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| **Supplemental Table S1*a*.** Number of subjects who had microbiome samples available, by assessment | | | |
|  | Microbiome samples from Day 14 | Microbiome samples from Day 30 | Microbiome samples from Day 180 |
| Emotional responsivity | 18 | 19 |  |
| Visual orientation | 18 | 19 |  |
| Motor maturity | 18 | 19 |  |
| Reward association |  |  | 18 |
| Cognitive flexibility |  |  | 15 |
| Impulsivity |  |  | 20 |

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| Supplementary Table S1b. Availability of fecal swabs and neuro-/cognitive development measures by subject (n=33)1 | | | | | | | | | |
| Subject ID | Day 14 / emotional responsivity measure | Day 14/visual orientation measure | Day 14/motor maturity measure | Day 30 / emotional responsivity measure | Day 30 / visual orientation measure | Day 30 / motor maturity measure | Day 180 / reward association measure | Day 180 / cognitive flexibility measure | Day 180 / impulsivity measure |
| ZP01 | NA | NA | NA | X | X | X | X | NA | X |
| ZP02 | X | X | X | X | X | X | X | X | X |
| ZP03 | X | X | X | NA | NA | NA | X | X | X |
| ZP04 | X | X | X | X | X | X | NA | NA | NA |
| ZP05 | X | X | X | X | X | X | NA | NA | NA |
| ZP06 | X | X | X | X | X | X | NA | NA | NA |
| ZP07 | X | X | X | X | X | X | X | X | X |
| ZP08 | X | X | X | X | X | X | NA | NA | NA |
| ZP09 | X | X | X | X | X | X | NA | NA | NA |
| ZP11 | X | X | X | X | X | X | NA | NA | NA |
| ZP12 | X | X | X | X | X | X | NA | NA | NA |
| ZP13 | X | X | X | X | X | X | NA | NA | NA |
| ZP14 | X | X | X | X | X | X | NA | NA | X |
| ZP15 | X | X | X | X | X | X | NA | NA | NA |
| ZP16 | X | X | X | X | X | X | NA | NA | NA |
| ZP17 | X | X | X | X | X | X | NA | NA | NA |
| ZP18 | X | X | X | NA | NA | NA | NA | NA | NA |
| ZP19 | X | X | X | X | X | X | X | X | X |
| ZP20 | X | X | X | X | X | X | X | NA | X |
| ZP21 | NA | NA | NA | X | X | X | X | NA | X |
| ZP22 | NA | NA | NA | X | X | X | NA | NA | NA |
| ZN02 | NA | NA | NA | NA | NA | NA | NA | NA | X |
| ZN04 | NA | NA | NA | NA | NA | NA | X | X | X |
| ZN07 | NA | NA | NA | NA | NA | NA | X | X | X |
| ZN32 | NA | NA | NA | NA | NA | NA | X | X | X |
| ZN36 | NA | NA | NA | NA | NA | NA | X | X | X |
| ZN37 | NA | NA | NA | NA | NA | NA | X | X | X |
| ZN39 | NA | NA | NA | NA | NA | NA | X | X | X |
| ZN41 | NA | NA | NA | NA | NA | NA | X | X | X |
| ZN42 | NA | NA | NA | NA | NA | NA | X | X | X |
| ZN43 | NA | NA | NA | NA | NA | NA | X | X | X |
| ZN44 | NA | NA | NA | NA | NA | NA | X | X | X |
| ZN45 | NA | NA | NA | NA | NA | NA | X | X | X |
| **Total Available** | 18 | 18 | 18 | 19 | 19 | 19 | 18 | 15 | 20 |
| 1. X = data available; NA = data not available | | | | | | | | | |

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| **Supplemental Tables S2*a*-*c***. Coabundance factor loadings for the top 10 most abundant gut microbes, by age group | | | |
| Genus | Factor 1 | Factor 2 | Factor 3 |
| **Table 2A.** Day 14 | | | |
| Catenibacterium | 0.90 |  |  |
| Lactobacillus | 0.74 | 0.44 |  |
| Eubacterium | -0.72 |  |  |
| Roseburia | -0.67 | 0.63 |  |
| Faecalibacterium | -0.6 |  | 0.52 |
| Bifidobacterium |  | -0.92 |  |
| Blautia | -0.33 | 0.89 |  |
| [Prevotella] | 0.31 | 0.67 |  |
| Prevotella |  |  | -0.85 |
| Collinsella | 0.36 |  | 0.79 |
| **% variance explained** | 40% | 36% | 24% |
| **Table 2B.** Day 30 | | | |
| [Prevotella] | 0.90 |  |  |
| Lactobacillus | 0.75 | -0.31 |  |
| Faecalibacterium | -0.70 | 0.51 | -0.30 |
| Bifidobacterium | -0.64 | -0.45 | -0.49 |
| Prevotella | 0.41 |  |  |
| Catenibacterium |  | -0.84 |  |
| Eubacterium |  | 0.80 |  |
| Blautia | 0.39 | 0.67 |  |
| Collinsella |  |  | 0.74 |
| Ruminococcus |  |  | 0.60 |
| **% variance explained** | 41% | 37% | 22% |
| **Table 2C.** Day 180 | | | |
| Bifidobacterium |  | -0.87 |  |
| Catenibacterium |  | 0.60 |  |
| Ruminococcus | -0.64 |  | 0.53 |
| Faecalibacterium |  |  | 0.59 |
| S24-7\_unclassified |  | 0.79 | -0.36 |
| Oscillospira |  |  | -0.69 |
| Roseburia | 0.80 |  |  |
| Prevotella | -0.56 | -0.33 | -0.44 |
| Lactobacillus |  |  | -0.64 |
| Blautia | 0.88 |  | -0.63 |
| **% variance explained** | 36% | 32% | 32% |
| 1. Loadings < 0.30 are not shown 2. [Prevotella] refers to *Prevotella* of Paraprevotellaceae family. | | | |
|

**Supplemental Tables S3*a-b.*** AIC model selection of multiple linear regression models comparing the predictive power of the gut microbiome (Co-Abundance Factors, Shannon diversity) and rearing environment-driven models

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| **Supplemental Table S3*a*.** AIC model selection of multiple linear regression models: Co-abundance factors and rearing environment-driven models | | | | |
|  | AICc | Delta\_AICc | AICcWt | Log Likelihood |
| Emotional responsivity, Day 14, Factor 1 | | | | |
| **Rearing** | **71.47** | **0.00** | **0.89** | **-28.24** |
| Rearing & Microbiome | 75.73 | 4.25 | 0.11 | -28.05 |
| Microbiome | 81.97 | 10.50 | 0.00 | -33.49 |
| Emotional responsivity, Day 14, Factor 2 | | | | |
| **Rearing** | **71.47** | **0.00** | **0.87** | **-28.24** |
| Rearing & Microbiome | 75.65 | 4.18 | 0.11 | -28.01 |
| Microbiome | 78.36 | 6.88 | 0.03 | -31.68 |
| Emotional responsivity, Day 14, Factor 3 | | | | |
| **Rearing** | **71.47** | **0.00** | **0.63** | **-28.24** |
| Rearing & Microbiome | 72.64 | 1.16 | 0.35 | -26.50 |
| Microbiome | 79.27 | 7.80 | 0.01 | -32.13 |
| Visual orientation, Day 14, Factor 1 | | | | |
| **Rearing** | **96.21** | **0.00** | **0.85** | **-40.61** |
| Rearing & Microbiome | 100.53 | 4.31 | 0.10 | -40.44 |
| Microbiome | 101.98 | 5.77 | 0.05 | -43.49 |
| Visual orientation, Day 14, Factor 2 | | | | |
| **Rearing** | **96.21** | **0.00** | **0.75** | **-40.61** |
| Microbiome | 99.28 | 3.06 | 0.16 | -42.14 |
| Rearing & Microbiome | 100.43 | 4.22 | 0.09 | -40.40 |
| Visual orientation, Day 14, Factor 3 | | | | |
| **Rearing** | **96.21** | **0.00** | **0.85** | **-40.61** |
| Rearing & Microbiome | 100.66 | 4.44 | 0.09 | -40.51 |
| Microbiome | 101.67 | 5.45 | 0.06 | -43.33 |
| Motor maturity, Day 14, Factor 1 | | | | |
| **Rearing** | **33.85** | **0.00** | **0.78** | **-9.43** |
| Rearing & Microbiome | 37.60 | 3.75 | 0.12 | -8.98 |
| Microbiome | 37.87 | 4.02 | 0.10 | -11.43 |
| Motor maturity, Day 14, Factor 2 | | | | |
| **Rearing** | **33.85** | **0.00** | **0.50** | **-9.43** |
| Microbiome | 34.23 | 0.38 | 0.41 | -9.62 |
| Rearing & Microbiome | 37.25 | 3.40 | 0.09 | -8.81 |
| Motor maturity, Day 14, Factor 3 | | | | |
| **Rearing** | **33.85** | **0.00** | **0.71** | **-9.43** |
| Rearing & Microbiome | 36.92 | 3.07 | 0.15 | -8.64 |
| Microbiome | 37.17 | 3.32 | 0.14 | -11.09 |
| Emotional responsivity, Day 30, Factor 1 | | | | |
| **Rearing & Microbiome** | **71.54** | **0.00** | **0.68** | **-26.27** |
| Rearing | 73.03 | 1.49 | 0.32 | -29.21 |
| Microbiome | 83.44 | 11.90 | 0.00 | -34.41 |
| Emotional responsivity, Day 30, Factor 2 | | | | |
| **Rearing** | **73.03** | **0.00** | **0.76** | **-29.21** |
| Rearing & Microbiome | 75.37 | 2.34 | 0.24 | -28.19 |
| Microbiome | 83.17 | 10.14 | 0.00 | -34.28 |
| Emotional responsivity, Day 30, Factor 3 | | | | |
| **Rearing** | **73.03** | **0.00** | **0.72** | **-29.21** |
| Rearing & Microbiome | 75.05 | 2.01 | 0.26 | -28.02 |
| Microbiome | 81.00 | 7.96 | 0.01 | -33.19 |
| Visual orientation, Day 30, Factor 1 | | | | |
| **Rearing** | **97.14** | **0.00** | **0.66** | **-41.26** |
| Microbiome | 99.01 | 1.87 | 0.26 | -42.20 |
| Rearing & Microbiome | 101.44 | 4.30 | 0.08 | -41.22 |
| Visual orientation, Day 30, Factor 2 | | | | |
| **Rearing** | **97.14** | **0.00** | **0.76** | **-41.26** |
| Rearing & Microbiome | 100.69 | 3.55 | 0.13 | -40.84 |
| Microbiome | 100.99 | 3.86 | 0.11 | -43.19 |
| Visual orientation, Day 30, Factor 3 | | | | |
| **Rearing** | **97.14** | **0.00** | **0.77** | **-41.26** |
| Rearing & Microbiome | 100.61 | 3.48 | 0.13 | -40.81 |
| Microbiome | 101.26 | 4.11 | 0.10 | -43.32 |
| Motor maturity, Day 30, Factor 1 | | | | |
| **Microbiome** | **35.96** | **0.00** | **0.47** | **-10.67** |
| Rearing | 36.07 | 0.12 | 0.44 | -10.73 |
| Rearing & Microbiome | 39.42 | 3.46 | 0.08 | -10.21 |
| Motor maturity, Day 30, Factor 2 | | | | |
| **Rearing** | **36.07** | **0.00** | **0.46** | **-10.73** |
| Rearing & Microbiome | 37.02 | 0.94 | 0.29 | -9.01 |
| Microbiome | 37.25 | 1.18 | 0.25 | -11.32 |
| Motor maturity, Day 30, Factor 3 | | | | |
| **Rearing** | **36.07** | **0.00** | **0.80** | **-10.73** |
| Rearing & Microbiome | 40.16 | 4.09 | 0.10 | -10.58 |
| Microbiome | 40.38 | 4.31 | 0.09 | -12.88 |
| Reward association, Day 180, Factor 1 | | | | |
| **Microbiome** | **129.98** | **0.00** | **0.78** | **-57.49** |
| Rearing | 133.35 | 3.38 | 0.14 | -59.18 |
| Rearing & Microbiome | 134.50 | 4.53 | 0.08 | -57.43 |
| Reward association, Day 180, Factor 2 | | | | |
| **Microbiome** | **133.06** | **0.00** | **0.51** | **-59.03** |
| Rearing | 133.35 | 0.29 | 0.44 | -59.18 |
| Rearing & Microbiome | 137.62 | 4.56 | 0.05 | -58.99 |
| Reward association, Day 180, Factor 3 | | | | |
| **Microbiome** | **131.21** | **0.00** | **0.69** | **-58.10** |
| Rearing | 133.35 | 2.14 | 0.24 | -59.18 |
| Rearing & Microbiome | 135.57 | 4.36 | 0.08 | -57.97 |
| Cognitive flexibility, Day 180, Factor 1 | | | | |
| **Microbiome** | **112.88** | **0.00** | **0.70** | **-48.11** |
| Rearing | 114.82 | 1.94 | 0.26 | -49.08 |
| Rearing & Microbiome | 118.66 | 5.78 | 0.04 | -48.08 |
| Cognitive flexibility, Day 180, Factor 2 | | | | |
| **Microbiome** | **113.15** | **0.00** | **0.66** | **-48.24** |
| Rearing | 114.82 | 1.67 | 0.29 | -49.08 |
| Rearing & Microbiome | 118.02 | 4.87 | 0.06 | -47.76 |
| Cognitive flexibility, Day 180, Factor 3 | | | | |
| **Microbiome** | **111.18** | **0.00** | **0.81** | **-47.26** |
| Rearing | 114.82 | 3.64 | 0.13 | -49.08 |
| Rearing & Microbiome | 116.31 | 5.14 | 0.06 | -46.91 |
| Impulsivity (composite), Day 180, Factor 1 | | | | |
| **Microbiome** | **95.08** | **0.00** | **0.50** | **-40.40** |
| Rearing | 95.33 | 0.25 | 0.44 | -40.52 |
| Rearing & Microbiome | 99.17 | 4.09 | 0.06 | -40.36 |
| Impulsivity (composite), Day 180, Factor 2 | | | | |
| **Microbiome** | **95.24** | **0.00** | **0.48** | **-40.48** |
| Rearing | 95.33 | 0.09 | 0.46 | -40.52 |
| Rearing & Microbiome | 99.31 | 4.07 | 0.06 | -40.43 |
| Impulsivity (composite), Day 180, Factor 3 | | | | |
| **Microbiome** | **94.95** | **0.00** | **0.51** | **-40.33** |
| Rearing | 95.33 | 0.38 | 0.42 | -40.52 |
| Rearing & Microbiome | 99.05 | 4.10 | 0.07 | -40.29 |

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| **Supplemental Table S3*b*.** AIC model selection of multiple linear regression models: Shannon diversity and rearing environment-driven models | | | | |
|  | AICc | Delta\_AICc | AICcWt | Log Likelihood |
| Emotional responsivity, Day 14 | | | | |
| **Rearing** | **71.47** | **0.00** | **0.89** | **-28.24** |
| Rearing & Microbiome | 76.00 | 4.53 | 0.09 | -28.18 |
| Microbiome | 79.79 | 8.31 | 0.01 | -32.39 |
| Visual orientation, Day 14 | | | | |
| **Rearing** | **96.21** | **0.00** | **0.81** | **-40.61** |
| Microbiome | 100.36 | 4.15 | 0.10 | -42.68 |
| Rearing & Microbiome | 100.74 | 4.53 | 0.08 | -40.55 |
| Motor maturity, Day 14 | | | | |
| **Rearing** | **33.85** | **0.00** | **0.73** | **-9.43** |
| Microbiome | 36.46 | 2.61 | 0.20 | -10.73 |
| Rearing & Microbiome | 38.36 | 4.51 | 0.08 | -9.36 |
| Emotional responsivity, Day 30 | | | | |
| **Rearing & Microbiome** | **70.23** | **0.00** | **0.80** | **-25.61** |
| Rearing | 73.03 | 2.80 | 0.20 | -29.21 |
| Microbiome | 83.94 | 13.71 | 0.0 | -34.66 |
| Visual orientation, Day 30 | | | | |
| **Rearing** | **97.14** | **0.00** | **0.76** | **-41.26** |
| Rearing & Microbiome | 100.33 | 3.20 | 0.15 | -40.67 |
| Microbiome | 101.41 | 4.28 | 0.09 | -43.40 |
| Motor maturity, Day 30 | | | | |
| **Rearing** | **36.07** | **0.00** | **0.70** | **-10.73** |
| Microbiome | 38.45 | 2.38 | 0.21 | -11.92 |
| Rearing & Microbiome | 40.27 | 4.20 | 0.09 | -10.64 |
| Reward association, Day 180 | | | | |
| **Microbiome** | **132.55** | **0.00** | **0.56** | **-58.77** |
| Rearing | 133.35 | 0.80 | 0.37 | -59.18 |
| Rearing & Microbiome | 136.64 | 4.09 | 0.07 | -58.50 |
| Cognitive flexibility, Day 180 | | | | |
| **Microbiome** | **114.69** | **0.00** | **0.50** | **-49.01** |
| Rearing | 114.82 | 0.13 | 0.47 | -49.08 |
| Rearing & Microbiome | 120.42 | 5.73 | 0.03 | -48.96 |
| Impulsivity (composite), Day 180 | | | | |
| **Microbiome** | **94.69** | **0.00** | **0.54** | **-40.20** |
| Rearing | 95.33 | 0.39 | 0.39 | -40.52 |
| Rearing & Microbiome | 98.86 | 0.07 | 0.07 | -40.20 |

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| **Supplemental Table S4.** Multiple linear regression models predicting average % correct responses on ODR (proxy of impulsivity) | | |
| *Microbiome co-abundance factors predicting average % correct responses on ODR* | | |
|  | β (95% CI) | p |
| Factor 1 | -0.24 (-2.56-2.07) | 0.82 |
| Factor 2 | -0.003 (-2.13-2.13) | 0.99 |
| Factor 3 | -0.88 (-2.94-1.19) | 0.38 |
| Infant sex (female) | 0.02 (-4.01-4.04) | 0.93 |
| Growth rate (g/Day) | -1.68 (-1.85-0.87) | 0.45 |
| Rearing environment (NR) | **5.97 (1.28-10.64)** | **0.02** |
| *Shannon diversity predicting average % correct responses on ODR* | | |
|  | β (95% CI) | p |
| Shannon diversity | -1.93 (-5.74-1.88) | 0.30 |
| Infant sex (female) | -0.27 (-3.89-3.35) | 0.88 |
| Growth rate (g/Day) | -0.36 (-1.69-0.98) | 0.58 |
| Rearing environment (NR) | **5.02 (0.09-9.94)** | **0.05** |

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| **Supplemental Table S5.** AIC model selection of multiple linear regression models predicting average % correct responses on ODR | | | | |
| Impulsivity, Day 180, Factor 1 | | | | |
| **Rearing** | **119.20** | **0.00** | **0.87** | **-52.46** |
| Rearing & Microbiome | 123.31 | 4.11 | 0.11 | -52.43 |
| Microbiome | 127.10 | 7.89 | 0.02 | -56.40 |
| Impulsivity, Day 180, Factor 2 | | | | |
| **Rearing** | **119.20** | **0.00** | **0.87** | **-52.46** |
| Rearing & Microbiome | 123.38 | 4.18 | 0.11 | -52.46 |
| Microbiome | 127.11 | 7.91 | 0.02 | -56.41 |
| Impulsivity, Day 180, Factor 3 | | | | |
| **Rearing** | **119.20** | **0.00** | **0.81** | **-52.46** |
| Rearing & Microbiome | 122.31 | 3.11 | 0.17 | -51.93 |
| Microbiome | 126.33 | 7.12 | 0.02 | -56.02 |
| Impulsivity, Day 180, Shannon diversity | | | | |
| **Rearing** | **119.20** | **0.00** | **0.71** | **-52.46** |
| Rearing & Microbiome | 121.89 | 2.68 | 0.19 | -51.71 |
| Microbiome | 123.18 | 3.97 | 0.10 | -54.45 |

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| **Supplemental Table S6.** Neurodevelopmental/cognitive development measures and Shannon diversity across surrogate-reared and peer-reared infants (Mann-Whitney U Tests) | | |
|  | Cliff’s Delta | p |
| *Day 14* | | |
| Emotional responsivity | 0.14 | 0.77 |
| Visual Orientation | -0.64 | 0.11 |
| Motor Maturity | -0.29 | 0.49 |
| Shannon diversity | 0.29 | 0.53 |
| *Day 30* | | |
| Emotional responsivity | 0.19 |  |
| **Visual Orientation** | **-1.0** | **0.02** |
| Motor Maturity | -0.33 | 0.47 |
| Shannon diversity | -0.24 | 0.67 |
| *Day 180* | | |
| Reward association | -0.20 | 0.64 |
| **Cognitive flexibility** | **0.77** | **0.03** |
| Impulsivity (composite) | 0.03 | 1.0 |
| Shannon diversity | -0.43 | 0.27 |

**Supplemental Figures S1*a-c*.** Alpha diversity (Shannon diversity index) by rearing environment and infant age

***Caption:*** Mann-Whitney U Test:

**1*a*.** Cliff's Delta: 0.79, p-value < 0.01; **1*b*.** Cliff’s Delta: 0.60, p-value = 0.02; **1*c.*** Cliff’s Delta: 0.29, p-value = 0.30

1*b.*

1*a.*

**A graph of a graph showing the same size

Description automatically generated with medium confidenceA graph of a graph showing the same number of objects

Description automatically generated with medium confidence**

1*c.*

**A graph of a graph showing the same size

Description automatically generated with medium confidence**

**Supplemental Figures S2*a*-*i*.** Microbiome co-abundance factors by rearing environment and infant age

**Supplemental Figures S2*a*-*c.*** Microbiome co-abundance factors by rearing environment at Day 14

***Caption:*** **2*a*.** Co-abundance factor 1 (high *Catenbacterium* and *Lactobacillus*): Cliff’s Delta = 0.69, p-value = 0.01; **2*b*.** Co-abundance factor 2 (low *Bifidobacterium* and high *Blautia*): Cliff's Delta = 0.58, p-value = 0.04; **2*c*.** Co-abundance factor 3 (low *Prevotella*): Cliff's Delta: 0.06, p-value = 0.86.

2*b*.

2*a*.

**A graph of a graph showing the number of reanimations

Description automatically generated with medium confidenceA graph of a graph showing the same size

Description automatically generated with medium confidence**

A graph of a diagram

Description automatically generated

2*c*.

**Supplemental Figures S2*d*-*f.*** Microbiome co-abundance factors by rearing environment at Day 30

**A graph of a graph showing the same size

Description automatically generated with medium confidenceA graph of a graph showing the same size of a graph

Description automatically generated with medium confidenceA graph of a graph showing the same size

Description automatically generated with medium confidence*Caption:* 2*d*.** Co-abundance Factor 1 (high *Prevotella* [Paraprevotellaceae family] and *Lactobacillus*, and low *Faecalibacterium*): Cliff's Delta = 0.80, p-value < 0.01; **2*e*.** Co-abundance Factor 2 (high *Eubacterium*, *Blautia* and low *Catenibacterium*): Cliff's Delta: -0.38, p-value = 0.09; **2*f*.** Co-abundance Factor 3 (high *Collinsella*, *Ruminococcus*, and low *Bifidobacterium*) Delta: 0.56, p-value = 0.24

2*f*.

2*e*.

2*d*.

**S2*g*-*i.*** Microbiome co-abundance factors by rearing environment at Day 180

***Caption***: **2*g*.** Co-abundance Factor 1 (high *Roseburia*, *Blautia*, and low *Ruminococcus* and *Prevotella*): Cliff's Delta = -0.19, p-value = 0.20; **2*h*.** Co-abundance Factor 2 (low abundance of *Bifidobacterium* and of an unclassified genus): Cliff's Delta = 0.00, p-value = 1.00; **2*i*.** Co-abundance Factor 3 **(**high *Prevotella* and low *Lactobacillus*): Cliff's Delta = -0.22, p-value = 0.18

**A diagram of a graph

Description automatically generatedA graph of a graph showing the size of a number of objects

Description automatically generated with medium confidence**

2*h*.

2*g*.

**A graph of a graph showing the same size of a graph

Description automatically generated with medium confidence**

2*i*.