

Electronic Supplementary Materials  
*Heterochrony in chimpanzee and bonobo spatial memory development*

**General Methods: Subject Characteristics**

<i>Subject</i>	<i>Species</i>	<i>Sex</i>	<i>Age</i>	<i>Study 1: Learning Mean</i>	<i>Study 1: Test Mean</i>	<i>Study 2: Test Pieces</i>	<i>Study 2: Control Pieces</i>	<i>Study 3: Motivation Control</i>
Api	B	M	11			0	0	
Baïelle	C	M	5	0.58	0.70	0	0	4
Betou	C	M	4	0.75	0.80	0	0	
Bili	B	M	10	0.83	0.90	0	0	4
Bisengo	B	M	6	0.92	0.80	3	1	
Boende	B	M	10	0.67	0.60	0	0	3
Botsomi	C	F	20	0.92	0.90			
Cherri	C	F	17	0.67	0.80			
Chinoc	C	M	20	0.58	0.50			
Dilolo	B	M	10	1.00	0.90			
Dipanda	C	M	6	0.67	0.50			
Dolisi	C	M	4	0.83	0.90	0	0	2
Dzeke	C	M	9			4	0	
Eleke	B	M	6	0.25	0.20	0	0	4
Elikya	B	F	5.5			0	0	
Ilebo	B	M	9	0.75	0.60	0	0	4
Imphondo	C	F	17	0.83	0.90			
Isabelle	C	F	6			0	0	
Isiro	B	F	13			0	0	
Kalina	B	F	13	0.58	0.80			
Kanaga	B	F	3	0.25	0.30	3	0	
Kaoka	C	M	5.5	0.75	0.90	1	0	4
Kasongo	B	M	9	0.00	0.20	0	0	
Katako	B	F	7	0.58	0.40	0	0	
Kefan	C	M	11	0.50	1.00			
Kikwit	B	M	13	0.92	0.40			
Kimba	C	M	3	0.33	0.60	0	0	2
Kimenga	C	M	8.5			2	2	
Kindu	B	F	3			1	0	4
Kinshasa	B	F	7	0.75	1.00	1	0	4
Kodoro	B	M	4	0.83	1.00	0	0	1
Kouilou	C	M	4	1.00	0.90	0	0	4
Kudia	C	F	6	0.42	0.60	0	0	4
Kuisa	C	F	6			3	0	
Leki	C	M	2			0	0	
Lemba	C	F	3			2	1	
Likabou	C	F	10	0.17	0.30			
Likasi	B	F	10	0.92	1.00	1	0	4
Likouala	C	M	3	0.83	1.00	0	0	
Lomako	B	M	4	0.92	NA	2	0	3
Lomami	B	M	12	0.50	NA	1	0	4
Loufoua	C	M	10			3	1	
Louise	C	F	7.5			0	0	2
Low-Low	C	F	18	0.83	0.80			
Luc	C	M	8			1	0	4
Lufumbu	C	M	9	0.75	0.60			
Lukuru	B	F	5	0.33	0.90	1	0	3
Lusingou	C	M	6	0.08	0.90	3	1	
M'Bolo	C	F	15	1.00	0.90			
M'Vouti	C	F	9.5	0.50	0.90	2	1	
Mabali	B	M	8	0.08	0.70	1	0	
Malaika	B	F	4			0	0	
Mambou	C	M	3			1	0	3
Maniema	B	M	9	0.42	0.30	0	0	

Manisa	C	F	5	0.58	1.00	2	1	4
Masisi	B	F	5	0.25	0.90	0	0	
Matadi	B	M	11	0.75	0.90			
Maya	C	M	17	0.75	1.00			
Mbandaka	B	M	9	0.67	0.80	1	0	4
Mbebo	C	M	2			0	0	
Mkazi	C	M	3			1	0	4
Moka	C	M	10			1	0	
Mona	C	F	3	0.50	0.90	0	0	4
Mosengo	C	M	5	0.50	NA	2	0	
Mossika	C	F	8			4	0	
Moundele	C	M	4	0.92	0.70	0	0	4
Moyi	B	M	4			0	0	
Muanda	B	F	7	0.58	0.40	0	1	4
N'Gao	C	F	9.5			4	0	
N'Golo	C	M	20	0.00	0.90			
N'Goro	C	F	6	0.25	0.40	3	0	
N'Tsere	C	M	16	0.25	0.70			
N'Zanbi	C	F	9.5	0.92	0.90			
Nzounzou	C	F	5			0	0	4
Olombo	C	F	4			0	0	
Ombwe	B	M	2.5			0	0	0
Oshwe	B	M	3			0	0	
Ouband	C	F	11	0.58	1.00			
Pema	C	F	9.5	0.92	1.00			
Pembele	C	F	19	0.83	1.00			
Podive	C	M	6			0	0	
Pongou	C	F	5	0.33	0.70	2	2	
Sake	B	F	6	0.75	1.00	2	0	
Sandoa	B	F	4	0.75	0.80	3	0	
Shanga	C	M	5	0.50	0.70	1	0	4
Shibombo	B	M	4	0.58	1.00	2	0	4
Silaho	C	F	13	0.83	1.00			
Simmy	C	M	6	0.33	NA			
Talian	C	M	11	0.92	0.90			
Tambikiissa	C	F	7			3	1	
Tchibanga	C	M	14	0.08	0.00			
Tchivgna	C	F	7			3	0	
Tiki	C	M	10	0.92	1.00			
Ulemvouka	C	F	11	0.67	0.70			
Ulungue	C	M	7			4	0	
Ultimo	C	M	5	0.00	0.00	0	0	
Waka	B	F	5	0.67	0.90	2	0	
Womin	C	F	11	0.92	1.00			
Wounda	C	F	9.5	0.58	0.70			
Yanco	C	F	4	0.67	1.00	1	0	
Yoko	C	M	15	0.67	0.90			
Yolo	B	M	8	0.83	0.90	2	0	4
Zimbana	C	F	6			0	0	4

**Table S1: Subjects from Studies 1, 2, and 3.** Under *Species*, C indicates chimpanzees and B indicates bonobos; under *Sex*, F indicates female and M indicates male. Individuals marked as NA under *Study 1: Test Mean* did not complete the entire session. *Study 1: Test Pieces* and *Study 2: Control Pieces* indicates the number of pieces found up to the first four total.

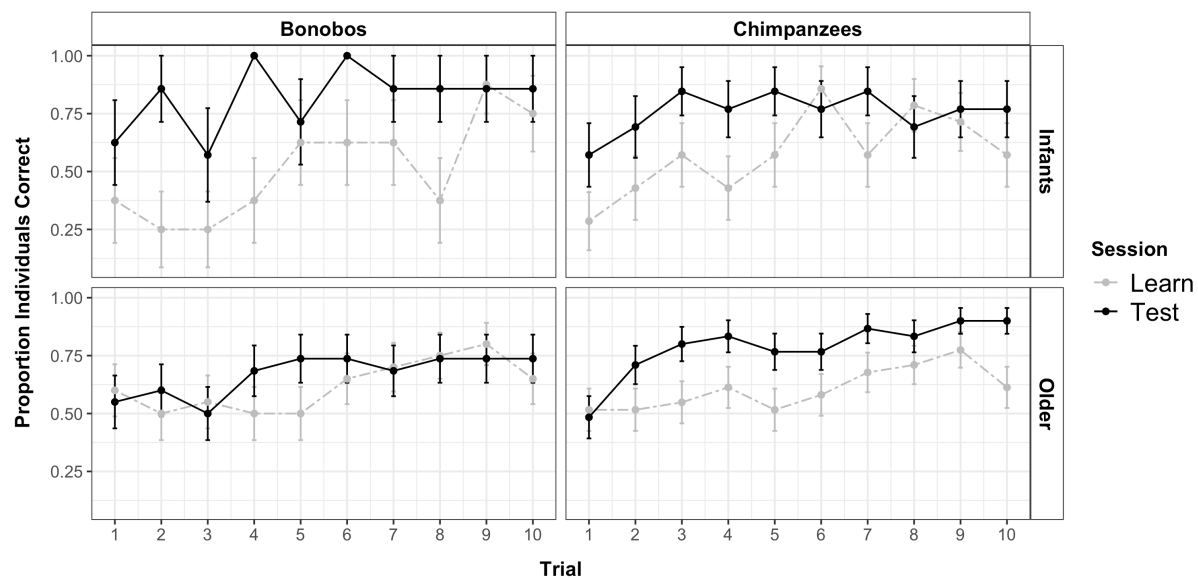
### **Supplementary Results: Study 1 (Long Delay)**

As reported in the main text, generalized linear mixed models (GLMM) were first used to examine improvements in performance across sessions (introductory versus test session after a delay), while accounting for trial-by-trial changes in performance due to learning. Two additional checks were performed on the main trial-by-trial analyses reported in the manuscript. First, two outlier chimpanzees were removed from the chimpanzee data (individuals with mean improvement between sessions exceeding 1.5 SD from the mean for chimpanzees). A re-analysis of this subset of data confirmed the same overall results reported in the main text: the inclusion of a three-way interaction between *Species*, *Cohort*, and *Session* [LRT:  $\chi^2 = 11.85$ ,  $df = 4$ ,  $p < 0.05$ ] improved fit. Pairwise comparisons again revealed that whereas infant bonobos and chimpanzees in both cohorts improved in the test relative to the introductory session [ $p < 0.005$ ], older bonobos did not. Second, curtailing the chimpanzee age range at 13 (such that it matched the range of bonobos that could be tested in this task) revealed the same key result as reported in the main text: inclusion of a three-way interaction between *Species*, *Cohort*, and *Session* improved model fit [LRT:  $\chi^2 = 13.25$ ,  $df = 4$ ,  $p < 0.05$ ], with the same result for significant pairwise comparisons. Overall, these results with a subset of the data aligns with the results from the full dataset, indicating that infant chimpanzees and older chimpanzees exhibited similar capacities to recall a single location over a long delay, whereas infant bonobos actually showed greater relative improvements than adults in the test session.

The same additional checks were then performed on the analyses of difference score, indexing the relative improvement each individual showed in the test session compared to their initial performance in the introductory session. First, the same basic result reported in the main text held when the two outlier chimpanzees were removed: model fit was improved by including

the *Age X Species* interaction [LRT:  $\chi^2 = 4.27$ ,  $df = 1$ ,  $p < 0.05$ ], and post-hoc comparisons of the two species' age effects revealed that bonobos showed a more negative relationship [ $p < 0.05$ ]. Second, an analysis of the subset of the data curtailing both species' age range at 13 years showed a trend for improved model fit [LRT:  $\chi^2 = 2.76$ ,  $df = 1$ ,  $p = 0.09$ ] when the *Age X Species* interaction was then added in a second model to test whether apes exhibited any developmental differences in their relative improvement: bonobos showed a trend for a decline compared to chimpanzees. Overall, the results from these checks using smaller subsets of the full data also align with results from the complete data set.

The final set of analyses for this study then examined trial-by-trial learning rates across the species and age cohorts. Figure 3 in the main text showed estimate effects of trial by trial learning for this analysis (accounting for other effects controlled for in the analysis, as well as unequal trial repeats for a few individuals who did not complete the entire test session). Figure S1 depicts actual trial-by-trial performance in the first 10 choice trials across sessions.



**Figure S1: Learning about rewarded locations over trials (Study 1).** Proportion of individuals who made a correct response in the first 10 learning trials (in the initial introductory session; note that that session included a total of 12 trials) compared to test trials (in the test session one week later). Error bars indicate SE.

*Supplementary Video Captions*

**Video S1: Long Delay (Study 1) – Bonobo.** Experimenter 1 (E1) baits and fake-baits the two containers (in counterbalanced order across trials) while Experimenter 2 (E2) attracts the bonobo to the centered starting location on the other side of the room. Once the baiting is complete, the bonobo approaches the left (correct) container and E1 then gives the food. In initial *learning trials* the ape could self-correct if they initially made an incorrect choice, whereas in *test trials* one week later they could not. Correct side was counterbalanced across individuals.

**Video S2: Long Delay (Study 1) – Chimpanzee.** Experimenter 1 (E1) baits and fake-baits the two containers (in counterbalanced order across trials) while Experimenter 2 (E2) attracts the chimpanzee to the centered starting location on the other side of the room. Once the baiting is complete, the chimpanzee approaches the left (correct) container and E1 then gives the food. In initial *learning trials* the ape could self-correct if they initially made an incorrect choice, whereas in *test trials* one week later they could not. Correct side was counterbalanced across individuals.

**Video S3: Multiple Locations (Study 2) – Bonobo.** The experimenter (E) initially hid four *test pieces* of food in the enclosure while the bonobo observed; four *control pieces* had been previously hidden while the ape was out of sight. The video shows the start of the *search phase* after a 10-minute delay following the baiting demonstration. This young bonobo is still in a nursery group, so a caretaker sits with her in the center of the enclosure (never providing any social cues). E signals to the caretaker that the 10-minute delay has concluded, and the bonobo is released. This subject rapidly approaches two test locations (a tree and a water pool). Test and control locations were counterbalanced across subjects tested in the same enclosure. This clip showed the first 30s of the search phase; the entire search phase lasted 10 min.

**Video S4: Multiple Locations (Study 2) – Chimpanzee.** The experimenter (E) initially hid four *test pieces* of food in the enclosure while the chimpanzee observed; four *control pieces* had been previously hidden while the ape was out of sight. The video shows the start of the *search phase* after a 10-minute delay following the baiting demonstration. This chimpanzee observed the baiting from an adjacent tunnel and is released by a caretaker after E signals the 10-minute delay has concluded. This subject rapidly approaches two test locations (a grass patch and a water fountain). Test and control locations were counterbalanced across subjects tested in the same enclosure. This clip showed the first 30s of the search phase; the entire search phase lasted 10 min.