The numerical size effect in symbolic numbers and everyday number frequency

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The study

The present study examines whether the size effect in Indo-Arabic numbers can be modified within a comparison task by changing the frequency with which the numbers are presented.

The ***size effect*** means that when two numbers are compared, performance deceases with larger numbers (Moyer & Landauer, 1967).

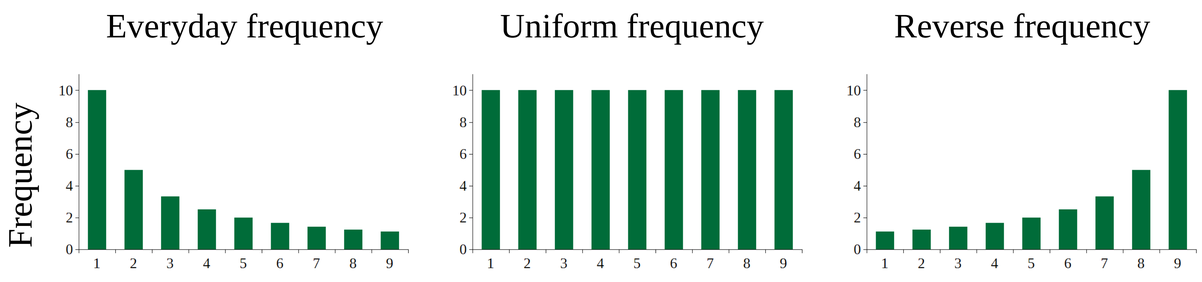
The current explanation for the size effect is the larger overlap of the representations of large numbers in the **Analogue Number System (ANS)** – an innate, continuous, noisy numerical representation (e.g., Dehaene, 2007).

The size effect can also be explained by a mental lexicon-like system termed the **Discrete Semantic System (DSS)** in which it depends on the ***frequency*** of the numbers (Dehaene & Mehler, 1992, Krajcsi et al., 2016; Verguts et al., 2005).

An earlier study showed that modifying the frequency of numbers induces a size effect in new, artificial symbols (Krajcsi et al., 2016).

Other effects in numerical cognition have been shown to change within a session of the comparison task (e.g., distance effect – Krajcsi & Kojouharova, submitted; Kojouharova & Krajcsi, in preparation)

The question: can we modify the size effect in Indo-Arabic numbers by manipulating the frequency of number presentation?



Possible outcomes

	1	2	3	4	5	6	7	8	9
1		-0.30	0.29	0.60	0.79	0.91	0.99	1.05	1.08
2	-0.30		-0.50	0.09	0.40	0.59	0.71	0.79	0.85
3	0.29	-0.50		-0.70	-0.11	0.20	0.39	0.51	0.59
4	0.60	0.09	-0.70		-0.90	-0.31	0.00	0.19	0.31
5	0.79	0.40	-0.11	-0.90		-1.10	-0.51	-0.20	-0.01
6	0.91	0.59	0.20	-0.31	-1.10		-1.30	-0.71	-0.40
7	0.99	0.71	0.39	0.00	-0.51	-1.30		-1.50	-0.91
8	1.05	0.79	0.51	0.19	-0.20	-0.71	-1.50		-1.70
9	1.08	0.85	0.59	0.31	-0.01	-0.40	-0.91	-1.70	

Size effect is present

	1	2	3	4	5	6	7	8	9
1		0.00	0.69	1.10	1.39	1.61	1.79	1.95	2.08
2	0.00		0.00	0.69	1.10	1.39	1.61	1.79	1.95
3	0.69	0.00		0.00	0.69	1.10	1.39	1.61	1.79
4	1.10	0.69	0.00		0.00	0.69	1.10	1.39	1.61
5	1.39	1.10	0.69	0.00		0.00	0.69	1.10	1.39
6	1.61	1.39	1.10	0.69	0.00		0.00	0.69	1.10
7	1.79	1.61	1.39	1.10	0.69	0.00		0.00	0.69
8	1.95	1.79	1.61	1.39	1.10	0.69	0.00		0.00
9	2.08	1.95	1.79	1.61	1.39	1.10	0.69	0.00	

Size effect is absent

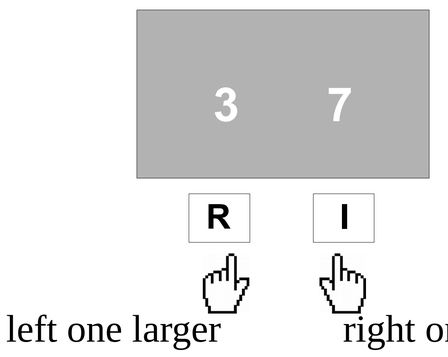
	1	2	3	4	5	6	7	8	9
1		0.30	1.09	1.60	1.99	2.31	2.59	2.85	3.08
2	0.30		0.50	1.29	1.80	2.19	2.51	2.79	3.05
3	1.09	0.50		0.70	1.49	2.00	2.39	2.71	2.99
4	1.60	1.29	0.70		0.90	1.69	2.20	2.59	2.91
5	1.99	1.80	1.49	0.90		1.10	1.89	2.40	2.79
6	2.31	2.19	2.00	1.69	1.10		1.30	2.09	2.60
7	2.59	2.51	2.39	2.20	1.89	1.30		1.50	2.29
8	2.85	2.79	2.71	2.59	2.40	2.09	1.50		1.70
9	3.08	3.05	2.99	2.91	2.79	2.60	2.29	1.70	

Size effect is present and reversed

Methods

- Indo-Arabic numbers from 1 to 9 presented in pairs, excluding ties
- Number comparison task, in which participants chose the larger number of a number pair by pressing a key
- Three conditions with different frequency of presentation for each number (everyday, uniform, reverse)
- 2382 trials in the everyday and reverse frequency conditions (794 trials per block) and 2376 trials in the uniform frequency condition (792 trials per block)

Comparison task



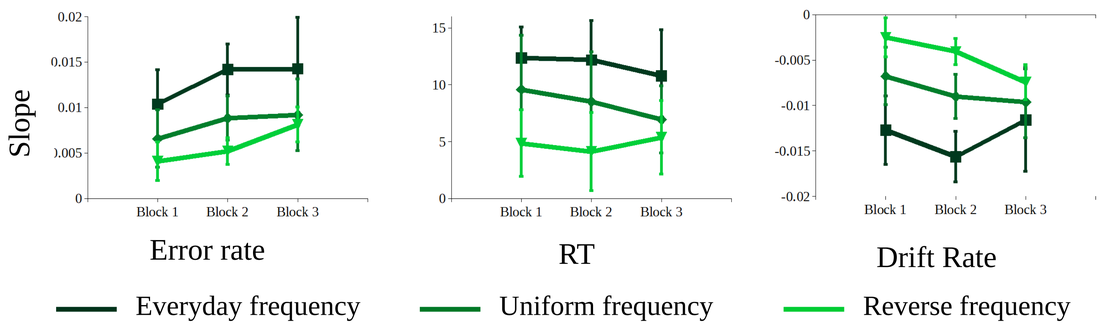
Participants

	Total	Female	Age
Everyday frequency	14	9	22.07 (*SD*=6.45)
Uniform frequency	11	8	21.64 (*SD*=2.57)
Reverse frequency	22	19	21.14 (*SD*=2.68)
All	47	36	21.53 (*SD*=4.18)

Results

- Stimulus frequency has a clear effect on the size effect.
- On the other hand, everyday statistics is also visible in the size effects (e.g., reversed stimulus frequency decreased the size effect, but did not reverse it entirely)
- Frequency of the stimuli are learned very quickly (in the first third of the session), and no further change is visible

	Comparison in the slope of the size effect between the three conditions
Error	$\chi2(2, N = 47) = 8.05, p = 0.018$
Reaction time	$\chi2(2, N = 47) = 15.2, p < 0.001$
Drift rate	$\chi2(2, N = 47) = 20.4, p < 0.001$



Everyday frequency

Error rate	1	2	3	4	5	6	7	8	9
1		0.015	0.010	0.006	0.008	0.008	0.013	0.001	0.005
2	0.016		0.054	0.063	0.026	0.005	0.048	0.024	0.024
3	0.010	0.030		0.137	0.054	0.036	0.077	0.018	0.048
4	0.009	0.025	0.075		0.060	0.063	0.091	0.063	0.032
5	0.010	0.017	0.042	0.067		0.107	0.149	0.065	0.060
6	0.011	0.014	0.036	0.024	0.137		0.232	0.113	0.083
7	0.011	0.040	0.095	0.087	0.202	0.244		0.155	0.095
8	0.008	0.005	0.021	0.016	0.071	0.101	0.208		0.155
9	0.002	0.019	0.030	0.024	0.071	0.036	0.214	0.238	

RT	1	2	3	4	5	6	7	8	9
1		508	484	485	481	469	468	476	467
2	491		559	548	519	503	527	495	513
3	489	539		627	551	558	539	522	536
4	475	507	594		620	575	555	528	537
5	473	499	557	566		639	622	585	613
6	461	496	551	558	638		644	610	556
7	474	518	545	539	613	703		615	619
8	467	501	522	518	581	628	638		631
9	479	492	511	524	554	606	624	650	

Drift Rate	1	2	3	4	5	6	7	8	9
1		0.318	0.357	0.365	0.337	0.409	0.382	0.361	0.362
2	0.332		0.271	0.271	0.328	0.366	0.311	0.349	0.351
3	0.331	0.289		0.185	0.285	0.279	0.270	0.341	0.299
4	0.361	0.330	0.238		0.233	0.249	0.243	0.281	0.338
5	0.358	0.344	0.265	0.248		0.210	0.189	0.262	0.222
6	0.398	0.340	0.269	0.286	0.201		0.129	0.222	0.264
7	0.368	0.297	0.259	0.260	0.181	0.116		0.182	0.218
8	0.382	0.360	0.333	0.297	0.241	0.211	0.151		0.209
9	0.362	0.349	0.336	0.287	0.304	0.261	0.156	0.178	

Uniform frequency

Error rate	1	2	3	4	5	6	7	8	9
1		0.030	0.025	0.030	0.036	0.014	0.011	0.017	0.014
2	0.052		0.033	0.039	0.028	0.008	0.041	0.011	0.025
3	0.047	0.055		0.094	0.050	0.028	0.050	0.017	0.022
4	0.036	0.052	0.061		0.072	0.033	0.061	0.022	0.017
5	0.039	0.041	0.050	0.069		0.074	0.083	0.063	0.039
6	0.044	0.030	0.030	0.069	0.096		0.152	0.080	0.061
7	0.033	0.041	0.047	0.091	0.165	0.168		0.146	0.066
8	0.039	0.050	0.055	0.047	0.080	0.099	0.204		0.116
9	0.039	0.033	0.041	0.052	0.061	0.063	0.149	0.149	

RT	1	2	3	4	5	6	7	8	9
1		571	554	528	538	524	509	517	512
2	585		604	604	580	567	567	525	533
3	563	618		672	628	619	588	546	552
4	541	579	649		615	604	585	586	557
5	567	557	607	637		659	641	620	615
6	550	563	589	599	677		663	641	608
7	530	563	594	628	660	709		673	611
8	533	551	543	580	618	681	686		662
9	526	543	541	563	593	624	661	692	

Drift Rate	1	2	3	4	5	6	7	8	9
1		0.270	0.308	0.332	0.279	0.336	0.329	0.350	0.343
2	0.272		0.276	0.267	0.297	0.317	0.282	0.358	0.332
3	0.259	0.237		0.209	0.250	0.287	0.266	0.322	0.334
4	0.306	0.271	0.228		0.244	0.267	0.250	0.267	0.316
5	0.285	0.290	0.259	0.218		0.222	0.231	0.236	0.257
6	0.291	0.308	0.264	0.249	0.197		0.163	0.226	0.246
7	0.320	0.280	0.273	0.216	0.158	0.157		0.162	0.237
8	0.307	0.296	0.319	0.299	0.221	0.202	0.140		0.199
9	0.299	0.316	0.331	0.282	0.276	0.249	0.165	0.169	

Reverse frequency

Error rate	1	2	3	4	5	6	7	8	9
1		0.008	0.038	0.008	0.008	0.010	0.000	0.012	0.005
2	0.015		0.083	0.042	0.011	0.010	0.023	0.023	0.011
3	0.038	0.042		0.091	0.015	0.015	0.036	0.017	0.012
4	0.015	0.027	0.030		0.038	0.035	0.038	0.021	0.016
5	0.000	0.011	0.034	0.083		0.056	0.074	0.026	0.022
6	0.015	0.015	0.023	0.030	0.081		0.159	0.060	0.023
7	0.008	0.032	0.045	0.045	0.097	0.211		0.067	0.057
8	0.006	0.012	0.006	0.017	0.035	0.074	0.098		0.073
9	0.011	0.013	0.017	0.023	0.023	0.031	0.054	0.073	

RT	1	2	3	4	5	6	7	8	9
1		593	562	561	525	522	517	509	494
2	607		633	601	560	546	552	540	514
3	572	607		632	602	594	581	536	521
4	576	589	650		634	604	585	564	522
5	563	572	608	641		648	640	572	539
6	524	565	591	614	666		672	624	577
7	523	564	599	604	636	722		611	560
8	521	527	540	555	591	644	650		593
9	502	514	527	527	548	577	570	596	

Drift Rate	1	2	3	4	5	6	7	8	9
1		0.272	0.297	0.282	0.314	0.323	0.353	0.336	0.385
2	0.265		0.228	0.250	0.307	0.338	0.313	0.306	0.360
3	0.265	0.270		0.240	0.302	0.294	0.294	0.347	0.347
4	0.254	0.279	0.245		0.255	0.274	0.288	0.302	0.346
5	0.310	0.286	0.259	0.239		0.249	0.230	0.277	0.318
6	0.312	0.312	0.278	0.275	0.216		0.161	0.238	0.280
7	0.343	0.303	0.274	0.258	0.214	0.139		0.219	0.245
8	0.331	0.331	0.329	0.317	0.278	0.216	0.191		0.231
9	0.366	0.343	0.343	0.320	0.303	0.279	0.250	0.237	

Conclusions

- It is possible that there are two sources of the size effect observed in a comparison task
- One of the sources is the frequency of the numbers in the session and is consistent with the DSS
- The other source can be the statistics experienced in everyday life, resulting in a more stable component of the effect, which could be consistent with both DSS and ANS models

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