Supplementary Material | Why men invest in non-biological offspring: Paternal care and paternity confidence among Himba pastoralists

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Table S1 – Descriptions of samples used in each analysis

	N Observations	N Individuals	N Fathers	Individual Age	Father Age	% Omoka
Anthropometrics[1]	236	170	58	8.5 (5.5)	53.9 (13.4)	18.2%
Livestock gifts - Children	137	137	44	9.6 (5.9)	54 (11.3)	19%
Livestock Gift - Adults	205	205	NA	39.8 (17)	NA	28.6%
Fosterage	429	429	NA	26.1 (19.7)	NA	27.3%
Brideprice	97	63	NA	51.0 (17.6)	NA	30.7%

[1] Number of observations and number of individuals differ because some participants have repeated longitudinal data included in this analysis

Additional statistical descriptions and notes

Additional model descriptions and posterior results presented below for each paternal care domain. Coefficient tables represent posterior medians and 89% prediction intervals. These intervals were used, in contrast to typical 95% intervals, to avoid confusion with significance tests, and because use of 95% intervals is arbitrary and based on convention. We refer readers (and reviewers) to McElreath (2015) for more details on this decision. Use of other intervals does not change interpretations in this paper, as we do not draw conclusion from percentile intervals. In cases where number observations differs, complete cases only are used to calculate WAIC values. For all models reported, models were ran on three chains with 10000 iterations per chain, half of which were warmup. All models were run using the *brms* package (Bürkner 2017). Convergence was assessed via visual inspection of Markov chains and use of Gelman-Rubin convergence diagnostic ($\check{R} = 1$ in all model results). For the few models that imputed missing data, 10 datasets were imputed via the *mice* package (Buuren and Groothuis-Oudshoorn 2011). Other statistical packages used include *tidyverse* (Wickham 2017), *cowplot* (Wilke 2017), and sjPlot (Ludecke 2018).

Anthropometric analysis

To generate age and sex specific residuals in order to assess the effects of paternity confidence on child anthropometric measures, sex specific regressions were run for all three anthropometric measures using the full sample of children younger than 20 (number of observations > 300 for each), with age fit using a spline. Using these regression equations, standardized residuals were then fit for all measurements. Any individual observation >/< 3 standard deviations was assumed to be measurement error or error in age reporting and excluded. All male and female residuals were then combined and individual regressions for height, weight, and BMI ran using the predictors described as below. All models included regularized priors for intercept [normal(0,1)], predictors [normal(0,2)], and variance parameters [half-cauchy (0,2)]. In all models, varying intercepts by individual was included to correct for repeated measures.

Figure S1 – Raw standardized residual anthropometric data

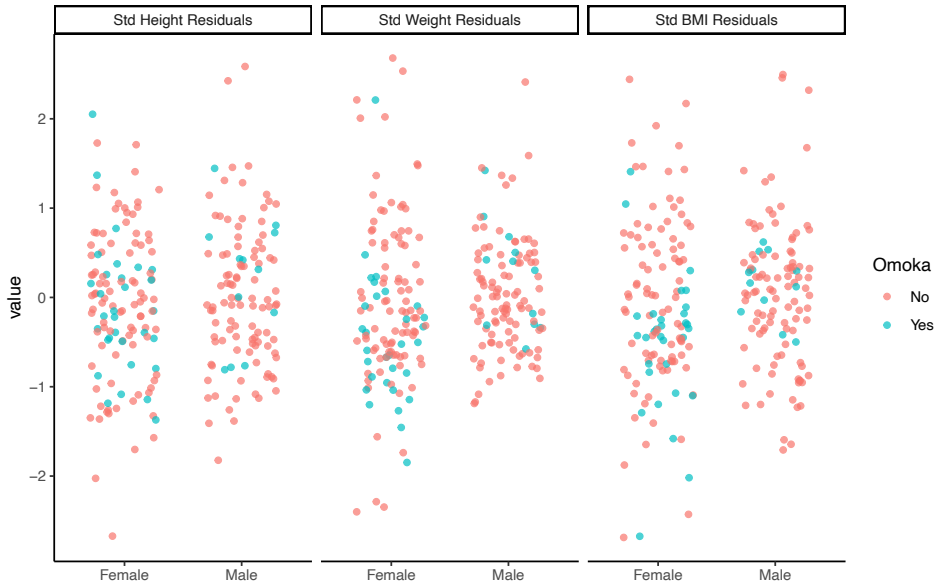

Table S2 – Coefficient table for height models

	Null		**+ Paternity**		**+ Interaction**	
Predictors	*Estimates*	*HDI (89%)*	*Estimates*	*HDI (89%)*	*Estimates*	*HDI (89%)*
Intercept	-0.01	-0.11 – 0.09	-0.01	-0.13 – 0.09	-0.02	-0.18 – 0.14
Omoka			0.05	-0.20 – 0.31	-0.02	-0.34 – 0.31
Male					0.01	-0.21 – 0.24
Interaction					0.18	-0.37 – 0.69
Random Effects						
σ^2	0.10		0.10		0.10	
τ_{00}	0.57 $_{ID}$		0.58 $_{ID}$		0.58 $_{ID}$	
Observations	213		213		213	
WAIC (weight)	246.3 (0.5)		247.05 (0.35)		248.7 (0.15)	

Table S3 – Coefficient table for weight models

	Null		+ Paternity		+ Interaction	
Predictors	*Estimates*	*HDI (89%)*	*Estimates*	*HDI (89%)*	*Estimates*	*HDI (89%)*
Intercept	-0.00	-0.10 – 0.09	0.03	-0.08 – 0.14	0.03	-0.12 – 0.19
Omoka			-0.18	-0.45 – 0.06	-0.38	-0.69 – -0.06
Male					-0.01	-0.22 – 0.21
Interaction					0.56	0.04 – 1.07
Random Effects						
σ^2	0.14		0.14		0.14	
τ_{00}	0.53 $_{ID}$		0.53 $_{ID}$		0.52 $_{ID}$	
Observations	236		236		236	
WAIC (weight)	322.51 (0.45)		322.54 (0.44)		325.29 (0.11)	

Table S4 – Coefficient table for BMI models

	Null		+ Paternity		+ Interaction	
Predictors	*Estimates*	*HDI (89%)*	*Estimates*	*HDI (89%)*	*Estimates*	*HDI (89%)*
Intercept	-0.03	-0.14 – 0.07	0.02	-0.10 – 0.13	-0.02	-0.18 – 0.16
Omoka			-0.27	-0.55 – -0.00	-0.43	-0.77 – -0.09
Male					0.06	-0.15 – 0.30
Interaction					0.51	-0.05 – 1.05
Random Effects						
σ^2	0.24		0.24		0.24	
τ_{00}	0.54 $_{ID}$		0.53 $_{ID}$		0.53 $_{ID}$	
Observations	236		236		236	
WAIC (weight)	449.40 (0.43)		449.96 (0.25)		450.45 (0.32)	

Livestock gift analysis

To estimate livestock gifts in kids (age<20), a hurdle gamma model was used, with varying intercepts by father, a spline for age of child, and a varying effect of offspring sex by father. Paternity added to this model as a varying slope by father, and finally as a varying interaction on offspring sex by father. These predictors and varying effects were included on both the hurdle component and the continuous outcome. For all models, regularized priors for intercept [normal(0,2)], predictors [normal(0,2)], and variance parameters [half-cauchy (0,2)]. For brevity, we don't display all age effects below, but see Figure S1.

Secondly, we examined the effects of father wealth on livestock gifts, since wealth was suspected to mediate livestock gifts to offspring. Here we hypothesize that wealth might mediate the effect of paternity uncertainty, since mis-allocated investment should be less costly for wealthy men. Male wealth was estimated through a multilevel model using longitudinal records of reported livestock from men, and these estimates were imported into the dataset matching fathers to their estimates of wealth. Model comparison was used assess the role of wealth, but father's wealth had little impact on model fit, and the effect of wealth by omoka interaction doesn't have meaningful impacts on outcomes.

The effect of paternity uncertainty on livestock gifts as reported by adults was also assessed with hurdle models, but only included fixed effect predictors, including sex, paternity, and an interaction. For 13 cases, we had no information on paternity assertions, so those cases were imputed and included in the model.

Figure S2 – Raw livestock gift data in children. Livestock number transformed to Log(tropical livestock units +1) for plotting purposes. Points jittered to avoid overplotting.

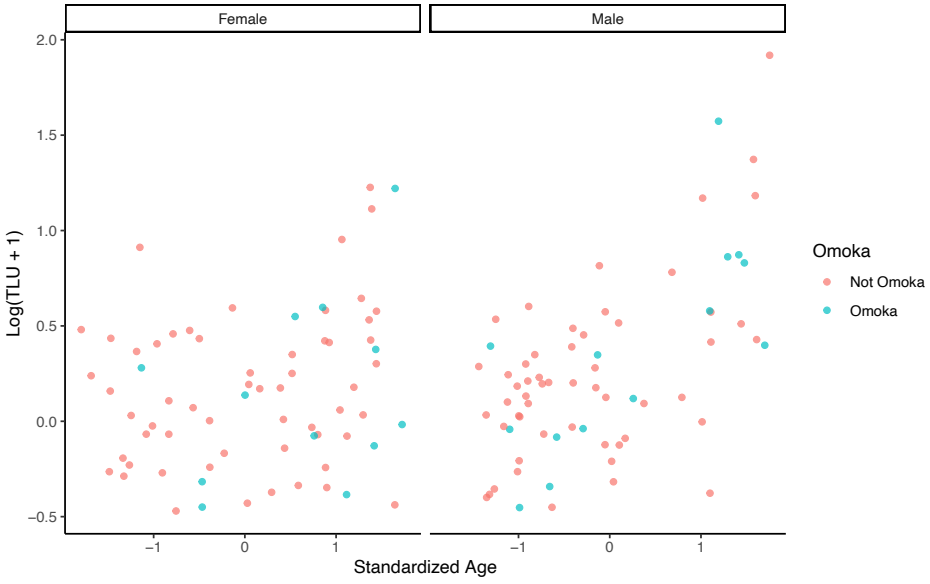

Table S5 – Coefficient table for hurdle model predicting livestock gifts in children

	Null		+ Paternity		+ Interaction	
Predictors	*Estimates*	*HDI (89%)*	*Estimates*	*HDI (89%)*	*Estimates*	*HDI (89%)*
Intercept	-1.32	-1.70 – -0.93	-1.27	-1.66 – -0.89	-1.15	-1.53 – -0.74
hurdle Intercept	0.69	-0.68 – 2.07	1.42	-0.54 – 3.59	0.79	-0.76 – 2.34
Male	0.32	-0.11 – 0.76	0.31	-0.09 – 0.78	0.10	-0.37 – 0.57
hurdle Male	-2.31	-3.91 – -0.68	-3.89	-7.56 – -1.16	-2.53	-4.30 – -0.79
Omoka			-0.22	-0.72 – 0.34	-0.62	-1.29 – 0.03
hurdle Omoka			-0.09	-2.18 – 2.01	-0.86	-3.11 – 1.26
Interaction					0.79	-0.26 – 1.71
hurdle Interaction					1.36	-1.17 – 3.75
Random Effects						
σ^2	0.40		0.43		0.44	
τ_{00}	0.34 $_{DadID}$		0.29 $_{DadID}$		0.27 $_{DadID}$	
Observations	137		137		137	
WAIC (weight)	141.85 (0.01)		134.32 (0.41)		133.64 (0.58)	

Figure S3 – Model predictions of the effect of age (via a spline) on livestock gifts in children

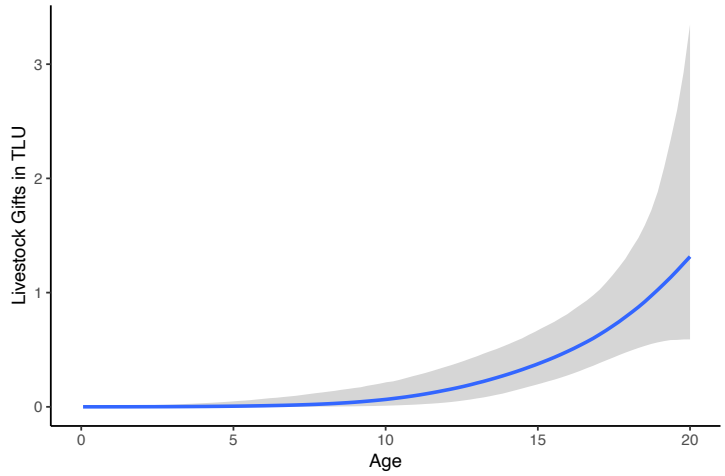

Table S6 – Comparing interaction model above to one that includes father wealth and an interaction with wealth and omoka assertions.

Model	WAIC
Interaction Model from Table S4	94.03
+ Wealth	94.17
+ Wealth interaction with paternity certainty	94.78

Table S7 – Coefficient table for hurdle models predicting livestock gifts in children including estimates of father's wealth

	Interaction model from Table S4		+ Wealth		+ Interaction	
Predictors	*Estimates*	*HDI (89%)*	*Estimates*	*HDI (89%)*	*Estimates*	*HDI (89%)*
Intercept	-1.50	-2.02 – -0.97	-0.94	-2.58 – 0.61	-0.97	-2.55 – 0.71
hurdle Intercept	1.12	-0.49 – 2.76	3.02	-3.50 – 10.17	3.18	-3.26 – 10.30
Male	0.24	-0.34 – 0.83	0.17	-0.49 – 0.79	0.17	-0.47 – 0.82
Omoka	0.08	-0.95 – 1.14	0.09	-1.02 – 1.09	0.28	-2.67 – 3.21
Omoka x Male	0.26	-1.06 – 1.60	0.32	-1.07 – 1.74	0.29	-1.06 – 1.71
hurdle Male	-2.42	-4.27 – -0.54	-2.47	-4.42 – -0.56	-2.62	-4.61 – -0.73
hurdle Omoka	-0.63	-2.93 – 1.61	-0.56	-2.98 – 1.73	0.38	-2.75 – 3.48
hurdle Omoka x Male	0.56	-2.01 – 3.19	0.50	-2.18 – 3.07	0.85	-1.99 – 3.55
Father wealth estimate			-0.15	-0.55 – 0.28	-0.14	-0.56 – 0.27
hurdle Father wealth estimate			-0.57	-2.67 – 1.20	-0.56	-2.47 – 1.29
Wealth x Omoka					-0.04	-0.85 – 0.71
hurdle Wealth x Omoka					-0.63	-2.04 – 0.67
Random Effects						
σ^2	0.48		0.50		0.49	
τ_{00}	0.35 $_{DadID}$		0.35 $_{DadID}$		0.34 $_{DadID}$	
Observations	104		104		104	

Figure S4 – Raw livestock gift data in Adults. Livestock number transformed to Log(tropical livestock units +1) for plotting purposes. Points jittered to avoid overplotting.

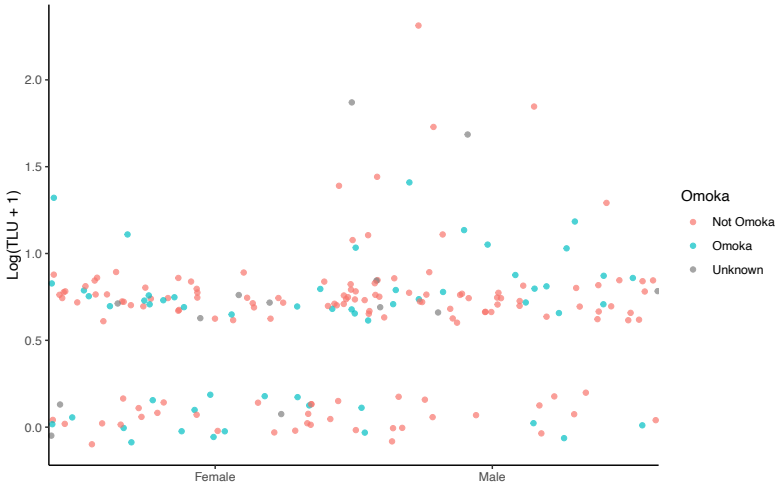

Table S8 – Coefficient table for livestock gifts in Adults

	Null		+ Paternity		+ Interaction	
Predictors	*Estimates*	*HDI (89%)*	*Estimates*	*HDI (89%)*	*Estimates*	*HDI (89%)*
Intercept	0.02	-0.10 – 0.14	0.01	-0.12 – 0.15	0.01	-0.14 – 0.16
hurdle Intercept	-1.55	-1.94 – -1.16	-1.76	-2.24 – -1.29	-1.82	-2.35 – -1.32
Male	0.31	0.13 – 0.49	0.31	0.14 – 0.50	0.33	0.11 – 0.54
hurdle Male	-0.53	-1.19 – 0.11	-0.51	-1.16 – 0.15	-0.35	-1.13 – 0.44
Omoka			0.02	-0.21 – 0.25	0.04	-0.26 – 0.36
hurdle Omoka			0.57	-0.14 – 1.24	0.72	-0.12 – 1.54
Omoka x Male					-0.05	-0.48 – 0.39
hurdle Omoka x Male					-0.53	-1.82 – 0.83
Observations	205		205 (imputed)		205 (imputed)	
WAIC (weight)	557.09 (0.79)		560.05 (0.18)		563.76 (0.03)	

Bride price analysis

The effects of paternity uncertainty on bride-price was assessed via hurdle gamma models. For all models, regularized priors for intercept [normal(0,2)], predictors [normal(0,2)], and variance parameters [half-cauchy (0,2)] were used. Additional predictors included standardized age at marriage, whether the marriage was a first

marriage (binary variable), and paternity assertion. Since many individuals had second and even third marriages, a varying intercept by participant was also included.

Figure S5 – Raw brideprice data. Livestock number transformed to Log(tropical livestock units +1) for plotting purposes. Points jittered to avoid overplotting.

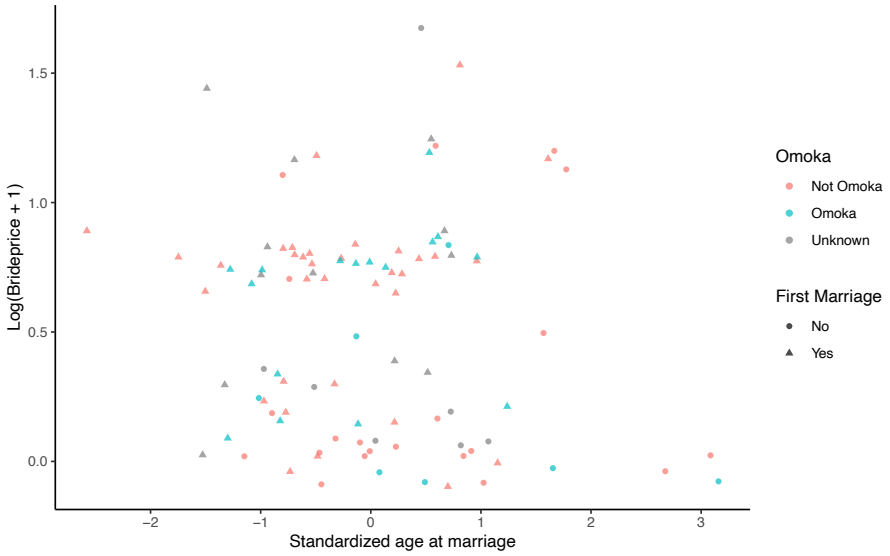

Table S9 – Coefficient table for models predicting bride price

	Null		+ Paternity	
Predictors	*Estimates*	*HDI (89%)*	*Estimates*	*HDI (89%)*
Intercept	-0.67	-1.10 – -0.27	-0.50	-0.95 – -0.11
hurdle Intercept	-1.48	-2.74 – -0.36	-1.52	-3.06 – -0.13
Age Married (std)	0.20	0.00 – 0.40	0.23	0.03 – 0.43
First Marriage	0.84	0.37 – 1.25	0.69	0.24 – 1.15
hurdle Age Married (std)	0.76	-0.00 – 1.72	1.01	0.05 – 2.10
hurdle First Marriage	-2.02	-3.55 – -0.60	-2.20	-3.84 – -0.67
Omoka			-0.15	-0.52 – 0.25
hurdle Omoka			0.30	-1.47 – 2.14
Random Effects				
σ^2	0.37		0.13	
τ_{00}	0.67		0.72	
Observations	97		78	
WAIC (weight)	176.46 (0.48)		176.34 (0.52)	

Fosterage analysis

Logistic regression models with fixed effect predictors including standardized age (via a spline) were used to assess the effect of sex and paternity on probability of fosterage. For all models, regularized priors for intercept [normal(0,2)], predictors [normal(0,2)], and variance parameters [half-cauchy (0,2)] were used. Models were run using data from children (<20) and adults (>20), and final models used all individuals. For brevity, age effects are excluded in the tables below.

Figure S6 – Raw fosterage data. Points jittered to avoid overplotting.

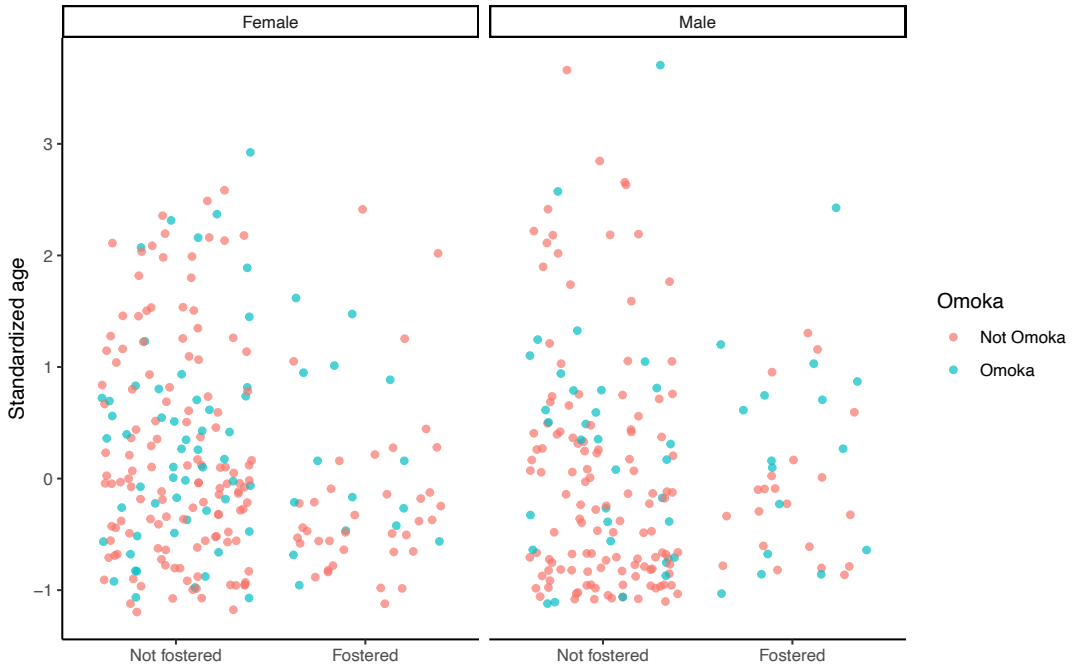

Table S10 – Coefficient table for models predicting fosterage for all individuals

	Null		**+ Paternity**		**+ Interaction**	
Predictors	*Log-Odds*	*HDI (89%)*	*Log-Odds*	*HDI (89%)*	*Log-Odds*	*HDI (89%)*
Intercept	-0.89	-1.09 – -0.70	-1.5	-1.81 – -1.20	-1.36	-1.68 – -1.06
Male	-0.01	-0.28 – 0.27	-0.12	-0.53 – 0.26	-0.47	-0.95 – 0.01
Omoka			0.49	0.09 – 0.93	0.04	-0.52 – 0.59
Interaction					1.09	0.29 – 1.92
Observations	670		429		429	
WAIC (weight)	439.01 (0.09)		437.67 (0.18)		434.81 (0.73)	

Table S11 – Coefficient table for models predicting fosterage for children only and adults only

	Children		Adults	
Predictors	*Log-Odds*	*HDI (89%)*	*Log-Odds*	*HDI (89%)*
Intercept	-0.8	-1.23 – -0.39	-1.94	-2.44 – -1.44
Male	-1	-1.64 – -0.27	0.1	-0.64 – 0.86
Omoka	-0.26	-1.08 – 0.53	0.32	-0.48 – 1.13
Interaction	1.23	-0.06 – 2.52	0.83	-0.39 – 1.97
Observations	200		237	

Bibliography

Bürkner, P.-C. (2017). brms: An R Package for Bayesian Multilevel Models Using Stan. *Journal of Statistical Software*, *80*(1), 1–28. https://doi.org/10.18637/jss.v080.i01

Buuren, S. van, & Groothuis-Oudshoorn, K. (2011). mice: Multivariate Imputation by Chained Equations in R. *Journal of Statistical Software*, *45*(1), 1–67. https://doi.org/10.18637/jss.v045.i03

Ludecke, D. (2018). *_sjPlot: Data Visualization for Statistics in Social Science_*. https://CRAN.R-project.org/package=sjPlot

McElreath, R. (2015). *Statistical Rethinking: A Bayesian Course with Examples in R and Stan* (1st ed.). Boca Raton, FL: CRC Press.

Wickham, H. (2017). *tidyverse: Easily Install and Load the "Tidyverse."* https://CRAN.R-project.org/package=tidyverse

Wilke, C. (2017). *cowplot: Streamlined Plot Theme and Plot Annotations for "ggplot2."* https://CRAN.R-project.org/package=cowplot

Paternity Counterfactual Prompts

A. A Himba man comes back to his compound from a trip and brings with him some meat given to him by a friend. His daughter, who is omoka, comes up to him asking for some of the food. But the man does not have enough for all of his children so he refuses, and later gives the meat to his other daughter, who is not omoka.

Comprehension Questions:	Correct	Incorrect
C1. Where did he get the meat?	☐	☐
C2. Who did he give the meat to?	☐	☐

Perception Questions:	Yes	No
P1. Was what the man did ok?	☐	☐
P2. Is this a common thing for Himba men to do?	☐	☐
P3. What would happen to a man if he did this?	☐	☐
P4. Have you heard about this happening?	☐	☐

If yes, explain

B. A Himba man and his wife have a child. However, the man suspects that the child is from his wife's boyfriend, and he is not the biological father. When the child is old enough to wean, he talks to his wife and tells her he thinks she should bring the child to her mother to raise.

Comprehension Questions:	Correct	Incorrect
C1. Who is the father of the child?	☐	☐
C2. Who does he think should foster?	☐	☐

Perception Questions:	Yes	No
P1. Was what the man did ok?	☐	☐
P2. Is this a common thing for Himba men to do?	☐	☐
P3. What would happen to a man if he did this?	☐	☐
P4. Have you heard about this happening?	☐	☐

If yes, explain

C. The son of a Himba man is ready to marry. His father was married to his mother when she was a child, but she never came to live with him (e.g. he is social father, but definitely not biological father). The man decides not to pay the brideprice for this boy, even though he has enough cattle to contribute.

Comprehension Questions:	Correct	Incorrect
C1. What is the relation to the boy?	☐	☐
C2. What did the boy need from the man?	☐	☐

Perception Questions:	Yes	No
P1. Was what the man did ok?	☐	☐
P2. Is this a common thing for Himba men to do?	☐	☐
P3. What would happen to a man if he did this?	☐	☐
P4. Have you heard about this happening?	☐	☐

If yes, explain

D. When each of his children is old enough to begin herding, a Himba man gifts them with some goats of their own. To the children who are biologically his, he gives 2 goats, but to the children he thinks are from his wife's boyfriends, he only gives one.

Comprehension Questions:	Correct	Incorrect
C1. How many goats to BC?	☐	☐
C2. How many goats to non BC?	☐	☐

Perception Questions:	Yes	No
P1. Was what the man did ok?	☐	☐
P2. Is this a common thing for Himba men to do?	☐	☐
P3. What would happen to a man if he did this?	☐	☐
P4. Have you heard about this happening?	☐	☐

If yes, explain