arbitrary, neutral stimuli which lack more obvious cues for their liking. If so, participants might take the learned order relation as proxy for generating their liking judgment which has been termed “metaphorical blending” (Coulson & Oakley, 2005; Fauconnier & Turner, 1998). Casasanto (2009) illustrates this: “Linguistic expressions like ‘the prime example’ conflate primacy with goodness (i.e., this phrase can mean the first example, the best example, or both). Speakers of languages like English may be predisposed to consider the leftmost item to be the first and therefore the best.” (p. 362). Under the blending hypothesis, higher liking is expected for stimuli closer to the maximum than to the minimum. We test this process by comparing the liking between the two elements of any pair, independent of fluency predictions, based on closeness to the maximum (e.g., the *oldest* when the comparator is *older*) versus minimum (the *least old*).

Because fluency effects are usually small (see Winkielman & Cacioppo, 2001; Winkielman et al., 2003), their detection in the present research could be severely compromised by metaphorical blending. However, there are ways to isolate them. Consider a learned sequence A > B > C > D > E > F > G > H, with maximum at A (e.g., "oldest"). According to the fluency hypothesis, liking for stimuli A and H (wide distance – therefore easy) should be greater than liking for stimuli D and E (narrow distance – therefore difficult). Metaphorical blending predicts the same as fluency for stimuli A vs. D, that is, it predicts that A should be liked better than D, however predicts the opposite for stimuli E and H (E should be liked better than H). Therefore, we adopt a statistical strategy: Our statistical models must show independent, significant evidence for the *distance* effect (fluency), even in the presence of a significant *orientation* effect (metaphorical blending), in order to count as evidence in support of the fluency hypothesis. Conversely, if a data pattern can be exclusively explained by the metaphorical blending hypothesis, the fluency factor should not exhibit a significant effect.

1.5. Overview

The experiments reported here follow the same basic methodology (Leth-Steensen & Marley, 2000; Potts, 1972, 1974; Smith & Foos, 1975; Pohl & Schumacher, 1991; Sedek & von Hecker, 2004; von Hecker et al., 2016). In a learning phase, all possible pair combinations of an even number of stimuli (e.g., 8 in Experiment 1) are presented in a self-paced random sequence. Each pair represents a comparison, for example S_1 is *older* than S_2, etc., such that across all presentations a transitive rank order between S_1, S_2, …, S_k can be mentally constructed. We assume that this way, an analog, spatial mental model will be constructed along a hypothetical dimension (e.g., "age") on which wider pairs are easier to discriminate than narrower pairs. A test phase immediately follows, except for Experiment 5 (see below). In the test phase, upon seeing a pair, participants press a marked key ("b" or "n") on the side of the dominant, for example, "older" element. Crucially, each test stimulus can only be experienced in the context of the same difficulty level. For example, assuming a rank order S_1, … S_8, with S_1 as *oldest*, only pairs S_1S_8, S_2S_7, S_3S_6, and S_4S_5 were queried. Thus, a participant should experience the easiest (most fluent) processing for S_1 and S_8, "less easy" for S_2 and S_7, "hard" for S_3 and S_6, and "hardest" for S_4 and S_5. In the final phase (except for Experiment 5) single elements are presented to be evaluated one by one, selected only from the hardest and easiest pairs, that is, S1 and S8 (easiest) as well as S4, and S5 (hardest).

We expect stimuli to be rated more positively when associated with more fluency. Experiment 1 uses unfamiliar ideographs. Experiment 2 uses non-words, Experiment 3 addresses a non-spatial alternative explanation. Experiment 4 is a high-powered replication of Experiment 1, whereas Experiment 5 tests the possibility that differences in liking may already be created during the learning phase. In the Appendix, we report an experiment yielding only marginal results.

We planned conservative sample sizes for Experiments 1, 2 and 5 to detect typical effects (e.g., Reber et al. 1998, approx. dz = .25), N=37 (Experiment 1), N=42 (Experiment 2), and N = 37 (Experiment 5). With this, we obtained effect sizes around dz = .20, indicating a small effect. In Experiments 3 and 4 we ran high-powered replications of Experiment 1. Data and R scripts for analyses can be accessed at

https://osf.io/b4p38/?view_only=f1ee575d66d743c3978e565f4d201505

2. Experiment 1: The Relational Fluency Effect

In a first experiment, four sets of eight unfamiliar ideographs were chosen as to-be-ordered stimuli. We expected higher accuracy and faster correct responding to wider pairs of ideographs, as well as more positive evaluations of elements from wider as compared to narrower pairs.

2.1. Method

2.1.1. Participants

Thirty-seven undergraduate students from Cardiff University, School of Psychology (31 female, 6 male, mean age = 20.4 years), all with English-spoken backgrounds, took part in the experiment against course credit.

2.1.2. Material and procedure

Participants completed the task in front of a 22-inch screen, being asked to memorize various rank relations within unfamiliar letters. Instructions continued that some of the letters had been found to be older, or more frequently used, than others. For each participant, these comparators were randomly assigned to the four letter sets (2 and 2).

The experiment consisted of four blocks of letters from Chinese, Georgian, Konkani, and Tigrinya (presumably unfamiliar to our students with English-spoken background). From each alphabet (block), eight letters were chosen. Each block consisted of a learning, a testing, and a rating phase. In each trial of the *learning phase*, two letters were presented side by side, one declared as “older”, or “more frequently used”. Participants were asked to memorize the pairwise relations, pressing the space bar to switch from pair to pair (self-paced). All 28 possible pairs of letters were presented twice in a random sequence (56 trials). All possible pairs were presented in the first 28 as well as in the last 28 learning trials, no pair immediately repeating in the sequence. In the following *testing phase*, four pairs representing the four distance levels were randomly presented, that is, S_1S_8, S_2S_7, S_3S_6, and S_4S_5. Participants were asked to decide as quickly and accurately as possible which of the two letters was older, or more frequently used. In the final, *rating phase*, single letters were presented to be rated one by one, selected only from the hardest and easiest pairs, that is, S_1 and S_8 (easiest) as well as S_4, and S_5 (hardest). These four *single* letters were each rated twice, consecutively for each letter, in a random sequence, on two 7-point scales ranging from 1 (*not at all*) to 7 (*a lot*): "How much do you like me?" and "How much do you want me on a mug?"

The order of the blocks was random. Participants completed a short distraction task between two blocks. After all procedures (lasting 20-25 minutes) participants were debriefed.

2.2. Results

For an overview of our approach to data analysis, and for all results concerning the SDE replication, see Supplement, Appendix E. All experiments yielded an SDE (accuracies and latencies). As substantially correlated (r=.60) the two preference questions were averaged. The final model contained fixed effects for pair distance (4/5, 1/8), ideograph style, orientation (towards maximum vs. minimum), and the interactions (see Appendix C). Pair distance revealed, $F(1,36) = 4.57$; $p = .03$, $dz = .20$, that ideographs were preferred more ($t(988) = -2.44$; $p = .014$) within pairs of type 1/8 ($M = 3.57$, SD=1.46) than within pairs of type 4/5 ($M = 3.36$, SD=1.45).

Pair distance and orientation interacted marginally significant, $F(1,988) = 3.52$; $p = .06$, see Figure 1, showing for outer pairs, participants liked stimuli closer to the maximum more than those closer to the minimum ($t(74.4) = -2.00$; $p = .04$). The same did not hold for inner pairs ($t(74.4) = .11$; $p = .91$). Response times for a stimulus (as inner- vs. outer) significantly predicted the preference for it, $F(1,68.91) = 6.21$; $p = .02$, $\beta = -.22$.

2.3. Discussion

Experiment 1 revealed a source of fluency, namely, self-generated difficulty levels resulting from transitive reasoning, presumably resulting in an spatial representation, associated with differential liking of the stimuli involved. No prior knowledge or external information could influence the task. Participants liked ideographs from wide more than from narrow distances. An SDE (Leth-Steensen & Marley, 2000; von Hecker et al., 2016) was confirmed. Shorter latencies during the test phase, indicating easier processing, were associated with greater liking. Influences from stimulus characteristics were ruled out by randomly allocating ideographs to order positions for each participant.

The blending hypothesis (Casasanto, 2009; Coulson & Oakley, 2005; Fauconnier & Turner, 1998) was supported for outer pairs, not inner pairs. In the absence of more salient cues, participants presumably used the dimension (*older* or and *more frequently used than*) as proxy or a cue for liking, though only at wider pair distances.

3. Experiment 2: Replication with Non-Words

Our argument that difficulty levels are self-generated via mental model construction is not tied to particular modalities of perception, or stimulus types. Therefore we selected verbal stimuli for a second test. Different from Experiment 1, linear order construction here is likely to be based on verbal (or phonetic) rehearsal. As similarity and dissimilarity perceptions within sets of non-words have been shown to be driven by phonetic characteristics of non-words (Hahn & Bailey, 2005), the present experiment taps into a different rehearsal modality than Experiment 1. Still, non-words can be deemed plausible objects for liking judgments as well as graphic designs (ideographs). Explicit liking for non-words has been shown to be influenced by the valence of experiences associated with these same words (Schmidt & de Houwer, 2012). Therefore, we expect that self-generated fluency derived from transitive reasoning about non-words will influence explicit liking of the same stimuli.

3.1. Method

3.1.1. Participants

Forty-two undergraduate students from Cardiff University, School of Psychology (36 female, 6 male, mean age = 18.9 years), all with English-spoken backgrounds, took part in the experiment against course credit.

3.1.2. Material and procedure

Thirty-two non-words were generated from materials used by Bailey & Hahn (2001) in a study on the wordlike-ness of non-words (see Appendix B). The experiment consisted of four blocks, using four different sets of eight non-words. Procedures were the same as in Experiment 1 except participants being told that they would be learning rank relations between words from a fictitious language, some older or more frequently used than others. The two comparators were randomly assigned to the four non-word blocks (2 for each). At the end of each block, each non-word of the series was rated using the question: “How much do you like me?”.

Within blocks, the non-words within each set, as listed in Appendix B, were randomly assigned to rank positions within the to-be-learned order. Blocks were presented in a random sequence. The experiment lasted around 20-25 minutes.

3.2. Results

The final model contained fixed effects for pair distance (pair 4/5, pair 1/8), nonword list (4 lists), and orientation (maximum vs. minimum), comparator (“*older than*” vs. “*more frequent than*”), and the interactions (Appendix C). Pair distance was significant, $F(1,41.53) = 7.86$; $p = .008$; $dz = .26$, showing that non-words were liked more when coming from pairs of type 1/8 ($M = 3.74$, SD=1.57) than type 4/5 ($M = 3.34$, SD=1.33, $t(41.5) = -2.80$; $p = .007$), see Figure 2. List had a significant effect, $F(3,682.37) = 4.94$; $p = .002$, list-3-non-words being liked less ($M_{list3} = 3.27$) than the average of all others ($M_{lists124} = 3.62$), $t = 2.78$; $p = .009$. Type of comparator and pair distance interacted, $F(1,1070.86) = 5.29$; $p = .02$, the distance effect on liking being more pronounced for “more frequently used” ($M_{outer} = 3.77$,

SD_{outer} =1.11; M_{inner} = 3.24, SD_{inner} =.81) than for “older than” (M_{outer} = 3.69, SD_{outer} =.68; M_{inner} = 3.44, SD_{inner} =.89). Orientation was insignificant, $F(1,41) = 2.08$; $p = .16$ (no metaphoric blending), with no interactions. Latencies during testing did not predict liking ($F(1,65.98)$ =.37; $p = .55$).

3.3. Discussion

Accuracies were slightly lower than in Experiment 1. Participants may have found those stimuli relatively difficult due to phonetic rehearsal. There was more liking for non-words from wider pairs, as compared to narrower pairs on the hypothetical mental model. Participants probably experienced greater fluency with the former than the latter.

The distance effect on liking was more pronounced for comparator type “more frequent than” as compared to “older than”. Perhaps the meaning of “*more frequent than*” triggered more phonetic rehearsal than the meaning of “*older than*”, which could have accentuated the fluency experience for “*more frequent than*” in the test phase. As well, in this experiment, semantics of “frequency” could have been conducive to the creation of fluency (see e.g., Wänke, 2013). In summary, in a second study, tapping into a different stimulus modality than the first, the predicted association between experienced fluency and positive affect was replicated. However, liking was not predicted by response latencies. The metaphorical blending hypothesis received no support from this experiment.

4. Experiment 3 : Number of “Wins”

As mentioned above, the SDE, rather than spatial, could alternatively be the result different activation levels between the stimuli (Hintzman, 1986; Leth-Steensen & Marley, 2000). In this case, perceivers might just notice that in an ordered sequence S_1, S_2, S_3, etc., the maximum stimulus, S_1, “wins” all comparisons within presented pairs, whereas the minimum stimulus will not win any of them. Tallying the “number of wins” for each stimulus might therefore be a mechanism leading to an order representation. With corresponding activation levels for each ideograph, this representation might produce an SDE without space being involved. Research on Evaluative Conditioning has found that winning or losing comparisons within US-CS pairs did influence CS likeability (Unkelbach & Fiedler, 2016). The present experiment rules out "wins" to occur at all.

Secondly, we test the emergence of an SDE in presentation modalities that use either *spatial* (Experiment 3a) or *temporal* cues (Experiment 3b) for indicating dominance, addressing the assumption that the SDE originates from an abstract, modality-independent cognitive entity (Huttenlocher, 1968; Gevers, Reynvoet, & Fias, 2003; Knauff, 2013; von Hecker et al., 2016).

4.1. Method

4.1.1. Participants

One-hundred and two (Experiment 3a) as well as 101 (Experiment 3b) undergraduate students from the University of California, San Diego, Department of Psychology, all with English-spoken backgrounds, took part in the experiment against course credit (3a: 74 female, 28 male, mean age = 20.1 years; 3b: 74 female, 26 male, one preferred not to say, mean age = 20.3 years).

4.1.2. Materials and Procedure

Materials were identical to Experiment 1 except only six letters from each ideograph style were used in each of the four blocks. Procedures were identical to Experiment 1 except detailed below. In both experiments, only the question "How much do you like me?"was used. In both experiments, one third of participants did two cycles as described, a third did five cycles, the remaining third did eight cycles.

Experiment 3a (spatial learning cues). In each block, the six letters were presented in a sequence from left to right on the screen, with the first letter occupying the leftmost screen position, and each subsequent letter occupying a stepwise-scaled position further on the right, such that at presentation of the sixth letter, the rightmost position on the screen was reached. Presentation was self-paced. After presentation had started with the first letter, upon pressing the space bar that letter would disappear and the second letter would appear further to the right, and so on. Only "older" was used as comparator, and participants were instructed that in the sequence, any letter positioned *left* to another was to be considered "older" than the other.

Experiment 3b (temporal learning cues). In each block, the six letters were presented centrally on the screen, with the first letter appearing first, and each subsequent letter at the same central position in temporal order. Presentation was self-paced. After the presentation had started with the first letter, upon pressing the space bar, that letter would disappear and the second letter would appear, and so on until the last letter. Only "older" was used as comparator, and participants were instructed that in the sequence, any letter appearing *prior* to another was to be considered "older" than the other.

4.2. Results

Experiment 3a (spatial learning cues). The final model used for analysis contained fixed effects for pair distance (pair 3/4, pair 1/6), ideograph style (Chinese, Georgian, Konkani, and Tigrinya), orientation (towards the maximum vs. towards the minimum of the dimension), number of learning cycles (2, 5, 8), and the interaction of these factors (for its random effect structure see Appendix C). Learning cycles was not involved in any effect. Pair distance yielded a significant effect, $F(1,94.11) = 12.24$; $p < .001$, $dz = .14$, showing that ideographs were preferred more when they had been tested within pairs of type 1/6 ($M = 4.59$, SD=1.80) than when tested within pairs of type 3/4 ($M = 4.29$, SD=1.61, t-$ratio$ = -3.49 (df = 94.1); $p < .001$), see Figure 3.

There was also a significant main effect for orientation, $F(1,94.83) = 5.15$; $p = .03$, indicating that stimuli closer to the maximum ($M = 4.55$, SD=1.73) were preferred to those closer to the minimum (*M* = 4.33, *SD*=1.69, *t-ratio* = 2.26 (*df* = 94.8); *p* = .03). Lastly, there was a significant interaction between pair distance and ideograph style, *F*(3,1175.45) = 2.55; *p* < .05, showing that the preference for ideographs as contained in pairs of type 1/6 over those in pairs 3/4 was more pronounced for Georgian and Konkani blocks (*p* = .006 and *p* = .007), as compared to Chinese and Tigrinya blocks (*p*s > .22). In a separate model, predicting preferences for the stimuli involved in inner and outer pairs by the response times to these stimuli, and participants as random factor, response times for a stimulus significantly predicted the preference for it, *F*(1,727) = 5.767; *p* = .02, *β* = -.12.

Experiment 3b (temporal learning cues).

The model with identical structure to the above was used for analysis (cf. Appendix C). Learning cycles was not involved in any effect. Pair distance yielded a significant effect, *F*(1,1248.82) = 11.90; *p* < .001, *dz* = .13, showing that ideographs were preferred more when they had been tested within pairs of type 1/6 (*M* = 4.49, *SD*=1.80) than when tested within pairs of type 3/4 (*M* = 4.20, *SD*=1.72, *t-ratio* = -3.45 (*df* = 1249); *p* < .001).

Orientation was associated with a significant main effect, *F*(1,1248.82) = 33.81; *p* < .001, indicating that stimuli closer to the maximum (*M* = 4.59, *SD*=1.72) were preferred to those closer to the minimum (*M* = 4.10, *SD*=1.77, *t-ratio* = 5.81 (*df* = 1249); *p* < .001). There were no more significant effects. In a separate model, predicting preferences for the stimuli involved in inner and outer pairs by the response times to these stimuli, and participants as random factor, response times for a stimulus did not significantly predict the preference for it, *F*(1,694) = .64; *p* = .42, *β* = -.05.

4.3. Discussion

We addressed the alternative hypothesis that the emergence of the SDE could be due to differentials in activation levels between the stimuli (Hintzman, 1986; Leth-Steensen & Marley, 2000). During the learning phase the six ideographs in a block could not be associated with differential numbers of "wins", that is, parings with other ideographs in which they would appear dominant. Using spatial or temporal primacy as learning cues for the generation of the order, we found strong SDE's in terms of accuracy and latency patterns. Therefore, we conclude that a spatial representation of a linear order does spontaneously result even without the number of wins playing a role (for spatial order representations on the basis of temporal information see von Hecker et al., 2016, 2019). The present findings support the idea that self-generated fluency differentials in our task are presumably based on differentials in the processing of ideograph pairs which are part of spatial order representations.

Our main target effect replicated in both conditions: Participants showed greater liking for the ideographs that were part of the outer pairs in the learned order as compared to the ideographs that were part of the inner pairs. This is presumably because the former were inducing more fluency during the test phase. Again, the metaphorical blending hypothesis (see Casasanto, 2009; Coulson & Oakley, 2005; Fauconnier & Turner, 1998) was supported. Presumably, the preference dimension can be mapped onto dimensional dominance.

5. Experiment 4: High-powered Replication and Scale Reversal

We attempted a high-powered replication, using the same materials and methods as in Experiment 1, except participants were asked to rate each letter on a 7-point scale ranging from 1 (*a lot*) to 7 (*not at all*) according to the questions: "How much do you like me?" and "How much do you want me on a mug?" (scale reversal). The effect size obtained in this experiment was $dz = .22$. An a priori power analysis (Gpower 3.1.3., Faul, Erdfelder, Buchner, & Lang, 2009) for detecting a one-tailed difference between two dependent means (t-test) required a minimum sample size of $N = 156$. Two-hundred and three undergraduate students from the University of California, San Diego, Department of Psychology, all with English-spoken backgrounds, took part in the experiment against course credit. We did not track each participant's gender and age individually, but the mean age of the participant population is about 21 years, SD = 5 years, and is 70% female.

5.1. Results

The final model contained fixed effects for pair distance (outer pairs 1/8 of distance 7 versus inner pairs 4/5 of distance 1), ideograph style (Chinese, Georgian, Konkani, and Tigrinya), orientation (towards the maximum vs. towards the minimum of the dimension) and the interaction between these factors (see Appendix C). Pair distance showed, $F(1,202) = 5.91$; $p = .014$, $dz = .17$, that ideographs were liked more when tested in pairs of type 1/8 ($M = 4.13$, SD=.85) than in pairs of type 4/5 ($M = 4.26$, SD=.82; $z = 2.47$; $p = .014$), see Figure 4. Stimuli oriented towards the maximum ($M = 4.01$, SD=1.65) were liked better than those oriented towards the minimum of the dimension ($M = 4.37$, SD=1.62), $F(1,202) = 38.72$; $p < .001$, $dz = .13$), supporting the blending hypothesis. The interaction between both of these factors was also significant, $F(1,5268) = 45.55$; $p < .001$. Bonferroni-Holm-corrected simple effects revealed that for outer pairs, stimuli closer to the maximum were preferred to those closer to the minimum ($p < .001$). As found in Experiment 1, the same did not hold for inner pairs ($p = .224$). Participants liked outer stimuli more than inner stimuli when these stimuli were oriented towards the maximum ($p < .001$), but the difference was not significant when oriented towards the minimum of the dimension. There were no further significant effects.

For stimuli oriented towards the maximum only, response times significantly predicted the preference for it, $F(1,355.92) = 6.38$; $p = .02$, $\beta = .14$, that is, the shorter the response time, the more a stimulus was liked.

5.2. Discussion

Again, stimuli further apart on the hypothetical mental model were liked more than those closer to each other. Participants also metaphorically blended dominance on the dimension ("*older*", "*more frequently used*") with preference, liking stimuli more when oriented towards the dominant than the non-dominant end of the dimension. None of these effects alone can fully explain the obtained results, as effects are superimposed on each other. At the non-dominant end, with overall less liking there, compared to the dominant end, the difference between outer and inner stimuli was not significant, qualifying the predicted fluency effect. At the dominant end, that is, looking at stimuli for which the pattern clearly shows an outer- vs. inner-difference in liking, response latencies during the test phase predicted liking, which is in line with fluency assumptions. Thus, the blending hypothesis was not fully supported because more liking for the dominant element was observed for pairs of type 1/8 but not for type 4/5.

These results were obtained with reversed scale from 1 (*a lot*) to 7 (*not at all*), ruling out that in earlier experiments, higher liking ratings might have been driven by greater value on a relevant dimension (one large magnitude, i.e., distance, possibly implying another large magnitude, i.e., liking).

6. Experiment 5: Liking differentials immediately after learning?

Response times on the widest versus the narrowest pair predicted the liking differential between these two types of pairs in Experiments 1, 3a, and partly 4 (only for the pairs that were close to the maximum), but did not predict liking in Experiments 2 and 3b. Thus, there might be another, distinct source of fluency experiences with these stimuli, possibly unrelated to the experience participants have during the testing phase. Indeed, wider elements in the hierarchy, especially the end elements of the array, may be associated with easier processing already in the mental order construction phase, during learning. Earlier research has established that pairs towards the end extremes, and particularly the end elements themselves, are privileged for quick responding early on in the learning trials, as soon as they are being identified as end elements or close to them (Leth-Steensen & Marley, 2000; Potts, 1972, 1974; Shoben et al., 1989; Holyoak & Patterson, 1981). All these studies only had learning phases and did not use an additional testing phase analogous to ours (in which fluency was intentionally trained). We tested therefore whether a differential in liking between the widest and the narrowest pair could already be observed directly after learning, without having undergone the testing phase.

6.1. Method

6.1.1. Participants

Thirty-four undergraduate students from the University of California, San Diego, Department of Psychology, all with English-spoken backgrounds, took part in the experiment against course credit. We did not track each participant's gender and age individually, but the mean age of the participant population is about 21 years, SD = 5 years, and is 70% female.

6.1.2. Materials and Procedure

Materials and procedures were identical to Experiment 2, except now we had two groups: Participants in the R-T group rated the nonword stimuli directly after learning, that is before the testing phase. Participants in the T-R group rated the nonword stimuli only after having completed the testing phase.

6.2. Results

The final model contained fixed effects for sequence (R-T vs. T-R), pair distance (outer pairs 1/8 of distance 7 versus inner pairs 4/5 of distance 1), and orientation (towards the maximum vs. towards the minimum of the dimension) and the interaction between these factors (see Appendix C). Supporting our main hypothesis, pair distance showed, $F(1,472) = 5.19$; $p < .02$, $dz = .17$, that ideographs were liked more when tested in outer (wide) pairs of type 1/8 ($M = 4.08$, SD=1.41) than in inner (narrow) pairs of type 4/5 ($M = 3.84$, SD=1.07), see Figure 5. Stimuli oriented towards the maximum ($M = 4.13$, SD=1.37) were liked better than those oriented towards the minimum of the dimension ($M = 3.79$, SD=1.11), $F(1,32) = 4.77$; $p < .03$), supporting the blending hypothesis as well. The interaction between both of these factors was also significant, $F(1,472) = 10.17$; $p = .002$. Bonferroni-Holm-corrected simple effects revealed that for outer pairs, stimuli closer to the maximum were preferred to those closer to the minimum ($p < .001$). As found in Experiment 1, the same did not hold for inner pairs (*ns*). Participants liked outer stimuli more than inner stimuli when these stimuli were oriented towards the maximum ($p < .001$), but the difference was not significant when oriented towards the minimum of the dimension. There were no further significant effects, including the sequence order (R-T vs. T-R). Latencies during testing did not predict liking ($F(1,503) =.00$; $p = .98$).

6.3. Discussion

In this experiment, participants liked stimuli from outer pairs (1/8) more than those from inner pairs (4/5). This occurred whether or not participants had been exposed to training on pairs of different pair distance. We had taken training of the widest and narrowest pairs as a proxy for generating high versus low fluency in the testing phase. The present results however reveal that differential liking of these two types of pairs is not necessarily rooted in such kind of training, and is therefore not necessarily based on fluency as experienced during the test phase.

The learning phase may instead, and alternatively, generate fluency differentials in its own right. Extreme elements in the hierarchy, and in particular end points, can bestow constructional advantages that make it easier to process such elements and again may create fluency experiences associated with these elements (Leth-Steensen & Marley, 2000; Potts, 1972, 1974; Shoben et al., 1989; Holyoak & Patterson, 1981; see also von Hecker & Klauer, 2021). The idea is that during construction of a linear mental model about the rank hierarchy, the end elements can serve as "anchor points" that subsequently facilitate the recognition of maximum and minimum within an abstract dimension. The fact that response times during training predicted liking of the stimuli only in half of our experiments can be speculatively explained by the assumption that in some cases either of these sources of experienced fluency will be more predominant than the other when it comes to generate liking responses in the later rating phase.

7. Internal Meta-Analysis

To test whether the pair distance effect on liking was robust across all six experiments (N = 519), a random effect meta-analysis was conducted, using Cohen's *dz* as effect sizes (the results remained the same when a fixed effects model instead of a random effects model was assumed). The analysis was based on the formulas provided by Borenstein, Hedges, Higgins, and Rothstein (2009) as implemented in the R package "rmeta" (Lumley, 2015). The overall effect size was *dz* = .18, 95% CI [.09, .27], suggesting that the effect is small, but robust.

8. General Discussion

This research explored whether self-generated fluency, arising from an internal mental model, shapes evaluative judgments. We propose that learning and using the mental model creates differences in difficulty levels when processing its elements, which then results in differential liking of the elements. A key feature of this process is that it is self-generated. By this we mean that distances between the elements derive solely from the participant's own reasoning, integrating all piecemeal information into one mental model. As such, the novelty of our results lies in the fact that the variations in fluency experiences do not stem from any external or pre-existing information about the stimuli (see Alter & Oppenheimer, 2008, 2009), but from the order construction process in a participants' mind. Therefore we propose that this cognitive activity, which is initiated in the learning phase (see Experiment 5) and continuing in the test phase (Experiments 1-4), is the key source of subjective experiences of ease/difficulty and positive/negative affect. In order for participants to feel more positive about some items, it takes less effort with those items when first establishing the integrated array representation, and then less effort when later using this representation to decide about the relative position of these items.

For experiences of effort to emerge during learning and during testing with stimuli of different pair distance, we assume that the primary driving factor is the self-generated, spatial positioning of stimuli in terms of a linear mental model (von Hecker & Klauer, 2021). As often argued for such a representation, stimuli of wider distance may be better discriminable than narrower distances (Holyoak & Patterson, 1981; Huttenlocher, 1968; Leth-Steensen & Marley, 2000), such that the dominant element in a pair can be learned and later identified more easily and reliably. Experiment 5 suggests that differences in liking are established already in the learning phase. We attribute this effect to fluency again, because it is probably easier to master the end points in a hierarchy, as compared to stimuli in the middle.

Overall, the crucial effect of pair distance on liking was obtained for unfamiliar ideographs (Experiments 1, 3, 4, 6), and non-words (Experiment 2 and 5). An internal meta-analysis confirmed the overall significance of the effect across individual experiments. Consistent with the idea that processing pairs of varying distances generates differences in fluency and liking, response times in the testing phase significantly predicted liking responses in the rating phase. However, this was true for Experiments 1, 3a, 4, and 6, but not in the remaining experiments. The fact that such prediction was significant in just half of our empirical data made us consider, in the first place, the possibility that differences in liking between different elements might arise already in the learning phase, as explained above. Our partial explanation for why the response times in the testing phase are only sometimes predictive of liking ratings lies in the assumption that one of the sources for fluency differentials, that is, either the learning or the testing phase, will eventually play a more dominant role in determining liking in the rating phase. To spell out the determinants of which source of fluency (at learning or at testing) will prevail in a given situation will be a matter of future research. We will shortly return to discuss additional challenges with measuring fluency in this paradigm.

The current studies also offer partial support for the metaphoric blending hypothesis, according to which participants might conflate dimensional dominance with preference and then take the learned rank order as proxy for their liking order (Casasanto, 2009; Coulson & Oakley, 2005; Fauconnier & Turner, 1998). In those experiments that yielded statistical support for this hypothesis (1 partly, 3, 4, 5, 6 partly), the effects held for stimuli from wider, but not narrower, pair distance. Whilst there is, therefore, some reason to believe that the position relative to maximum within the learned order influences the generation of liking judgments, there is nevertheless a statistically independent contribution of the fluency factor.

The pair distance effect on liking cannot be explained by metaphorical association of wider distances with greater liking, as in Experiment 4 the rating scale was reversed such that greater liking was represented by smaller numbers on the scale, in which case we found again greater liking (as indicated by numerically smaller values) for stimuli from wider-distanced pairs.

It is also unlikely that participants like the distant items more only because they "correctly" solved them because we did not give them feedback on their responses. At the same time, we assume that a participant, in order to generate a liking response, may consider the experience of progress, rightness, or confidence when learning or using that item, without explicitly knowing whether they are right or wrong. We submit that the quality of these subjective experiences is covered by the broad notion of fluency (Fazendeiro et al., 2005; Reber et al., 1998; Topolinski et al., 2009; Whittlesea, 1993; Winkielman et al., 2015).

In terms of external validity, our project shares a particular burden of proof with other research on fluency, which is that the subjective experience of fluency as such is not directly measured. Fluency is only stipulated to have a quality of subjective experience. In some of our experiments we did observe that response latencies in the test phase predicted liking (Reber, Wurtz, & Zimmermann, 2004) of the same stimuli in the rating phase (Experiments 1, 3a, 4, and 6). Given that Experiments 3 and 4 in particular had sufficient power to detect reliable effects, we still suppose that shorter response latencies for high-fluent than low-fluent processing in the test phase, had an effect on liking in the mentioned experiments.

8.1. Superposition of metaphorical blending and fluency effects

Where we find at least partial support for blending (Experiments 1, 3, 4, 5 and 6) the pattern suggests that fluency and blending may have the same (positive) effect on the dominant end of the ordering whilst their effects might cancel out on the lower end (symmetric blending). Alternatively, metaphorical blending may only occur at the dominant but not the non-dominant end of the ordering (asymmetric blending). As yet, there is empirical support for asymmetric blending in studies (von Hecker et al., 2016, Experiments 4a and b) where rank orders were presented with the unmarked or marked label ("older than" vs. younger than"; see Hamilton & Deese, 1971). We found blending with unmarked ("older than") but not marked dimensional semantics ("younger than"). If the preference for elements from wide pairs over the elements from narrow pairs was entirely due to asymmetric blending, we would not obtain statistically independent contributions of "pair distance" in our analytic models, as opposed to the variance explained by "orientation". The fact that we consistently observe independent variance contributions of "pair distance" in the models, in the presence of "orientation" effects, suggests a case of superposition of one effect (blending) upon another (fluency). Note that we can predict the "orientation" effect on the grounds of asymmetric metaphorical blending.

8.2. Self-generated fluency

As discussed earlier, the present investigation is different from earlier approaches where fluency manipulations focused on external contexts or stimulus features, that is, factors outside the participant. The processing in our experiments is determined by the *relation in which the stimulus stands with other learned stimuli*, within an overall mental model that comprises all stimuli in relational terms. This model does not exist in the external world but is a mental construction, yielding a representation with spatial characteristics (Baranski & Petrusic, 1992; Huttenlocher, 1968; Leth-Steensen & Marley, 2000; Pohl & Schumacher, 1991; Potts, 1972, 1974; Smith & Foos, 1975)[1]. Experiment 5 has provided evidence suggesting that mental operations in the learning phase might already create differentials in effort and liking between the stimuli.

8.3. Other approaches to self-generated differences in experienced fluency

The research interest in fluency origins that are self-generated is, as such, not new. Accordingly, we will next discuss three such approaches with respect to a possible overlap with the present paradigm.

(1) Unkelbach (2006) used mental rotation in order to implement differences in experienced task fluency. The task involved "*same* / *different*" judgments on geometric shapes, matched against a comparison shape, requiring either a small (easy) or a large (difficult) rotation in mental space (Shepard & Metzler, 1971). Both Unkelbach's (2006) and our technique attempt to create differences in fluency experience by mental activity, but in different ways. In Unkelbach (2006) the *amount* of mental rotation is still externally determined by the graphical display of the rotated figures. In our paradigm no external constraints exist. Only pairwise rank statements (e.g., "A is older than B") are presented with no hint at the required length of the order chain, or at any spatial representation at all. Therefore, the emerging differences in item difficulty are entirely self-generated.

(2) The second paradigm to compare with ours is *ease of retrieval* (Schwarz, Bless, Strack, Klumpp, & Rittenauer-Schatka, 1991; Wänke, Bless, & Biller, 1996; Wänke & Hansen, 2015). Here, participants are, non-intuitively, more favorable toward an issue after retrieving just a *few* favorable arguments for it (easy), compared with successfully retrieving many favorable arguments (difficult). Both our method and theirs involve self-initiated mental processes. However, in the *ease-of-retrieval paradigm* the number of to-be-retrieved arguments is externally pre-set, so the amount of difference in experienced difficulty between the high- and the low-fluency condition is externally determined. In our method, the number of steps between two ideographs is not externally fixed, but self-generated through the mental construction of the order.

(3) Another related stream of research examines how liking is related to the mental representation of a category and its prototype (Ryali et al., 2020; Vogel et al., 2018, 2021. This research demonstrates the tendency for individuals to prefer a prototypical exemplar of a neutral category over atypical exemplars. This preference is partially due to the relative fluency of the prototype (Winkielman et al., 2006). Importantly, it emerges in situations where the prototype itself was never shown, but had to be formed on the basis of shown exemplars. As such, the prototype is self-generated. The common ground between this effect and ours is the assumption that a mental process can create an internal structure not presented during learning but nevertheless determining subsequent liking responses. Different from our research, the prototype is generated based on perceptual, automatic processes; for example, of storing summary images in memory (Posner & Keele, 1968, Rosch, 1978) or exemplars (Kruschke, 1992, see also Husaim & Cohen, 1981; Younger, 1990, for prototype abstraction in habituation paradigms and in early infants). In contrast, the processes involved in our paradigm are assumed to be consciously taken steps of transitive inference (in the learning phase), in order to establish a linear hierarchy in working memory.

8.4. Limitations and boundary conditions

The novelty of the present approach consists in a demonstration that self-generated differences in cognitive fluency can yield differences in evaluative response. We believe that this has a number of implications.

Boundary conditions. Variables that can determine fluency, such as exposure frequency, exposure duration and figure-ground contrast tend to have the strongest influence on evaluative judgments when the stimuli are novel, neutral and brief, thus minimizing the role of external sources of meaning and value (e.g., Bornstein & D'Agostino, 1992; Reber, Winkielman, & Schwarz, 1998). With more meaningful stimuli, the contribution of fluency to the evaluation is likely diminished. If a perceiver has well-established, or even overlearned, meaningful criteria available to generate a response, then fluency will have low priority or low relevance when generating a judgment (Schwarz, 1998). The small effect sizes observed for fluency manipulations suggests that fluency represents a decision criterion to be mainly used in situations where no ecologically more relevant or salient criterion is available (see Winkielman et al. 2003; Winkielman & Caccioppo, 2001). Fluency can be seen as a relatively weak, occasionally used fallback criterion in day-to-day affective experience and expression[2]. In the laboratory, the effects might show up most clearly when using neutral and novel stimuli, as they do not elicit pre-existing evaluative associations.

Limitation: Mediation. Basically, in our paper we argue that a spatial representation of a linear rank order (X) influences liking (Y), and that this is due to differences in fluency (M), as experienced vis-à-vis paired stimuli of different distance on the spatial dimension. We show evidence regarding X → Y, and previous fluency research suggests that M → Y and the accuracy/rt data on SDE speak for X → M. However, we do not strictly show that the effect of X → Y is due to M (fluency). At present, it remains unclear why, across all experiments, response times do not consistently predict liking judgments. It is possible that in the present paradigm, processing ease is not captured by response times as measured here. At any rate, our interpretation that fluency is responsible for the X → Y effect must have a caveat.

In future research, one might consider using subjective fluency measures, for example, subjective ratings of difficulty (Graf et al., 2018). One can then follow a correlative approach to evaluate its potential causal role (mediation). In the present paradigm, such subjective measures also have the advantage that they can be assessed for individual stimuli instead of pairs (the liking ratings are made on individual stimuli). Alternatively, one might manipulate naïve theories on what the subjective ease of processing implies for liking (Reber et al., 2004; Winkielman & Schwarz, 2001). If it was demonstrated that a different naïve theory of fluency (e.g., difficulty means positivity) eliminates or even reverses the effect of wider distances on liking, this would be strong evidence that fluency is at least part of the underlying process for how participants make liking judgments in this paradigm.

Conclusions

Cognitive fluency can be seen as a factor that can translate processing dynamics, perceptual or conceptual, into affective judgments. We submit that the construction of a linear mental model, under the assumption of its spatial characteristics (Huttenlocher, 1968; von Hecker et al., 2016), constitutes a source of fluency: Elements on a linear mental model that are wide apart can be easier discriminated than elements that are close to each other on the simulated dimension. During model construction, anchoring elements, such as stimuli at the minimum and the maximum of the hierarchy, make the mental operations easy. Elements that are more fluently learned and later more fluently discriminated are liked more than less fluent elements. Processing difficulty in this sense is entirely dependent on the *location of an object relative to another one* on a mentally simulated dimension. As far as this source of cognitive fluency can be influential in any given judgmental situation, we can say that there exists a factor based in reasoning alone (that is, with no external informational input about the stimuli) that will co-determine our liking.

The authors report there are no competing interests to declare.

9. References

Acuna, B. D., Eliassen, J. C., Donoghue, J. P., & Sanes, J. N. (2002). Frontal and parietal lobe activation during transitive inference in humans. *Cerebral Cortex 12,*1312–1321.

Alter, A. L., & Oppenheimer, D. M. (2008). Easy on the mind, easy on the wallet: The roles of familiarity and processing fluency in valuation judgments. *Psychonomic Bulletin & Review, 15*, 985-990.

Alter, A. L., & Oppenheimer, D. M. (2009). Uniting the tribes of fluency to form a metacognitive nation. *Personality and Social Psychology Review, 13*, 219-235.

Anderson, N. H. (1981). *Foundation of information integration theory*. New York, NY: Academic Press.

Bailey, T. M., & Hahn, U. (2001). Determinants of wordlikeness: Phonotactics or lexical neighborhoods? *Journal of Memory and Language, 44*, 568-591.

Baranski, J. V., & Petrusic, W. M. (1992). The discriminability of remembered magnitudes. *Memory & Cognition*, 20, 254-270.

Bates, D., Maechler, M., Bolker, B. M., & Walker, S. (2015). “Fitting Linear Mixed-Effects Models using lme4.” ArXiv e-print; in press, *Journal of Statistical Software*, http://arxiv.org/abs/1406.5823.

Borenstein, M., Hedges, L. V., Higgins, J. P. T., & Rothstein, H. (2009*). Introduction to meta-analysis*. Chichester: John Wiley & Sons.

Bornstein, R. F. (1989). Exposure and affect: Overview and meta-analysis of research, 1968-1987. *Psychological Bulletin, 106*, 265-289.

Bornstein, R. F., & D’Agostino, P. R. (1992). Stimulus recognition and the mere exposure effect. *Journal of Personality and Social Psychology, 63*, 545-552.

Casasanto, D. (2009). Embodiment of abstract concepts: Good and bad in right- and left-handers. *Journal of Experimental Psychology: General, 138*, 351-367.

Christoff, K., Prabhakaran, V., Dorfman, J., Zhao, Z., Kroger, J.K., Holyoak, K.J., et al. (2001). Rostrolateral prefrontal cortex involvement in relational integration during reasoning. *Neuroimage 14*, 1136–1149.

Clark-Carter, D. (2004*). Quantitative psychological research: A student's handbook*. New York: Psychology Press.

Clore, G. L. (1992). Cognitive phenomenology: Feelings and the construction of judgment. In L. L. Martin & A. Tesser (Eds.), *Handbook of social cognition* (pp. 323-417). Hillsdale, NJ: Erlbaum.

Coulson, S., & Oakley, T. (2005). Blending and coded meaning: Literal and figurative meaning in cognitive semantics. *Journal of Pragmatics, 37*, 1510-1536.

Desimone, R., Miller, E. K., Chelazzi, L., & Lueschow, A. (1995). Multiple memory systems in the visual cortex. In M. S. Gazzaniga (Ed.), *The cognitive neurosciences* (pp. 475-490). Cambridge, MA: MIT Press.

Fauconnier, G., & Turner, M. (1998). Conceptual integration networks. *Cognitive Science, 22*, 133-187.

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods, 39*, 175-191.

Fazendeiro, T., Winkielman, P., Luo, C., & Lorah, C. (2005). False recognition across meaning, language, and stimulus format: Conceptual relatedness and the feeling of familiarity. *Memory and Cognition, 33*, 249-260.

Fiske, A. P. (2004). Four modes of constituting relationships: Consubstantial assimilation; space, magnitude, time, and force; concrete procedures; abstract symbolism. In N. Haslam (Ed.), *Relational models theory*. A contemporary overview (pp. 61-146). Mahwah, NJ: Erlbaum.

Gevers, W., Reynvoet, B., & Fias, W. (2003). The mental representation of ordinal sequences is spatially organized. *Cognition, 87*, B87–B9.

Giessner, S. R., & Schubert, T. W. (2007). High in the hierarchy: How vertical location and judgments of leaders' power are interrelated. *Organizational Behavior and Human Decision Processes, 104*, 30-44.

Graf, L. K. M., Mayer, S., & Landwehr, J. R. (2018). Measuring processing fluency: One versus five items. *Journal of Consumer Psychology, 28*, 393–411.

Greeno, J. G. (1989). Situations, mental models, and generative knowledge. In D. Klahr & K. Kotovsky (Eds.), *Complex information processing* (pp. 285–318). Hillsdale, NJ: Erlbaum.

Hahn, U., & Bailey, T. (2005). What makes words sound similar? *Cognition, 97*, 227-267.

Hamilton, H. W., & Deese, J. (1971). Does linguistic marking have a psychological correlate?. *Journal of Verbal Learning and Verbal Behavior, 10*, 707-714.

Hegarty, M. (2004). Mechanical reasoning by mental simulation. *Trends in Cognitive Sciences, 8*, 280–285.

Hinton, E. C., Dymond, S, von Hecker, U. & Evans, C. J. (2010). Neural correlates of relational reasoning and the symbolic distance effect: Involvement of parietal cortex. *Neuroscience, 168*, 138-148.

Hintzman, D. L. (1986). " Schema abstraction" in a multiple-trace memory model. *Psychological Review, 93*, 411.

Holyoak, K. J., & Patterson, K. K. (1981). A positional discriminability model of linear-order judgments. Journal of Experimental Psychology: *Human Perception and Performance, 7*, 1283-1302.

Husaim, J., & Cohen, L. (1981). Infant learning of ill-defined categories. *Merrill–Palmer Quarterly, 27*, 443–456.

Huttenlocher, J. (1968). Constructing spatial images: A strategy in reasoning. *Psychological Review, 75*, 550-560.

Running Head: Relational fluency

Jaeger, T. F. (2008). Categorical data analysis: Away from ANOVAs (transformation or not) and towards logit mixed models. *Journal of Memory and Language, 59*, 434-446.

Jost, J. T., Kruglanski, A. W., & Nelson, T. O. (1998). Social metacognition: An expansionist review. *Personality and Social Psychology Review, 2*, 137-154.

Judd, C. M., Westfall, J., & Kenny D. A. (2012). Treating stimuli as a random factor in social psychology: A new and comprehensive solution to a pervasive but largely ignored problema. *Journal of Personality and Social Psychology, 103*, 54-69.

Judge, T. A., & Cable, D. M. (2004). The effect of physical height on workplace success and income: preliminary test of a theoretical model. *Journal of Applied Psychology, 89*, 428–441.

Kaminska, O.K., Magnuski, M., Olszanowski, M., Gola, M., Brzezicka, A, & Winkielman, P. (2020). Ambiguous at the second sight: Mixed facial expressions trigger late electrophysiological responses linked to lower social impressions. *Cognitive, Affective, & Behavioral Neuroscience, 20*, 441–454.

Knauff, M. (2013). *Space to reason. A spatial theory of human thought*. Cambridge, MA: MIT Press.

Kruschke, J. K. (1992). ALCOVE: An exemplar-based connectionist model of category learning. *Psychological Review, 99*, 22–44.

Lakens, D., & Etz, A. (2017). Too true to be bad: When sets of studies with significant and non-significant findings are probably true. *Manuscript, retrieved January 17, 2017, from* https://osf.io/preprints/psyarxiv/nnkg9.

Lumley, T. (2015). *Package "rmeta". Version 2.16*. Retrieved from cran.r-project.org/web/packages/rmeta/rmeta.pdf

Pohl, R., & Schumacher, S. (1991). Handlungssequenzen und Wortlisten als hierarchische lineare Ordnungen: Einflüsse auf den Distanzeffekt [Action sequences and word lists as hierarchical linear orderings: Influences on the distance effect]. *Zeitschrift für experimentelle und angewandte Psychologie, 38*, 43–62.

Posner, M. I., & Keele, S. W. (1968). On the genesis of abstract ideas. *Journal of Experimental Psychology, 77*, 353.

Potts, G. R. (1972). Information processes used in the encoding of linear orderings. *Journal of Verbal Learning and Verbal Behaviour, 11*, 727-740.

Potts, G. R. (1974). Storing and retrieving information about ordered relationships. *Journal of Experimental Psychology, 103*, 431–439.

R Core Team (2013). R: A language and environment for statistical computing. *R Foundation for Statistical Computing, Vienna, Austria*. URL http://www.R-project.org/.

Reber, R., Schwarz, N., & Winkielman, P. (2004). Processing Fluency and Aesthetic Pleasure: Is Beauty in the Perceiver's Processing Experience? *Personality and Social Psychology Review, 8*, 364–382.

Reber, R., Winkielman, P., & Schwarz, N. (1998). Effects of perceptual fluency on affective judgments. *Psychological Science, 9*, 45-48.

Reber, R., Wurtz, P., & Zimmermann, T. D. (2004). Exploring "fringe" consciousness: The subjective experience of perceptual fluency and its objective bases. *Consciousness and cognition*, 13, 47-60.

Rosch, E. (1978). Principles of categorization. In E. Rosch (Ed.), *Cognition and categorization* (pp. 27–48). Hillsdale, NJ: Erlbaum.

Rosenthal, R. (1979). File drawer problem and tolerance for null results. *Psychological Bulletin, 86*, 638–641.

Ryali, C. K., Goffin, S., Winkielman, P., & Yu, A. J. (2020). From likely to likable: The role of statistical typicality in human social assessment of faces. *Proceedings of the National Academy of Sciences, 117*, 29371–29380.

Schmidt, J. A., & De Houwer, J. (2012). Contingency learning with evaluative stimuli. Testing the generality of contingency learning in a performance paradigm. *Experimental Psychology, 59,* 175-182.

Schubert, T. (2005). Your Highness: Vertical Positions as Perceptual Symbols of Power. *Journal of Personality and Social Psychology, 89*, 1-21.

Schwarz, N. (1998). Accessible content and accessibility experiences: The interplay of declarative and experiential information in judgment. *Personality and Social Psychology Review, 2*, 87-99.

Schwarz, N., & Clore, G.L. (1996). Feelings and phenomenal experiences. In E. T. Higgins & A. W. Kruglanski (Eds.), *Social Psychology: Handbook of Basic Principles* (pp. 385–407). New York: The Guilford Press.

Schwarz, N., Bless, H., Strack, F., Klumpp, G., Rittenauer-Schatka, H., & Simons, A. (1991). Ease of retrieval as information: Another look at the availability heuristic. *Journal of Personality and Social Psychology, 61*, 195–202.

Sedek, G., & von Hecker, U. (2004). Effects of subclinical depression and aging on generative reasoning about linear orders: Same or different processing limitations? *Journal of Experimental Psychology: General, 133,* 237-260.

Shepard, R.N., & Metzler, J. (1971). Mental rotation of three-dimensional objects. *Science, 171*, 701–703.

Shoben, E. J., Cech, C. G., Schwanenflugel, P. J., & Sailor, K. M. (1989). Serial position effects in comparative judgments. *Journal of Experimental Psychology: Human Perception and Performance, 15*, 273-286.

Singmann, H., Bolker, B., Westfall, J., & Aust, F. (2018). afex: Analysis of Factorial Experiments. R package version 0.20-2. *https://CRAN.R-project.org/package=afex*

Smith, K. H., & Foos, P. W. (1975). Effect of presentation order on the construction of linear orders. *Memory and Cognition, 3,* 614–618.

Strack, F., Martin, L. L., & Stepper, S. (1988). Inhibiting and facilitating condition of facial expressions: A non-obtrusive test of the facial feedback hypothesis. *Journal of Personality and Social Psychology, 54*, 768-777.

Topolinski, S., Likowski, K. U., Weyers, P., & Strack, F. (2009). The face of fluency: Semantic coherence automatically elicits a specific pattern of facial muscle reactions. *Cognition and Emotion, 23,* 260-271.

Unkelbach, C. (2006). The learned interpretation of cognitive fluency. *Psychological Science*, *17*, 339-345.

Unkelbach, C., & Fiedler, K. (2016). Contrastive CS-US relations reverse evaluative conditioning effects. *Social Cognition*, *34*, 413-434.

van Opstal, F., Fias, W., Peigneux, P., & Verguts, T. (2009). The neural representation of extensively trained ordered sequences. *Neuroimage, 47,* 367–275.

Vogel, T., Ingendahl, M., & Winkielman, P. (2021). The Architecture of Prototype Preferences: Typicality, Fluency, and Valence. *Journal of Experimental Psychology: General, 150*, 187–194. https://doi.org/10.1037/xge0000798

Vogel, T., Carr, E. W., Davis, T., & Winkielman, P. (2018). Category structure determines the relative attractiveness of global versus local averages. Jo*urnal of Experimental Psychology: Learning, Memory, and Cognition, 44*, 250–267. American Psychological Association. https://doi.org/10.1037/xlm0000446 von Hecker, U., & Conway, M. (2010). Magnitude of negative priming varies with conceptual task difficulty: Attentional resources are involved in episodic retrieval processes. *Quarterly Journal of Experimental Psychology, 63,* 666-678.

von Hecker, U., & Klauer, K. C. (2021). Are rank orders mentally represented by spatial arrays? *Frontiers in Psychology, 12*.

von Hecker, U., Klauer, K. C., & Aßfalg, A. (2019). A robust anchoring effect in linear ordering. *Quarterly Journal of Experimental Psychology, 72*, 2680-2689.

von Hecker U., & Klauer, K. C, Wolf, L., & Fazilat-Pour, M. (2016). Spatial processes in linear ordering. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 42, 1003-1033.

Wänke, M. (2013). Almost everything you always wanted to know about ease-of-retrieval effects. In R. Greifeneder & C. Unkelbach (Eds.), *The experience of thinking: How the fluency of mental processes influences cognition and behavior* (pp. 151–169). London, England: Psychology Press.

Wänke, M., & Hansen, J. (2015). Relative processing fluency. *Current Directions in Psychological Science, 24*, 195-199.

Wänke, M., Bless, H., & Biller, B. (1996). Subjective experience versus content of information in the construction of attitude judgments. *Personality and Social Psychology Bulletin, 22*, 1105–1113.

Westfall, J. (2016). PANGEA: Power ANalysis for GEneral Anova designs. *University of Texas at Austin*: Unpublished manuscript.

Whittlesea, B. W. A. (1993). Illusions of familiarity. *Journal of Experimental Psychology: Learning, Memory, & Cognition, 19*, 1235-1253.

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Winkielman, P., & Cacioppo, J. T. (2001). Mind at ease puts a smile on the face: Psychophysiological evidence that processing facilitation elicits positive affect. *Journal of Personality and Social Psychology, 81*, 989-1000.

Winkielman, P., Halberstadt, J., Fazendeiro, T., & Catty, S. (2006). Prototypes are attractive because they are easy on the mind. *Psychological Science, 17*, 799 – 806. http://dx.doi.org/10.1111/j.1467-9280.2006.01785.

Winkielman, P., Olszanowski, M., & Gola, M. (2015). Faces in-between: Evaluations reflect the interplay of facial features and task-dependent fluency. *Emotion, 15*, 232-242.

Winkielman, P., & Schwarz, N. (2001). How pleasant was your childhood? Beliefs about memory shape inferences from experienced difficulty of recall. *Psychological Science, 12*, 176-179.

Winkielman, P., Schwarz, N., Fazendeiro, T., & Reber, R. (2003). The hedonic marking of processing fluency: Implications for evaluative judgment. In J. Musch & K. C. Klauer (Eds.), *The psychology of evaluation: Affective processes in cognition and emotion* (pp. 189–217). Mahwah, NJ: Lawrence Erlbaum.

Witherspoon, D., & Allan, L. G. (1985). The effects of a prior presentation on temporal judgments in a perceptual identification task. *Memory and Cognition, 13*, 103-111.

Younger, B. (1990). Infant categorization: Memory for category-level and specific item information. *Journal of Experimental Child Psychology, 50*, 131–155.

Zajonc, R. B. (1968). Attitudinal effects of mere exposure. *Journal of Personality and Social Psychology: Monograph Supplement, 9*, 1-27.

Zalesak, M., & Heckers, S. (2009). The role of the hippocampus in transitive inference. *Psychiatry Research, 172,* 24–30.

Footnotes

1

We do not, in the context of this paper, discuss the question to what extent spatial characteristics are a necessary element of forming such orders, or indeed, to what extent the SDE needs spatial assumptions in order to be explained (but see Leth-Steensen & Marley, 2000 for such a discussion). Instead, we refer the reader to a series of studies in which we provided experimental evidence for spatial characteristics to be genuine and essential for the construction of linear orders such as used here (von Hecker et al., 2016, see also von Hecker & Klauer, 2021).

2

As a reviewer pointed out, another perspective on the obtained results would be to see our target effect as an indirect fluency effect: External experimental constraints make a decision easy/fluent versus difficult/dysfluent (i.e., asking participants to give liking ratings to stimuli of pair type A-F versus pair type C-D). In this perspective, it is not the fluency per se that is self-generated but only the internal model of the stimuli arrangement from which the level of fluency derives, depending on what decision is asked for. The interesting part is that the fluency of the decision is transferred or associated with the stimuli involved in the decision process. In antecipation of future research, one could assume that--if asked--participants also like the decision process A-F better than the decision process C-D. And liking of the decision process would correlate with liking of the stimulus. The interpretation as *indirect* fluency effect may additionally explain why the more *direct* blending effect is larger than the more indirect self-generated fluency effect investigated in the present research.

Running Head: Relational fluency

Table 1 **Experiment 1**, Accuracies and Response latencies by Pair distance.

	Pair distance							
	Pair 4/5		Pair 3/6		Pair 2/7		Pair 1/8	
Accuracy	.670	(.415)	.819	(.346)	.863	(.296)	.931	(.211)
Latency	1715	(1001)	1620	(1038)	1512	(866)	1371	(701)

Note. Accuracies are given in proportion of correct responses. Response latencies are given in milliseconds. Standard deviations are presented in brackets.

Running Head: Relational fluency

Table 2 **Experiment 2**, Accuracies and Response latencies by Pair distance.

	Pair distance							
	Pair 4/5		Pair 3/6		Pair 2/7		Pair 1/8	
Accuracy	.555	(.380)	.718	(.325)	.748	(.323)	.822	(.269)
Latency	1735	(920)	1800	(952)	1649	(869)	1591	(949)

Note. Accuracies are given in proportion of correct responses. Response latencies are given in milliseconds. Standard deviations are presented in brackets.

Table 3 **Experiments 3a and 3b**, Accuracies and Response latencies by Pair distance.

Experiment 3a.

	Pair 3/4		Pair 2/5		Pair 1/6	
Accuracy	.898	(.216)	.946	(.152)	.964	(.129)
Latency	2160	(1133)	1748	(645)	1469	(607)

Experiment 3b.

	Pair 3/4		Pair 2/5		Pair 1/6	
Accuracy	.948	(.124)	.979	(.074)	.978	(.079)
Latency	2077	(875)	1808	(902)	1437	(520)

Note. Accuracies are given in proportion of correct responses. Response latencies are given in milliseconds. Standard deviations are presented in brackets.

Table 4 **Experiment 4**, Accuracies and Response latencies by Pair distance.

Pair distance

	Pair 4/5		Pair 3/6		Pair 2/7		Pair 1/8	
Accuracy	.670	(.414)	.801	(.325)	.870	(.297)	.916	(.234)
Latency	1790	(913)	1694	(816)	1601	(766)	1491	(758)

Note. Accuracies are given in proportion of correct responses. Response latencies are given in milliseconds. Standard deviations are presented in brackets.

Table 5 **Experiment 5**, Accuracies and Response latencies by Pair distance.

	Pair distance							
	Pair 4/5		Pair 3/6		Pair 2/7		Pair 1/8	
Accuracy	.654	(.185)	.694	(.205)	.750	(.165)	.808	(.160)
Latency	1305	(728)	1329	(750)	1157	(697)	1187	(548)

Note. Accuracies are given in proportion of correct responses. Response latencies are given in milliseconds. Standard deviations are presented in brackets.

Figure 1 Caption: Experiment 1: Mean liking for stimuli from outer and inner test pairs, located closer to the maximum or the minimum of the dimension.

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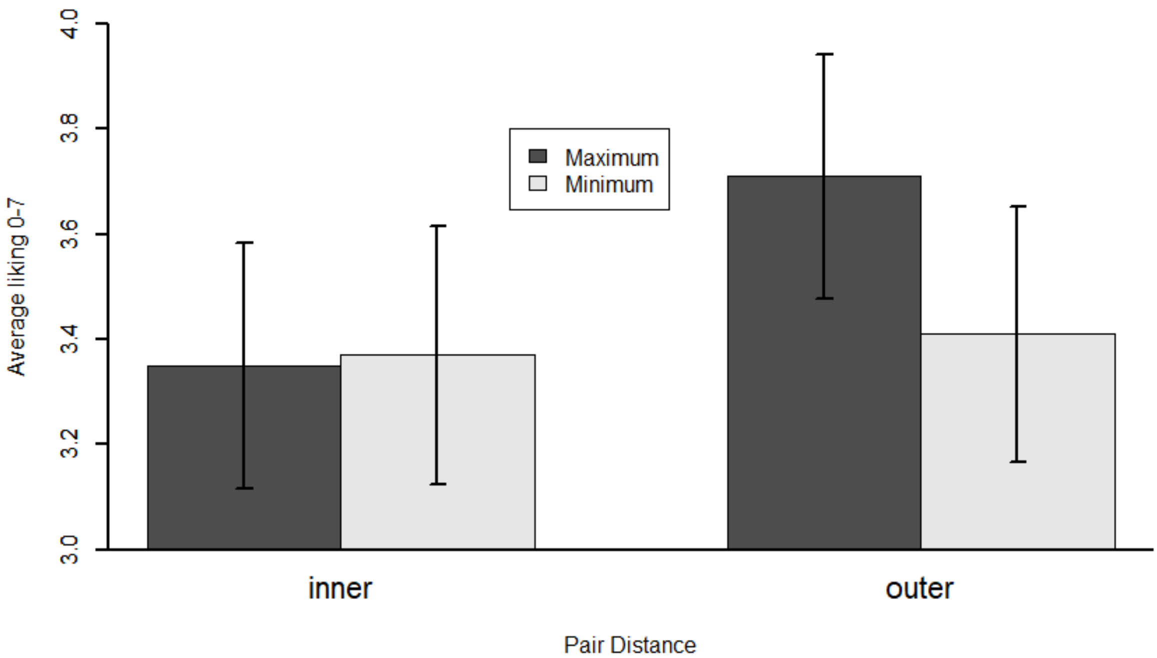


Legend: Preference (e.g., "how much do you like me?") was judged on a scale from 1 (not at all) to 7 (very much). Error bars show 1 SE above and below the mean. Dark bars show liking for stimuli closer to the maximum, light bars closer to the minimum of the dimension.

Figure 2 Caption: Experiment 2: Mean liking for stimuli from outer and inner test pairs. Error bars show SE above and below the mean.

Figure 3 Caption: Experiment 3: Mean liking for stimuli from outer and inner test pairs, averaged across Experiments 3a and 3b. Error bars show SE above and below the mean.

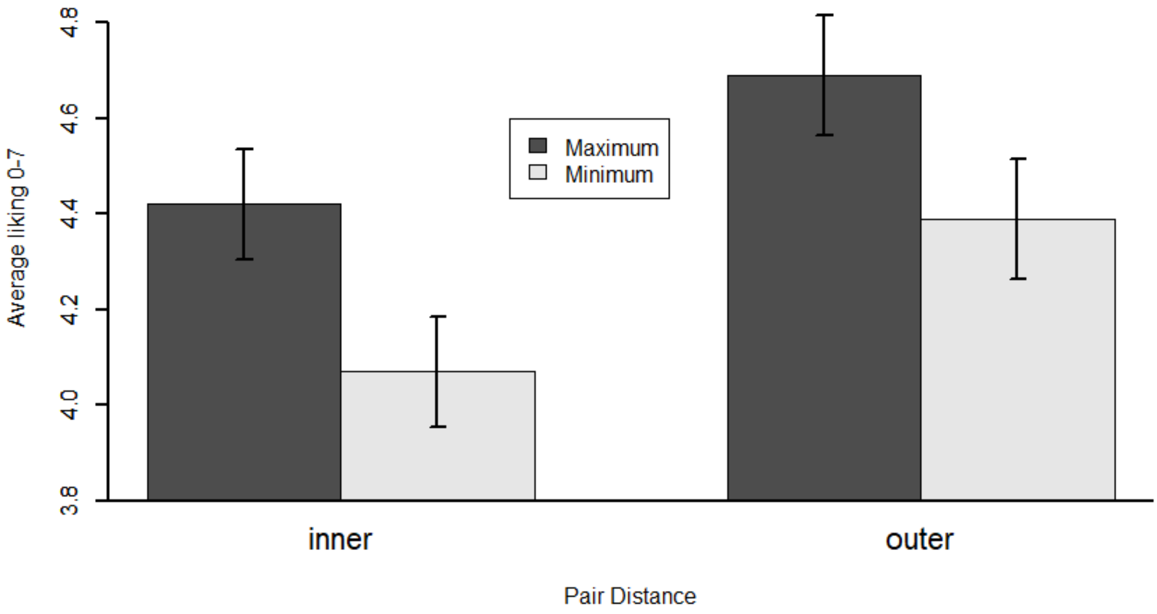


Figure 4 Caption: Experiment 4: Mean liking for stimuli from outer and inner test pairs. Error bars show SE above and below the mean.

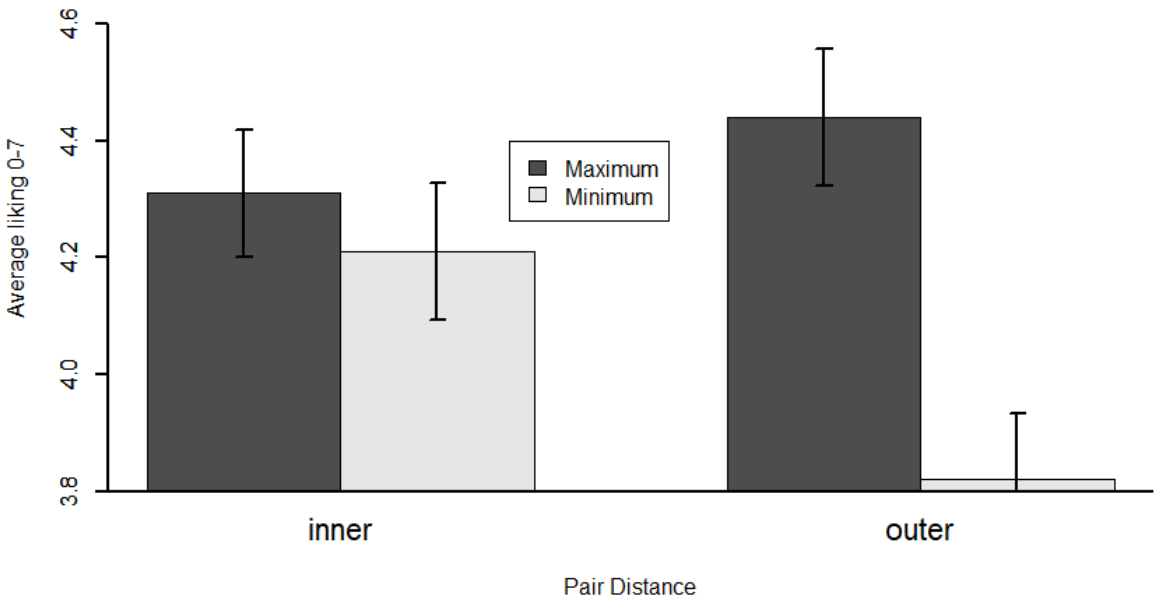
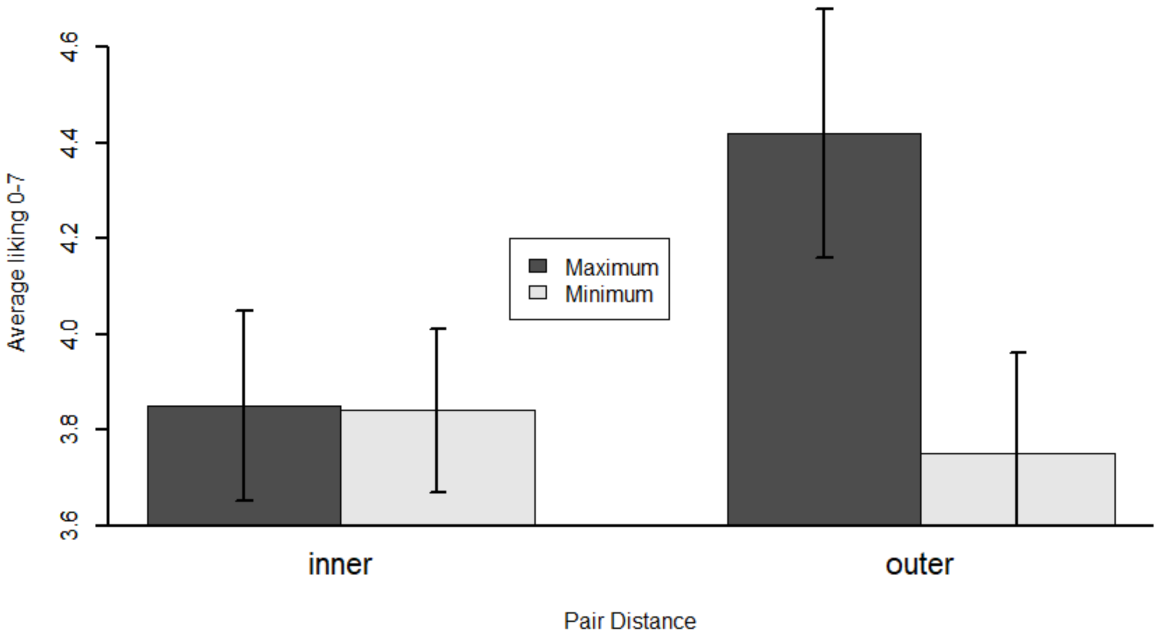


Figure 5 Caption: Experiment 5: Mean liking for stimuli from outer and inner test pairs. Error bars show SE above and below the mean.



Average liking 0-7
3.6
3.8
4.0
4.2
4.4
4.6
Maximum
Minimum
inner
outer
Pair Distance