Supplement D

Data Analysis Broken Down by Material Type and Test Type

In this supplement, we compared performance across memory phases as a function of material types and testing formats. The aim is to address whether the changes that we observed in our overall analyses are due to changes in either of these cases. We did this both for the prediction analyses and the exponent analyses. While there are a relatively small number of memory tests in our corpus of data sets, there is a much larger range of material types. To address this, we sorted the materials into one of seven categories. These categories were defined based on the relative complexity of the materials. These categories are listed in Table D.1.

Table D.1
Levels of Material Complexity

Level	Materials
1	letters, characters, letter trigrams, letter strings, nonsense syllables, visual arrays, abstract images
2	words, idioms, class grades, names, faces, pictures of objects, odors
3	word-digit pairs, symbol-digit pairs, word-trigram pairs, English-Swahili pairs, spatial position
4	word pairs, word triads generated words, word definitions, new vocabulary words, math problems, famous faces, famous names, famous voices, names of television programs, names of racehorses
5	sentences, classroom concepts, word generation, pictures of scenes, famous scenes
6	poems, a directed walk through town, faces and events, events and names
7	stories, course material, autobiographical events, flashbulb events, public news events, novels, videos of activities

Level 1 includes materials with little to no meaning and which were presented in isolation with no relation to other items.

Level 2 includes materials with meaning, either through prior knowledge or individual experiences, and which were presented in isolation with little to no relation among them.

Level 3 includes materials where there is some interrelation among items of some type, and while one of the items is meaningful, the other, at least from the participant's perspective, is not.

Level 4 includes materials with an association between two or more meaningful items. Moreover, this is not enough information to form a complete proposition.

Level 5 includes materials which convey at least one complete idea or proposition.

Level 6 includes materials that go beyond a single proposition to involve multiple ideas. There is also likely to be elaborative processing. However, the information is less likely to convey a coherent situation or event, or collection of such. Faces and events materials are placed here because they only involve simpler elements of more complex materials.

Level 7 includes materials that involve situations and events, often that span across time, with several elements and inter-relations.

Analyses

We broke our analyses down into three main sections. We first present data from the prediction analysis, addressing the influence of memory test type and material type. Then, we present analyses of the power function exponents comparing changes from one phase to another. Finally, we present analysis of the exponents within a phase. For both the second and third sections, we separate the data based on single and multiple exposure studies.

Because some of the measures and material category types had small numbers of observations, we limited ourselves to only those comparisons in which there were at least five observations for both memory phases. This allowed us to have more confidence in the outcomes.

Prediction Analyses

Within Phase. These analyses relate to whether the ability of prior memory performance, over an initial four delay intervals, can be used to predict future memory performance. Our first consideration is whether there was the same pattern of prediction within each of the four phases. The data sets, broken down by test type, are summarized in Table D.2 and broken down by material type are in Table D.3. For WM, like the overall analysis in the main paper, the actual values did not differ from predicted.

Table D.2

Breakdown of the prediction data within each of the four memory phases as a function of different test type, along with t-tests of differences from predicted.

Test Type	Number of data points	Mean Deviation from Prediction	SE	*t* value	*p*	Cohen's *d*
WM						
Cued recall	8	.01	.02	< 1		
Free recall	3	-.06	.07			
Recognition	2	-.01	.03			
e-LTM						
Cued recall	40	.04	.01	5.23	< .001	.83
Free recall	11	.03	.03	1.19	.26	.36
Recognition	24	.01	.01	< 1		
Savings	5	-.02	.05	< 1		
Stem Completion	44	.06	.01	7.45	< .001	1.12
t-LTM						
Cued recall	11	-.12	.03	4.33	.001	1.31
Free recall	8	-.08	.02	3.72	.007	1.32
Recognition	9	-.01	.04	< 1		
Savings	32	.04	.02	2.38	.02	.42
Multiple Choice	6	-.08	.03	2.78	.04	1.14
LLM						
Cued recall	140	-.09	.01	9.28	< .001	.78
Free recall	155	-.04	.01	4.93	< .001	.40
Recognition	41	-.06	.01	5.88	< .001	.92
Savings	14	-.06	.03	1.75	.10	.47
Multiple Choice	189	-.04	.01	6.32	< .001	.46
Matching	15	-.12	.02	6.01	< 001	1.55

Table D.3

Breakdown of the prediction data within each of the four memory phases as a function of different material types.

Material Complexity Category	Number of data points	Mean Deviation from Prediction	SE	*t* value	*p*	Cohen's *d*
			WM			
2	10	-.02	.03	< 1		
3	1	.08				
5	2	-.01	.03			
			e-LTM			
1	11	-.02	.03	< 1		
2	99	.05	.01	9.26	< .001	.93
3	5	.09	.01	7.85	.001	3.51
5	9	-.03	.01	2.62	.03	.87
			t-LTM			
1	43	.01	.02	< 1		
2	4	-.06	.01			
3	2	-.12	.06			
4	9	-.12	.03	3.63	.007	1.21
7	8	.01	.04	< 1		
			LLM			
1	13	-.04	.04	1.13	.28	.32
2	123	-.05	.01	4.72	< .001	.43
3	6	-.09	.04	2.26	.07	-.92
4	67	-.06	.01	5.40	< .001	.66
5	50	-.10	.02	5.86	< .001	.83
6	12	-.01	.02	< 1		
7	283	-.06	.01	9.78	< .001	.58

For e-LTM, the finding of the main analysis was that the data were better than predicted. For the memory test types, all the values were greater than zero, two significantly so, except for savings. However, the savings measure also had the smallest sample size. For material types, the values were more mixed, with Category 1 and 5 materials worse than predicted, Category 5 materials significantly so. It should also be noted that the Category 5 materials are from only a single study (Begg & Wickelgren, 1974). Overall, while more test and materials types were consistent with the overall analyses, there was some inconsistency for this phase.

For t-LTM, the finding of the main analysis was that the data were worse than predicted. In terms of the memory test types, all the exponents were now negative, three significantly so, except, again, for savings, which was positive. In terms of the material types, three of the five material types were negative, one significantly so. Categories 1 and 7 were positive, but not significantly different from predicted. Overall, these data are more consistent with the main analyses. However, there are two things to note. First, it is as if studies involving savings are showing a delayed pattern relative to other test types. Second, although not overwhelmingly negative, it is expected that this is a phase of transition, so the lack of deviation from predicted values for some materials is not out of line with the larger picture.

Finally, For LLM, the finding of the main analysis was that the data were even worse than predicted relative to t-LTM. In terms of the memory test types, all the exponents were negative, with all of these being significant except for the one with the smallest number of data sets. All the values were also negative for all the material types, four of which were significant, one which was marginally significant, and the two nonsignificant ones having smaller numbers of data sets. Overall, the general negativity was consistent with the overall analysis.

Across Phases. Next, we consider changes in predictability as memory shifts from one phase to the next. Our main finding was that there were shifts. We consider any influences of test and material types. In all these cases, we can only make a meaningful assessment of the change if the same material type is present for both phases. Thus, we only deal with data sets in which there are common test or material types for both phases.

WM vs. e-LTM. In terms of type of memory test, only cued recall met our criteria. These data were submitted to a 2 -way (Phase) ANOVA. The effect of Phase did not reach significance, $F(1,46) = 2.09$, $MSE = .003$, $p = 0.16$, $\eta_p^2 = .04$. That said, the nominal change was in the correct direction. Thus, this lack of significance is likely due to a smaller sample size. In terms of type of materials, only Category 2 materials met our criteria. These data were submitted to a 2-way (Phase) ANOVA. The main effect of Phase was significant, $F(1,107) = 12.53$, $MSE = .003$, $p < .001$, $\eta_p^2 = .11$. This is consistent with the overall main analysis.

e-LTM vs. t-LTM. In terms of the type of memory test, we used the cued recall, free recall, recognition, and savings data, which were submitted to a 2 (Phase) X 4 (Memory Test Type) ANOVA. The main effect of Phase was significant, $F(1,132) = 12.13$, $MSE = .005$, $p < 0.001$, $\eta_p^2 = .08$. There was a marginally significant main effect of Test Type, $F(3,132) = 2.62$, $MSE = .005$, $p = 0.05$, $\eta_p^2 = .06$, and the interaction was significant, $F(3,132) = 11.33$ $MSE = .005$, $p < .001$, $\eta_p^2 = .21$. Simple effects test revealed a more negative average exponent for t-LTM than e-LTM for cued recall, $F(1,49) = 61.09$, $MSE = .004$, $p < 0.001$, $\eta_p^2 = .56$, free recall, $F(1,17) = 9.89$, $MSE = .006$, $p = 0.006$, $\eta_p^2 = .37$, but no difference for recognition, $F(1,31) = .05$, $MSE = .002$, $p = 0.83$, $\eta_p^2 = .001$, or savings, $F(1,35) = 1.55$, $MSE = .010$, $p = 0.22$, $\eta_p^2 = .04$. Note that there was only a single study assessing recognition for e-LTM (Begg & Wickelgren, 1974), and for multiple choice for t-LTM (Luh, 1922). In terms of type of materials, only the Category 1 materials met our criteria. These data were submitted to a 2 -way (Phase) ANOVA, which revealed no significant difference, $F(1,52) = .69$, $MSE = .010$, $p = 0.41$, $\eta_p^2 = .01$. There were no shifts in the opposite direction.

t-LTM vs. LLM. In terms of type of memory test, we used the cued recall, free recall, recognition, savings, and multiple-choice data. These data were submitted to a 2 (Phase) X 5 (Memory Test Type) ANOVA. The main effect of Phase was not significant, $F(1,595) = .60$, $MSE = .005$, $p < 0.001$, $\eta_p^2 = .08$. There was a significant main effect of Test Type, $F(4,595) = 5.41$, $MSE = .009$, $p < 0.001$, $\eta_p^2 = .04$, and the interaction was significant, $F(4,595) = 3.65$ $MSE = .009$, $p = .006$, $\eta_p^2 = .02$. Simple effects test revealed a more negative average exponent for LLM than t-LTM for recognition, $F(1,48) = 6.21$, $MSE = .005$, $p = 0.02$, $\eta_p^2 = .12$, and savings, $F(1,44) = 8.49$, $MSE = .01$, $p = 0.006$, $\eta_p^2 = .16$, but no difference for cued recall, $F(1,149) = .56$, $MSE = .01$, $p = 0.46$, $\eta_p^2 = .004$, free recall, $F(1,161) = .90$, $MSE = .01$, $p = 0.34$, $\eta_p^2 = .006$, or multiple choice, $F(1,193) = 1.40$, $MSE = .006$, $p = 0.24$, $\eta_p^2 = .007$. Note, again, that there was only a single study assessing multiple choice for t-LTM (Luh, 1922).

In terms of type of materials, we used the Category 1, 4, and 7 data. These data were submitted to a 2 (Phase) X 5 (Material Type) ANOVA. The main effect of Phase was not significant, $F(1,548) = .01$, $MSE = .01$, $p = .95$, $\eta_p^2 < .001$. The main effect of Material Type was significant, $F(4,548) = 3.54$, $MSE = .01$, $p = 0.007$, $\eta_p^2 = .03$, and the interaction was marginally significant, $F(4,548) = 2.20$, $MSE = .01$, $p = .07$, $\eta_p^2 = .02$. Simple effects test revealed a marginally more negative average exponent for Category 4, $F(1,74) = 3834$, $MSE = .008$, $p = 0.07$, $\eta_p^2 = .04$, and significant effect for Category 7, $F(1,289) = 4.12$, $MSE = .009$, $p = 0.04$, $\eta_p^2 = .01$, but no difference for Category 1 materials, $F(1,54) = 2.09$, $MSE = .011$, $p = 0.15$, $\eta_p^2 = .04$. Overall, the patterns of data were either significantly in the appropriate direction or were not significant. There were no significant shifts in the opposite direction.

Exponent Analysis

For these analyses, we assess the rate of forgetting as defined by the exponents of the power functions. We first consider the influence of memory test and material types on the rate of forgetting within each of the memory phases, followed by a consideration of changes in the exponents from one phase to the next. Within each of these two approaches, we divide our consideration into studies involving a single exposure, and those involving multiple exposures.

Single Exposure. For the single exposure data, the exponents were separately considered for each memory test and memoranda type for each memory phase. This data divided into the different test types are shown in Table D.4. Although it is not critical for or main arguments, we did a comparison of the forgetting rates of different test and materials types within each phase of memory.

For WM, the difference in the rates of forgetting for free recall and recognition tests was just significant, $F(1,83) = 4.16$, $MSE = .034$, $p = 0.045$, $\eta_p^2 = .05$, with memories being lost more rapidly when tested using free recall than recognition. For e-LTM, when the multiple choice data were excluded (there was only a single data point) the difference in the rates of forgetting was significant, $F(3,32) = 14.30$, $MSE = .017$, $p < 0.001$, $\eta_p^2 = .57$, with cued recall and stem completion showing more pronounced forgetting, and recognition and multiple choice measures showing less. For t-LTM, the difference in the rates of forgetting was significant, $F(4,89) = 6.82$, $MSE = .002$, $p < 0.001$, $\eta_p^2 = .24$, with cued and free recall showing more rapid forgetting, and recognition, multiple choice, and source monitoring tasks showing less. For LLM, the stem completion data were excluded (there was only a single data point) the difference in the rates of forgetting was just significant, $F(4,141) = 2.361$ $MSE = .010$, $p = 0.04$, $\eta_p^2 = .07$, with cued recall and free recall showing more pronounced forgetting, and the other measures showing less.

Table D.4
Breakdown of the single exposure exponent data within each of the four memory phases as a function of different test types.

Test Type	Number of data sets	Mean Exponent	SE
WM			
Free recall	65	-.15	.03
Recognition	20	-.05	.01
e-LTM			
Cued recall	13	-.38	.05

Free recall	5	-.06	.02
Recognition	6	-.02	.01
Multiple Choice	1	-.03	
Stem Completion	12	-.19	.02
t-LTM			
Cued recall	4	-.07	.04
Free recall	51	-.09	.01
Recognition	33	-.03	.003
Multiple Choice	4	-.03	.01
Source Monitoring	2	-.01	.004
LLM			
Cued recall	16	-.12	.02
Free recall	69	-.12	.02
Recognition	30	-.05	.01
Multiple Choice	28	-.10	.02
Stem Completion	1	-.09	
Fragment Completion	3	-.03	.01

These single exposure data divided into the different test types are shown in Table D.5. For WM, the difference were not significant, $F(2,82) = 1.04$, $MSE = .035$, $p = 0.36$, $\eta_p^2 = .03$. For e-LTM, levels 4 and 5 were excluded for having just a single data point each, and the differences were not significant, $F(2,32) = 1.86$, $MSE = .034$, $p = 0.17$, $\eta_p^2 = .10$. For t-LTM, the differences were significant, $F(5,88) = 2.81$, $MSE = .003$, $p = 0.02$, $\eta_p^2 = .14$, with forgetting being faster for materials in Categories 3 and 7, and less for materials in Category 1 and 2, 4, and 5. For LLM, the differences were significant, $F(6,140) = 4.28$, $MSE = .009$, $p < 0.001$, $\eta_p^2 = .16$, with forgetting being faster for materials in Categories 3, 4, and 7, less for the others.

Table D.5
Breakdown of the single exposure exponent data within each of the four memory phases as a function of different material types.

Material Complexity	Number of data sets	Mean Exponent	SE
WM			
1	61	-.14	.03
2	15	-.07	.02
4	9	-.10	.02
e-LTM			
1	2	-.08	.004
2	31	-.24	.03
4	1	-.07	
5	1	-.05	
7	2	-.02	.01
t-LTM			
1	6	-.02	.01
2	38	-.06	.01

3	8	-.11	.03
4	2	-.04	.03
5	18	-.05	.01
7	22	-.08	.01
LLM			
1	10	-.06	.02
2	39	-.09	.02
3	9	-.18	.05
4	6	-.17	.05
5	12	-.02	.003
6	6	-.03	.01
7	65	-.12	.01

Multiple Exposure. The multiple exposure data, divided into the different test types, are shown in Table D.6. For WM, there was only a single study. For e-LTM, the savings and stem completion data were excluded (there were only a single data point in each). The difference in the rates of forgetting was not significant, $F(2,7) = 2.40$, $MSE = .005$, $p = 0.16$, $\eta_p^2 = .41$. For t-LTM, the anagram solution data were excluded (there was only a single data point). The difference in the rates of forgetting was marginally significant, $F(7,60) = 2.13$, $MSE = .003$, $p = 0.054$, $\eta_p^2 = .20$, with stem completion, cued recall, and savings showing more rapid forgetting compared to the others. For LLM, the difference in the rates of forgetting was not significant, $F(6,195) = 1.80$ $MSE = .016$, $p = 0.10$, $\eta_p^2 = .05$.

Table D.6
Breakdown of the multiple exposure exponent data within each of the four memory phases as a function of different test types.

Test Type	Number of data sets	Mean Exponent	SE
WM			
Free recall	3	-.38	.14
e-LTM			
Cued recall	2	-.03	.01
Free recall	6	-.15	.03
Recognition	1	-.01	
Savings	2	-.17	.02
Stem Completion	1	-.10	
t-LTM			
Cued recall	11	-.09	.01
Free recall	22	-.06	.01
Recognition	13	-.05	.02
Multiple Choice	3	-.02	.01
Savings	3	-.09	.01
Stem Completion	6	-.13	.04
Fragment Completion	8	-.04	.01
Matching	2	-.05	.02
Anagram Solution	1	-.01	

LLM			
Cued recall	25	-.14	.02
Free recall	89	-.14	.02
Recognition	56	-.10	.02
Multiple Choice	15	-.10	.02
Savings	8	-.16	.01
Matching	5	-.08	.03
Problem Solving	4	-.08	.02

These multiple exposure data divided into the different test types are shown in Table D.7. For WM, there was only a single study. For e-LTM, the differences were not significant, $F(2,9) = 1.99$, $MSE = .006$, $p = 0.19$, $\eta_p^2 = .31$. For t-LTM, the differences were significant, $F(4,64) = 4.76$, $MSE = .003$, $p = 0.02$, $\eta_p^2 = .23$, with forgetting being faster for materials in Categories 1 and 5. For LLM, the differences were marginally significant, $F(6,195) = 2.14$, $MSE = .016$, $p = 0.050$, $\eta_p^2 = .06$, with forgetting being much faster for materials in Category 3, and much slower in Category 6.

Table D.7
Breakdown of the multiple exposure exponent data within each of the four memory phases as a function of different material types.

Material Complexity	Number of data sets	Mean Exponent	SE
WM			
1	3	-.38	.14
e-LTM			
1	6	-.15	.03
2	4	-.11	.04
3	2	-.03	.01
t-LTM			
1	13	-.10	.02
2	32	-.05	.01
4	13	-.07	.01
5	2	-.15	.03
7	9	-.04	.01
LLM			
1	12	-.09	.02
2	30	-.11	.02
3	7	-.25	.09
4	61	-.13	.02
5	32	-.14	.03
6	8	-.04	.01
7	52	-.11	.02

Exponent Change Analysis

The prior analyses show that the rate of forgetting varied with memory test and material types. However, our primary concern is with whether the rate of forgetting changed from one phase to the next. We next assessed whether changes in the rates of forgetting observed in the overall data were influenced by different memory task and material types. To do this analysis, we assessed whether a change from one phase to the next was also observed for a given test or material type, for each of these present in both phases.

Single Exposure. For the single exposure studies, the comparison of shifts from one phase of memory to the next are shown in Table D.8. As can be seen, nine of the 15 sub-analyses were in line with the overall analysis, even if they did not reach significance when considered separately, three were non-significantly in the opposite direction, and two were significantly in the opposite direction. We consider these deviations in turn.

Table D.8
Results of the single exposure exponent comparisons across the memory phases broken down by test types.

	WM	e-LTM	F	MSE	p	η_p^2
Free Recall	-.15	-.06	< 1	.04	.37	.01
Recognition	-.05	-.02	9.12	.0004	.006	.28
Category 2	-.07	-.24	11.08	.03	.002	.20
	e-LTM	t-LTM	F	MSE	p	η_p^2
Cued Recall	-.38	-.07	9.17	.032	.008	.38
Free Recall	-.06	-.09	< 1	.003	.46	.01
Recognition	-.02	-.03	1.29	.0004	.26	.03
Category 2	-.24	-.06	32.84	.017	< .001	.33
	t-LTM	LLM	F	MSE	p	η_p^2
Free recall	-.09	-.12	3.11	.010	.08	.03
Recognition	-.03	-.05	2.64	.003	.11	.04
Category 1	-.02	-.06	2.09	.002	.17	.13
Category 2	-.06	-.09	2.95	.007	.09	.04
Category 3	-.11	-.18	1.12	.015	.31	.07
Category 5	-.05	-.02	4.54	.002	.04	.14
Category 7	-.08	-.12	4.14	.008	.045	.05

For the shift from WM to e-LTM, for the number of free recall data sets for e-LTM was relatively small (5). This also played into the e-LTM and t-LTM comparisons as well. Thus, this difference could be due to sampling error. That said, we would also like to note that the values are in the proper direction from t-LTM to LLM, as well as for recall comparisons for multiple exposure studies (see the next section). Thus, overall, this does not provide strong evidence against the inclusive main analysis.

For recognition, while one reversal was not significant, the other was. As with recall, the number of e-LTM data sets were again small (6). That said, the other two comparisons involving recognition (one for single exposure and one for multiple exposure studies) that involved larger numbers of studies were in the appropriate direction, but not significantly so. Thus, the evidence against the more inclusive main analysis is far from clear and overwhelming. It should also be noted that the changes in the rates of forgetting when recognition is involved are smaller overall, as are the sizes of the exponents.

Finally, when the materials categories are considered, while most of the differences were in the same direction as the overall analysis; however, the results were in the opposite direction for Category 5 materials (sentences, classroom concepts, word generation, pictures of scenes, famous scenes). It may be that, given the other material types, this is an aberration. Alternatively, it may be that it reflects some systematic differences about these materials. Looking at the kind of items that were placed into this category, one characteristic that we noticed is that there are several material types within this category that are more semantic in nature (classroom concepts and famous scenes). One possibility is that more semantic memories are undergoing a processes of continued persistence condition, which makes them more resistant to forgetting as they are integrated into the semantic network.

Multiple Exposure. For the multiple exposure studies, the comparison of shifts from one phase of memory to the next are shown in Table D.9. As can be seen, nine of the ten sub-analyses were in line with the overall analysis, even if they did not reach significance when considered separately, and one was non-significantly in the opposite direction.

Table D.9
Results of the multiple exposure exponent comparisons across the memory phases broken down by test and material types.

	e-LTM	t-LTM	F	MSE	p	η_p^2
Free Recall	-.15	-.06	10.85	.004	.003	.29
Category 1	-.15	-.10	2.27	.005	.15	.12
	t-LTM	LLM	F	MSE	p	η_p^2
Cued Recall	-.09	-.14	4.70	.005	.04	.12
Free Recall	-.06	-.14	5.26	.023	.02	.05
Recognition	-.05	-.08	1.49	.007	.23	.02
Category 1	-.10	-.09	< 1	.005	.53	.02
Category 2	-.05	-.11	11.04	.005	.002	.16
Category 4	-.07	-.13	2.31	.015	.13	.03
Category 7	-.04	-.11	3.28	.012	.08	.05

The one exception to the overall pattern is for Category 1 materials (letters, characters, letter trigrams, letter strings, nonsense syllables, visual arrays, abstract images). This is likely an anomalous finding given that (a) the other two comparisons involving Category 1 are in the same direction as the overall analysis, (b) the change in the opposite direction is very small, and (c) it is nowhere near significant.

Overall Assessment

Looking across the various analyses, the pattern of data that was observed in the main analysis was not uniformly observed when the data were broken down into the different memory test and materials types. A significant effect was observed, consistent with the main overall analysis, 63% (41/65) of the time. This is a respectable amount, but far from uniform.

Another 29% (19/65) of the time there was no significant effect. This may be due to a small sample sizes with reduced data sets. When considering the sample sizes, or the smaller of the pairs for phase shift comparisons, the average size was 12.3. Moreover, in 14/19 of these cases, there were fewer than 12 observations. These nonsignificant outcomes were distributed across various types of test and material types. That said, Category 1 materials (largely meaningless, isolated lists of items) appeared to be least likely to be significant.

Finally, 8% (5/65) of the time, the data were significantly in the opposite direction. These were distributed across different test types (one each savings, cued recall, and recognition). Although, both times one of the material types was significantly in the wrong direction, it involved items from Category 5 (single idea materials). Three of these five had smaller sample sizes (less than 12), so there is also some possibility of sampling error here.

Overall, there is not strong evidence that some test or material types consistently and meaningfully differ from the patterns observed in the more inclusive main analysis. We acknowledge that this does not mean that such deviations do not exist. They may. However, there is no strong evidence for this in our corpus.

References

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