



HAL
open science

A metabolic trade-off impacting childhood language development and body growth

Sophie Bouton, Coralie Chevallier, Aminata Hallimat Cissé, Barbara Heude,
Pierre Jacquet

► **To cite this version:**

Sophie Bouton, Coralie Chevallier, Aminata Hallimat Cissé, Barbara Heude, Pierre Jacquet. A metabolic trade-off impacting childhood language development and body growth. 2023. hal-04304158

HAL Id: hal-04304158

<https://hal.science/hal-04304158>

Preprint submitted on 24 Nov 2023

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution 4.0 International License

1 A metabolic trade-off impacting childhood language 2 development and body growth

3 Sophie Bouton^{1,2}, Coralie Chevallier³, Aminata Hallimat Cissé⁴, Barbara Heude^{4*},
4 Pierre O. Jacquet^{3,5,6*}

5 1. Institut Pasteur, Université Paris Cité, Inserm, Institut de l'Audition, F-75012 Paris,
6 France

7 2. Laboratoire de Sciences Cognitives et Psycholinguistique, Ecole Normale
8 Supérieure, Université PSL, INSERM, 75005 Paris, France

9 3. LNC², Département d'études cognitives, Ecole Normale Supérieure, Université
10 PSL, INSERM, 75005 Paris, France

11 4. INSERM UMR 1153, Epidemiology and Biostatistics Sorbonne Paris Cité Center
12 (CRESS), Developmental Origins of Health and Disease (ORCHAD) Team, F-94807
13 Villejuif, Paris Descartes University, France

14 5. Centre de recherche en épidémiologie et santé des populations, Inserm U1018,
15 université Paris-Saclay, université Versailles Saint-Quentin, Paris, France

16 6. Institut du Psychotraumatisme de l'Enfant et de l'Adolescent, Conseil
17 Départemental Yvelines et Hauts-de-Seine et Centre Hospitalier des Versailles,
18 78000, Versailles, France

19 **equal-contribution*

20 Corresponding authors:

21 Pierre O. Jacquet

22 E-Mail address: pierre.ol.jacquet@gmail.com

23 ORCID: <https://orcid.org/0000-0002-6495-5581>

24 Sophie Bouton

25 E-Mail address: sophie.bouton@cnrs.fr

26 ORCID: <https://orcid.org/0000-0001-5496-4583>

27

28 Highlights

29 1. Neurocognitive development's high energy demand necessitates a trade-off in
30 human children between brain growth and other biological functions, including
31 body growth.

32 2. Previous studies indicate that the peak of brain energy consumption at around
33 age 5 aligns with the nadir of childhood body mass increase, termed 'adiposity
34 rebound'.

35 3. A delayed adiposity rebound, indicative of slower growth may correlate
36 enhanced language abilities in children.

37 4. Our preregistered study confirms this correlation in girls and associates early
38 cognitive stimulation with improved language skills and adiposity rebound time.

39 Abstract

40 During human childhood, brain development and body growth compete for limited
41 metabolic resources, resulting in a trade-off where energy allocated to brain
42 development can decrease as body growth accelerates. This preregistered study
43 explores the potential links between language skills, used as a proxy for brain
44 development, and body mass index at 3 distinct developmental stages, serving as
45 proxies for body growth. Analyzing longitudinal data from 2002 children in the EDEN
46 mother-child cohort using structural equation modeling, we identified a compelling
47 pattern of associations: girls with a delayed adiposity rebound, signaling slower growth
48 rate, demonstrated better language proficiency at ages 5-6. Importantly, this
49 correlation appears specific to language skills and does not extend to non-verbal
50 cognitive abilities. Exploratory analyses show that early environmental factors that
51 contribute to enhanced cognitive development, such as higher parental socio-
52 economic status and higher levels of cognitive stimulation, are positively linked to both
53 language skills and the age at which adiposity rebound occurs in girls. Overall, our
54 findings lend support to the existence of an energy allocation trade-off mechanism that
55 appears to prioritize language function over body growth investment, in girls.

56 Keywords

57 Development
58 Body growth
59 Language
60 Life History trade-off
61 Early life environment

62 Introduction

63 The importance of language proficiency for mental health and academic success is
64 widely acknowledged (Henry et al., 2014; Miller et al., 2018; Pace et al., 2018), but the
65 variability in children's language skills remains largely unexplained (Kidd & Donnelly,
66 2020). One approach to understand this variability is to investigate the interplay
67 between the metabolic demands of the developing brain and those of bodily growth,
68 as well as the environmental factors that influence these intricate developmental
69 processes.

70 Current theoretical frameworks suggest that language development depends in part
71 on how organisms trade their limited stock of energy resources between competing
72 biological functions (Kaplan & Robson, 2002; Longman et al., 2017; Urlacher et al.,
73 2019). The distribution of energy between the brain and the rest of the body (Aiello &
74 Wells, 2002), particularly during periods of growth, is thought to be a critical
75 determinant of cognitive and physical development (Kaplan et al., 2000; Kuzawa &
76 Blair, 2019). Given the substantial and fluctuating metabolic demands of the brain
77 throughout childhood (Chugani, 1998; Leonard et al., 2003; Madsen et al., 1995;
78 Madsen & Vorstrup, 1991), the organism must finely tune its energy budget to support
79 cognitive development adequately (Aronoff et al., 2022; Navarrete et al., 2011).

80 In human children, a trade-off in resource allocation between brain development and
81 body growth has been shown at the population level (Aronov et al., 2022; Kuzawa et
82 al., 2014), with emerging studies beginning to analyze data from individual children
83 (Blair et al., 2019; Rollins et al., 2021). These investigations propose that an inverse
84 relationship between the rates of body growth and brain development may manifest at
85 various stages, especially during infancy and early childhood. Infants typically have
86 substantial body fat at birth, which predominantly drives the energetic cost of growth
87 during the initial 6-9 months (Kuzawa, 1998; Nilsson et al., 2017). At birth, the body's
88 glucose utilization surpasses that of the brain; however, at around 9 months of age,
89 the body's metabolic expenditure starts to be limited by the brain's glucose
90 consumption (Kuzawa et al., 2014), a growth milestone referred to as the "infancy BMI
91 peak" (Silverwood et al., 2009; Wen et al., 2012). By around 18 months, the brain's
92 glucose consumption exceeds that of the body, peaking at 5 years of age when it
93 accounts for approximately 65% of the organism's metabolism at rest (Holliday, 1986)
94 – in comparison the brain accounts for ~20% of resting metabolic rate at adulthood
95 (Mergenthaler et al., 2013). At age five, when body growth slows to its lowest, a
96 metabolic shift occurs, redirecting resources to body growth during a phase known as
97 the 'adiposity rebound' (Rolland-Cachera et al., 1984), which also marks a decrease
98 in the proportion of energy devoted to brain development (Kuzawa et al., 2014).

99 The interplay of early metabolic exchanges between the brain and body has prompted
100 researchers to formulate new theoretical propositions regarding the pace of cognitive
101 development (Kuzawa & Blair, 2019). It is posited that the rate of body growth may
102 inversely reflect the allocation of resources towards developing high-level cognitive
103 functions. Recent empirical evidence suggests a trade-off where a slower enhancement
104 in executive functions from age 3 to 5 years is associated with accelerated body
105 growth, spanning from infancy (Blair et al., 2019) through to adolescence (Rollins et
106 al., 2021). Building upon these findings, this article examines the relationship between
107 specific body growth milestones and language proficiency in early and middle
108 childhood. The developmental interdependence of language and executive functions
109 is well-documented (Bohlmann et al., 2015; Daneri & Blair, 2017), with the trajectory

110 of executive functions being influenced by early language development (Romeo et al.,
111 2022; Slot & von Suchodoletz, 2018). Consequently, it is plausible that more rapid
112 growth in the early years of life may correspond with language capabilities. In this
113 context, language proficiency, akin to executive functions, serves as a metric of
114 cognitive development, offering a lens through which to infer the energetic demands
115 of brain maturation.

116 Specifically, prioritizing early investment in body growth may be indicative of atypical
117 cognitive functioning in early to middle childhood. Given the rapid development of
118 language during early childhood, and particularly in the preschool years (i.e., ages 0–
119 3 years) (Gervain, 2020), this study aims to explore the association between body-
120 mass index (BMI) trajectories and language abilities from birth to three developmental
121 milestones (Cole, 2004; Rolland-Cachera et al., 1984; Silverwood et al., 2009; Wen et
122 al., 2012): (i) the infancy BMI peak, occurring around 9 months, marking the highest
123 BMI value before it begins to decline; (ii) the inflection point in BMI velocity, around 12
124 months, indicating when the rate of BMI change starts to slow down; (iii) the adiposity
125 rebound, typically around 5-6 years, when BMI starts to rise again after reaching its
126 lowest point in a child's lifetime. The infancy BMI peak and the adiposity rebound are
127 established risk factors for obesity (Cole et al., 2004; Rolland-Cachera et al., 1984;
128 Roy et al., 2016), while the BMI inflection point signals the shift from rapid to more
129 stable or slower growth patterns.

130 Three pre-registered hypotheses are tested:

- 131 • **Hypothesis 1** states that the individuals' age (model 1a) or BMI magnitude (model
132 1b) at which the infancy BMI peak is predictive of general language abilities at 5-6
133 years via the level of vocabulary measured at 24 months.
- 134 • **Hypothesis 2** posits that the individuals' age (model 2a) or BMI magnitude (model
135 2b) at the BMI inflection point is correlated with language abilities at 5-6 years.
- 136 • **Hypothesis 3** proposes that the individuals' age (model 3a) or BMI magnitude
137 (model 3b) at the adiposity rebound is associated with language abilities at 5-6-
138 years.

139 We expect that earlier attainment of these key growth milestones may be inversely
140 related to language proficiency at 24 months and/or 5-6 years. Specifically, children
141 who experience an early infancy BMI peak should display weaker language abilities
142 at 24 months, potentially influencing language abilities at 5-6 years. A similar
143 relationship is expected between adiposity rebound (or BMI inflection point) and
144 language abilities, with an early adiposity rebounds possibly leading to poorer
145 language outcomes at 5-6 years.

146 To test these hypotheses, we applied multivariate structural equation modelling (SEM)
147 (Kline, 2016) on longitudinal data from the EDEN mother-child study, a prospective
148 cohort designed to assess pre- and postnatal determinants of child health and
149 development (Heude et al., 2016).

150 Method

151 The data were collected as part of the EDEN cohort project (Heude et al., 2016). The
152 methodology described in this report differs by three points from the pre-recorded
153 report. A comprehensive explanation of these modifications is provided in the
154 supplementary material.

155 Participants

156 The EDEN mother–child study is a prospective cohort designed to assess pre- and
157 postnatal factors that influence the health and development of children (Heude et al.,
158 2016). The study was approved by the ethics research committee of Kremlin-Bicêtre
159 Hospital (ID 0270 of 12 December 2012) and by Data Protection Authority (CNIL, ID
160 902267 of 12 December 2012), and is in accordance with the Declaration of Helsinki
161 (World Medical Association, 2008). Both parents gave their written informed consents.

162 The cohort included 2,002 mother-child pairs, who were recruited between 2003 and
163 2006 in two university hospital in Nancy and Poitiers (France). The inclusion criteria
164 stipulated that the mothers were before 24 weeks of amenorrhea. Exclusion criteria
165 were mothers younger than 18 years, who had multiple pregnancies, had a history of
166 diabetes, were illiterate and expressed an intention to move out of the region within
167 the next 3 years.

168 Among the 2,002 children included in the EDEN study, we focus on a subset of
169 children who had complete data at which one of the 3 milestones of body growth were
170 calculated, i.e., age at infancy BMI peak, age at BMI inflection point, and age at
171 adiposity rebound. Consequently, we were left with a sample of N=1713 children who
172 had complete data for the age at infancy BMI peak, a sample of N=1519 children with
173 complete data for the age at BMI inflection point, and a sample of N=1415 with
174 complete data for the age at adiposity rebound.

175 Measures

176 Two types of measures are analyzed: (i) measures related to body growth and (ii)
177 measures related to language skill. We provide an overview of the age range for each
178 of the measures in table 1. In table 2, we present the descriptive statistics for the raw
179 variables for boys and girls, respectively. These tables provide a comprehensive
180 summary of our data, including mean values, standard deviations, and other key
181 statistical measures.

182 Body Growth

183 *Anthropometric measurements.* At birth, all weight and height measures were
184 collected from health records. At 4 and 8 months, and 2 and 4 years, mothers
185 completed mailed questionnaires in which they reported their infant's weight and
186 length taken at routine health checkups. These measures were taken by the family
187 practitioner and documented in the infant's personal health record booklet. At ages 1,
188 3 and 5 years, the children were measured in a standardized fashion, with height and
189 weight being measured twice and then averaged. This ensured that the measurements
190 were as accurate as possible. Height was measured to the nearest 0.1 cm using wall-
191 mounted stadiometers (Model 208; SECA, Hamburg, Germany) as the children stood
192 barefoot. Weight was measured to the nearest 0.2 kg with an electronic scale (Model
193 888; SECA, Hamburg, Germany). The children wore light underwear during these
194 measurements to minimize any additional weight.

195 *Measurement of BMI (Body Mass Index) and BMI curve indicators.* BMI was calculated
196 at each age by dividing weight in kilograms by the square of height in meters. On
197 average, children had 10 BMI measurements between birth and 13 years. By
198 collecting BMI measurements at multiple points throughout childhood, we were able
199 to track changes in body mass composition over time and identify three developmental

200 points: the infancy BMI peak, the BMI curve inflection, and the adiposity rebound. To
201 measure these points, we used data from specific time periods. We used data from
202 day 3 and 24 months to measure the infancy BMI peak, data from 6 to 36 months to
203 measure the BMI curve inflection, and data from 18 months and the maximum age
204 available to measure the adiposity rebound.

205 We modeled separate BMI curves for each time period using a cubic mixed-effects
206 models with random effects for intercept, slope, quadratic, and cubic terms (equation
207 1). The following equation describes the general model applied for the i^{th} individual at
208 the t^{th} time point, whatever the period considered (Cissé et al., 2021).

$$209 \quad \log(\text{BMI}_{it}) = \beta_0 + \sum_{j=1}^3 \beta_j \text{Age}_{it}^j + b_{0i} + \sum_{j=1}^3 b_{ji} \text{Age}_{it}^j + \varepsilon_{it} \quad \text{equation 1}$$

210 where:

- 211 • $\beta_0, \beta_1, \beta_2, \beta_3$ are the parameters for the fixed effects,
- 212 • $b_{0i}, b_{1i}, b_{2i}, b_{3i}$ are the parameter estimates for the random effects on the
213 polynomial coefficients for each individual.

214 This equation allowed us to obtain individual period-specific BMI curves for each child.

215 We then calculated the first and second derivatives functions for each curve, which
216 provide information about the rate of change in BMI over time. Specifically, the first
217 derivative, or velocity, helps us pinpoint when the BMI growth rate is at its peak or
218 when it reaches a rebound. The second derivative, or acceleration, is crucial for
219 identifying inflection points in the BMI curve that signal transitions in the growth
220 trajectory.

221 Thus, to determine the age at which the infancy BMI peak occurred, we looked for the
222 point at which the first derivative was zero, and the second derivative was negative or
223 zero (S1a-b Figure). Similarly, to determine the age at which the adiposity rebound
224 occurred, we looked for the point at which the first derivative was zero, and the second
225 derivative was positive or zero (S1c-d Figure). After the infancy BMI peak, the BMI
226 decreased rapidly until it reached an inflection point where the decrease slowed down
227 and the BMI velocity increased. The inflection point was assessed as the age at which
228 the second derivative of the BMI curve was zero and the third derivative was positive
229 (S1e-f Figure).

230 Language abilities

231 The language proficiency was assessed using the following measures at different
232 ages.

233 At 2 years of age

234 *Expressive vocabulary* was evaluated using the short French version of the
235 MacArthur-Bates Communicative Development Inventory (CDI-2) (Kern et al., 2010;
236 Kern & Gayraud, 2010; Peyre et al., 2014). Parents were asked to indicate which
237 words from a list of 100 words their children could say spontaneously, and the child's
238 score was the sum of the words produced. This measure of vocabulary growth is
239 important as early word production is one of the earliest reliable indicators of language
240 acquisition and is a stable linguistic trait in childhood (Rowe et al., 2012).

241

242 At 5-6 years of age

243 Trained psychologists administered neuropsychological tests from the Wechsler
244 Preschool and Primary Scale of Intelligence (WPPSI-III) (Wechsler, 1967) and the
245 Developmental NEuroPSYchological Assessment (NEPSY) (Korkman et al., 2003) to
246 assess each child's cognitive skill. The WPPSI-III subtests were used to assess
247 several skills contributing to verbal intelligence, which is an overall score of linguistic
248 ability. In contrast, the sub-tests of the NEPSY were designed to provide a score on a
249 specific language skill, namely the ability to manipulate short units of speech.

250 *Conceptualization* (WPPSI-III). This subtest is used to assess a child's ability to
251 understand and use abstract concepts and relationships. The test measures a child's
252 ability to categorize and group objects based on their similarities and differences. The
253 test involves showing to the child a series of pictures and asking them to describe how
254 they are related or how they are different. The subtest conceptualization is a measure
255 of a child's ability to think abstractly and use reasoning skills to solve problems.

256 *Vocabulary* (WPPSI-III). This subtest is used to measure a child's ability to understand
257 and use language. The subtest consists of a series of pictures, and the child is asked
258 to name the objects or actions depicted in the pictures. The child's responses are then
259 evaluated to determine their level of vocabulary knowledge and understanding.

260 *Verbal reasoning* (WPPSI-III). This subtest consists of a series of questions that
261 require the child to use their language and reasoning skills to identify similarities and
262 differences between objects, to complete sentences and to identify missing words.
263 The questions are designed to be progressively more difficult, so that the child's level
264 of verbal reasoning can be accurately assessed.

265 *Nonword repetition* (NEPSY). This subtest assesses a child's phonological processing
266 and verbal short-term memory skills. In this task, the child is asked to repeat a series
267 of pseudowords, which have been designed to be progressively more difficult. The
268 subtest measures the child's ability to accurately repeat the sounds and syllables of
269 the pseudowords.

270 *Phonological processing* (NEPSY). This subtest is composed of two tasks designed
271 to assess a child ability to process and manipulate the sounds of language (i.e.,
272 phonological awareness). In the word segment recognition task, the child is asked to
273 identify words from short sentences. In the phonological segmentation task, the child
274 is asked to repeat a word and then to create a new word by omitting a syllable or a
275 phoneme, or by substituting one phoneme for another.

276 *Sentence repetition* (NEPSY). This subtest is designed to assess the ability to repeat
277 sentences of increasing complexity and length. The child is read a series of sentences
278 and asked to recall each sentence immediately after it is presented.

279 Covariates

280 The structural equation models used in this study were adjusted for three factors
281 potentially associated with cognitive development and/or body growth. Firstly,
282 children's sex was included as a grouping factor to address any disparities between
283 boys and girls in the relationships between body growth and the language proficiency
284 (Girls = 1; Boys = 0). Secondly, the respondents' recruitment center was taken into
285 account (Poitiers = 1; Nancy = 0). Previous research has shown differences in
286 language outcomes among children recruited from these two hospital centers within
287 the EDEN cohort (Peyre et al., 2016). Finally, we created an adjustment variable using
288 a composite score that reflect the level of adversity experienced by children before

289 and immediately after birth. This composite score encompassed nine factors known
290 to affect early childhood diet (Gentner & Leppert, 2019; Lindsay et al., 2019) as well
291 as neural, cognitive and behavioral development (Bath, 2020; Frankenhuis et al.,
292 2020). These factors included gestational age at birth (in weeks), exposure to alcohol
293 and cigarette smoking during pregnancy (no = 1), breastfeeding (yes = 1), father
294 absence (no = 1), monthly household income at birth (in €), education levels of both
295 mother and father (each scored from 1 = did not attend school to 9 = university, based
296 on the French school system), and household density (number of adults and children
297 living in the house divided by the number of rooms). Scores for these nine variables
298 were z-scored, allowing their cumulative sum to reflect the degree of perinatal
299 adversity. A higher score on this composite variable indicated greater exposure to
300 perinatal adversity. Our approach of summing z-scores is grounded in both theoretical
301 and empirical research. Current models suggest that factors contributing to adversity
302 vary in nature and do not necessarily correlate with each other (McLaughlin et al.,
303 2021; Ellis et al., 2009) (S2 Figure). Such emergent variables have been effectively
304 modelled in prior studies using sums of z-scored indicators (Baptista et al., 2023;
305 Brumbach et al., 2009; Jacquet et al., 2019; Mell et al., 2018). Moreover, this
306 composite scoring approach inherently assigns greater weight to more dispersed
307 indicators, which represent rarer adverse events.

308 Pre-registered analyses

309 Structural equation models

310 Our study employed structural equation modeling (SEM) to conduct multivariate
311 analyses on our three samples. These SEMs were carried out using R ([https://www.r-](https://www.r-project.org/)
312 [project.org/](https://www.r-project.org/)) with R Studio using the R package *lavaan* (Rosseel, 2012). These SEMs
313 involved a measurement model that relates observed indicators to a smaller set of
314 unobservable latent variables, and a structural model that estimates the strength of
315 the link between latent variables and single indicators by specifying paths between
316 them. The detailed specification of the measurement and structural models of each
317 SEM used in our analysis are provided in supplementary materials section
318 'Supplementary Methods. Detailed specification of the structural equation models').

319 We specified three sets of SEMs: Models 1a and 1b test Hypothesis 1 on Sample 1,
320 Models 2a and 2b test Hypothesis 2 on Sample 2, and Models 3a and 3b test
321 Hypothesis 3 on Sample 3. Each model involved one reflective latent variable aimed
322 at capturing language proficiency in 5-6-year-old children, which was modeled either
323 as the indirect (Model 1) or direct (Models 2 and 3) outcome of body growth
324 parameters. Models 1a and 1b incorporated a variable assessing early vocabulary
325 size, as a mediator of the association between body growth parameters and language
326 proficiency. Moreover, if we observe a relationship between adiposity rebound and
327 language proficiency at 5-6 years, a complementary model testing whether the effect
328 of the adiposity rebound is specifically related to language skills, or whether it can be
329 generalized to non-verbal cognitive functioning, will be fitted.

330 These SEMs allowed us to examine whether and how variations in the timing of the
331 infancy BMI peak (model 1), the BMI inflection point (model 2), and the adiposity
332 rebound (model 3) – influences language acquisition in boys and girls, while adjusting
333 for recruitment center and perinatal adversity. To achieve this, we utilized a multi-
334 group approach. First, sex differences were qualitatively assessed by examining the

335 associations between body growth milestones and the language proficiency latent
336 factor in both groups. Next, they were quantitatively assessed using a Chi-squared
337 difference test, which compared the goodness of fit of a first model where all
338 parameters were freely estimated to the goodness of fit of a second model where the
339 parameters estimating the associations between body growth milestones and the
340 language proficiency latent factor were constrained to be equal between girls and
341 boys. A significant improvement in fit for the first model indicated that girls and boys
342 differ with respect to how body growth is related to language proficiency.

343 To minimize the risk of overfitting, all coefficients, standard errors and their 95%
344 confidence intervals were estimated using a non-parametric bootstrapping procedure,
345 which involved 1000 random samplings with replacement for each model (MacKinnon
346 et al., 2004; Preacher & Hayes, 2008). This approach does not rely on normality
347 assumptions and allows for the calculation uncertainty in any confidence interval of
348 any kind of distribution.

349 Missing Data

350 Two approaches were used to explore assumptions related to missing data. Firstly,
351 we conducted Little's test (Little, 1988) to examine whether the data conformed to the
352 'Missing Completely At Random' (MCAR) assumption, which postulates that the
353 absence of data is independent of any observed and unobserved variable). The test
354 results rejected the null hypothesis of MCAR ($\chi^2_{(1463)} = 2361.6, p < .001$). Secondly,
355 we investigated patterns of missingness by conducting pairwise comparisons. For
356 continuous data, we used Kruskal-Wallis tests, while for discrete data, we used Chi
357 squared tests. These comparisons examined the relationship between missingness
358 and explanatory variables for the six indicators of language proficiency at 5-6 years.
359 After controlling for the false discovery rate (FDR) using the Benjamini-Hochberg
360 approach (Benjamini & Hochberg, 1995), the comparisons revealed a systematic
361 relationship between missingness and two out of nine indicators of perinatal adversity.
362 In each case, children with missing scores on the language proficiency indicators had
363 higher values for these adversity indicators.

364 Thus, the missingness of our data is unlikely to satisfy the 'Missing Completely At
365 Random' (MCAR) assumption, where missingness is independent of any studied
366 variable. While we cannot entirely rule out the potential for the 'Missing Not At Random'
367 (MNAR) assumption (where missingness is related to the unobserved study factors),
368 it is more pragmatic and parsimonious to adopt the 'Missing At Random' (MAR)
369 assumption. This assumption hypothesizes that the missingness of data is related to
370 the observed variables (e.g., the demographic characteristics or the recruitment
371 center) and not to the unobserved factors we aim to study (e.g., the BMI trajectories
372 or the latent variable 'language proficiency at 5-6 years'). To handle missing data, we
373 employed a statistical technique known as full information maximum likelihood
374 estimation (FIML). Previous research has indicated that FIML performs relatively well
375 in several situations, even in scenarios where data may be MNAR. It demonstrates
376 reduced bias and sampling variability when compared to ad hoc methods (Muthén et
377 al., 1987; Enders & Bandalos, 2001; Baraldi & Enders, 2010).

378 It is important to note that FIML cannot be applied to SEMs with exogenous variables
379 that are non-random, resulting in the automatic deletion of missing values. In our case,
380 perinatal adversity is one such non-random covariate subject to this deletion
381 procedure. Models 1, 2 and 3 were fitted on dataset consisting of 1498 children (757

382 girls, 741 boys), 1334 children (674 girls, 660 boys), and 1259 children (647 girls, 612
383 boys), respectively. Note that the fit indices and estimated parameters described
384 below are replicated in the Supplementary Material (Tables S8 to S16), with models
385 fitted on the complete cases (Models 1: N = 849; Models 2: N = 881; Models 3: N =
386 931).

387 Fitting procedure

388 The fitting of all the models described above was accomplished by using a Maximum
389 Likelihood estimator (ML) coupled with a Full Information Maximum Likelihood (FIML)
390 algorithm, as this method is able to handle Missing At Random (MAR) data. The
391 goodness of fit was assessed by considering several statistics, namely χ^2 ,
392 Comparative Fit Index (CFI), Root Mean Square Error of Approximation (RMSEA) and
393 standardized Root Mean Square Residual (SRMR) statistics. In general, a model's fit
394 is considered excellent when the RMSEA is close to 0.05, the CFI is close to 0.95 and
395 SRMR is close to 0.08 (Hu & Bentler, 1999).

396

397 Results of the pre-registered analyses

398 The results reported in Table 3 indicate that all models exhibit good-to-excellent fit
399 indices (with CFI values greater than 0.93, RMSEA values around 0.03, and SRMR
400 values \leq .08). The models performed better than their null versions, which included
401 only the variance of the indicators as parameters.

402 Parameter estimates are reported in the main text for Models 1a, 2a and 3a (Tables
403 4, 5 and 6) and in the supplementary information for Models 1b, 2b and 3b (Tables
404 S4, S5 and S6). These tables contain standardized coefficients and standard
405 deviations extracted from the measurement and structural parts of each model,
406 expressed in terms of their bootstrapped means, for girls and boys. The tables also
407 provide the 95% confidence intervals (CI) and exact p-values, which represent the
408 proportion of bootstrap samples whose estimated CI includes zero.

409 Hypothesis 1 - Models 1a and 1b

410 *Measurement model.* The measurement parts of Models 1a and 1b showed that the 6
411 language-related indicators were positively correlated with the latent variable
412 language proficiency, indicating that children who scored high on the latent variable
413 also scored high in conceptualization, vocabulary, verbal reasoning, non-word
414 repetition, sentence repetition and, to a lesser extent, phonological processing. This
415 association was observed in both girls and boys.

416 *Structural model.* The structural parts of both models indicated that children with a
417 larger vocabulary size at 24 months tended to exhibit higher language proficiency
418 scores at 5-6 years. However, no significant linear or quadratic associations were
419 found between the age at infancy BMI peak and latent language proficiency at 5-6
420 years for either boys or girls (Table 4). Interestingly, in Model 1b, a weakly negative
421 and significant indirect quadratic association emerged between boys' BMI values at
422 the age peak and language proficiency at 5-6 years. This association was mediated
423 by vocabulary size at 24 months (Table S4). Notably, this association was not
424 observed in girls (Table S4). To further investigate potential sex differences, we
425 conducted a Chi-squared difference test comparing the goodness-of-fit of a free model

426 to a constrained model. The free model, where all parameters were freely estimated,
427 did not provide a better fit compared to the constrained model, where the parameters
428 of the indirect association were constrained to be equal between girls and boys (df =
429 38 vs 39, Chi-squared = 228.64 vs 234.56, Chi-squared diff = 5.92, $p = .116$). This
430 finding indicates that the observed qualitative sex difference was not statistically
431 significant.

432 Overall, we provide evidence that early vocabulary size is a strong predictor of later
433 language proficiency in both boys and girls (an established fact, (Lee, 2011; Peyre et
434 al., 2014)), but our analyses failed to verify that the infancy BMI peak is related to later
435 language proficiency (at 2 or 5-6 years).

436 Hypothesis 2 - Models 2a and 2b

437 *Measurement model.* The measurement part of Models 2a and 2b showed results that
438 were fully identical to those reported for Models 1a and 1b, indicating high correlations
439 between the latent language proficiency at 5-6 years and 5 out of its 6 indicators (a
440 smaller correlation is again observed for the phonological processing indicator). This
441 pattern was observed in both girls and boys (Table 5, Table S5).

442 *Structural model.* The structural part of both models showed no significant linear or
443 quadratic associations between the age at BMI inflection (or the BMI value at that age)
444 and language proficiency at 5-6 years, for either boys or girls.

445 Therefore, Models 2a and 2b did not validate Hypothesis 2, that the BMI infection point
446 is related to later language skills (at 5-6 years).

447 Hypothesis 3 - Models 3a and 3b

448 *Measurement model.* The measurement part of models 3a and 3b showed the same
449 results as the previous models, indicating a high correlation between the latent
450 language proficiency at 5-6 years and its indicators for both girls and boys. Specifically,
451 high scores on the latent language proficiency at 5-6 years were associated with high
452 scores in conceptualization, vocabulary, verbal reasoning, non-word repetition,
453 sentence repetition and, to a lesser extent, phonological processing.

454 *Structural model.* The structural parts of these models show no quadratic association
455 between the age at adiposity rebound (or the BMI magnitude at that age) and language
456 proficiency at 5-6 years for both girls and boys (Table 6, Table S6). Interestingly, a
457 modest albeit significant linear association is observed in Model 3a between the age
458 at adiposity rebound and language proficiency at 5-6 years for girls only (Table 6). This
459 suggests that girls who reach the nadir of their body growth at a later age are more
460 likely than others to express better language proficiency at 5-6 years than those who
461 reach it earlier.

462 To further investigate the observed sex difference, we also ran a Chi-squared
463 difference test to compare the fit of a free model with a constrained model. The
464 analysis revealed a significant difference between girls and boys in the relationship
465 between their age at adiposity rebound and language proficiency at 5-6 years. The
466 free model demonstrated a superior fit compared to the constrained model (df = 38 vs
467 39, Chi-squared = 189.09 vs 193.83, Chi-squared diff = 4.75, $p = .029$).

468 In summary, Model 3a validates Hypothesis 3 for girls only, indicating a linear
469 association between age at adiposity rebound and language proficiency at 5-6 years
470 in girls (Figure 1). Results from the complementary model suggest that this association

471 is specific to language development and does not extend to non-verbal cognitive
472 functioning (Table S7).

473 **Complementary model. Is adiposity rebound specifically tied to language**
474 **proficiency at 5-6 years or does it extend to more general cognitive**
475 **functioning?**

476 In this complementary model, our aim was to investigate whether the relationship
477 between adiposity rebound and language proficiency, as observed in Model 3a
478 extends to other cognitive measures. Due to the observed sex effect in Model 3a, we
479 focused on analyzing data exclusively from the girl sample. This model does not
480 involve a measurement component as no latent variable is being estimated. Therefore,
481 absolute and comparative fit indices are not informative.

482 The analysis did not reveal a significant association between age at adiposity rebound
483 and girls' processing speed. However, a positive linear trend was observed with the
484 non-verbal performance score. This association was qualitatively weaker compared to
485 the significant one found with the verbal score (Table S7).

486 To further quantify this relationship, we fitted two additional models called
487 Complementary Model PERF and Complementary Model VERB. In Complementary
488 Model PERF, the regression parameter linking age at adiposity rebound and the non-
489 verbal performance score was fixed at zero, while all other parameters were freely
490 estimated. The same approach was applied in Complementary Model VERB, with the
491 parameter linking age at adiposity rebound and the verbal score fixed to zero. We then
492 compared the fit of each model with the original model using a chi-squared difference
493 test. The rationale behind these comparisons is that fixing a parameter that
494 significantly contributes to variance explanation to zero should result in a decrease in
495 model fit compared to the original model. Therefore, if the age at adiposity rebound is
496 specifically tied to language ability, then only the fit of Complementary Model VERB
497 should be significantly degraded. On the other hand, if the age at adiposity rebound
498 generalizes its effect on non-verbal cognition, then the fit of Complementary Model
499 PERF should also be degraded.

500 The chi-squared difference tests showed a degraded fit for Complementary Model
501 VERB (df = 0 vs 2, Chi-squared = 0 vs 7.86, Chi-squared diff = 7.86, $p = .02$), but not
502 for Complementary Model PERF (df = 0 vs 2, Chi-squared = 0 vs 3.57, Chi-squared
503 diff = 3.57, $p = .17$). These results suggest a specific association between body growth
504 and language development.

505

506 **Unregistered analyses**

507 To further investigate the association evidenced in girls between the age at adiposity
508 rebound and language proficiency at 5-6 years, an additional SEM was designed and
509 fitted to the girl sample. The model aimed to take both the age at adiposity rebound
510 and language proficiency at 5-6 years, estimating a correlational parameter between
511 them. Our hypothesis posits that a metabolic trade-off (a latent mechanism dictating
512 resource allocation between two traits) influences their relationship. Within the SEM
513 framework, such a hidden factor can be modelled by a parameter that accounts for the
514 residual variance in the regression, reflecting a partial correlation. Consequently, we

515 use this parameter as an index to ascertain whether an unobserved trade-off
516 mechanism moderates the observed relationship between the age at adiposity
517 rebound and language abilities at 5-6 years. We suppose here that early life
518 environmental factors might increase the energy demand of the brain through direct
519 or indirect stimulation of language functions (Farah et al., 2008; Tooley et al., 2021).
520 Subsequently, the high energy demands of a proficient language functioning at 5-6
521 years of age is made possible at the cost of a delayed investment in body growth.
522 Crucially, our dataset allows for building 5 environmental constructs:

523 *Parents socio-economic status (SES)* is determined by the combined scores of 3
524 items, which include the educational level of both the mother and the father, as well
525 as the household density and yearly household income collected at the child's 24th
526 months of life. A higher sum of z-scores indicates a higher socio-economic status for
527 the parents, i.e. a higher level of education and a more affluent life.

528 *Cognitive stimulation* reflects the sum of scores obtained on 9 items of the HOME
529 inventory (Home Observation Measurement of the Environment) (Bradley et al., 1992),
530 which assesses the quality of cognitive stimulation and emotional support provided by
531 the child's family. The number of times per week the mother and father engaged with
532 their child in activities based on active linguistic interactions through singing, telling
533 stories and playing indoor games, at 2 and 3 years of age, are reported. The higher
534 the sum of z-score, the more the parents stimulated the child's cognitive and language
535 functions at these ages.

536 *Physical stimulation* reflects the sum of scores obtained on 6 items of the HOME
537 inventory that assess the number of times per week the mother and father engaged in
538 physical activities with their child through walking or playing outdoor games (e.g., ball
539 play), at 2 and 3 years of age. The higher the sum of z-score, the more the parents
540 stimulate the child's physical capacities at these ages.

541 *Primary needs* is a construct that reflects the sum of scores obtained on 6 items of the
542 HOME inventory, which measure how frequently the mother and the father
543 independently met their child's primary needs at the age of 2. These six items evaluate
544 3 aspects of primary needs, namely basic hygiene, food intake, and bedtime. The sum
545 of z-scores indicates the extent to which the parents are personally engaged in fulfilling
546 their child's primary needs, with a higher z-score indicating greater parental
547 involvement.

548 *Physiological stress* is measured by the combined scores of 4 items, namely tobacco
549 and alcohol exposure during gestation, gestational age, and absence of breastfeeding.
550 These items assess the level of exposure to factors that may impact the child's
551 physiological development during gestation and immediate post-natal period. A higher
552 sum of z-scores indicates a greater level of exposure to physiological stress during
553 this critical period.

554 The model fitting procedure used in this analysis was identical to the one employed in
555 the pre-registered SEMs. Missing values of endogenous variables (i.e., the 6
556 indicators of the latent factor) were handled using a FILM method, while missing cases
557 of exogenous variables (i.e., the five early environmental variables described above)
558 were automatically removed, resulting in a sample size of N = 442 girls. All coefficients,
559 standard errors, and 95% confidence intervals estimated by the model were obtained
560 using a non-parametric bootstrapping procedure, with 1000 random samplings with
561 replacement (MacKinnon et al., 2004; Preacher & Hayes, 2008).

562 Unregistered Model. Is there a link between environmental factors that
563 stimulate cognition in children aged 2-3 years, their language proficiency
564 at 5-6 years, and the age at which adiposity rebound occurs?

565 *Specification of the measurement model.* Language proficiency at 5-6 years of age is
566 modelled as an endogenous latent factor, which captures the shared variance of 6
567 indicators: conceptualization, vocabulary, verbal reasoning, non-word repetition,
568 sentence repetition, and phonological processing. These indicators were scored and
569 z-transformed such that higher scores indicate greater language proficiency, and the
570 variance of this latent variable was scaled to 1. Additionally, the age at adiposity
571 rebound was entered as the second endogenous outcome, with a greater score
572 indicating a later rebound. All indicators were adjusted for the effect of Recruitment
573 center.

574 The exogenous predictors of the two outcomes, including parental socio-economic
575 status (SES), cognitive stimulation, physical stimulation, primary needs, and
576 physiological stress, were also entered in this model.

577 *Specification of the structural model.* Our unregistered hypothesis was tested through
578 the estimation of several parameters, including: i) a parameter that captures the partial
579 correlation between the residuals of the language proficiency latent variable and the
580 residuals of the *age at* adiposity rebound, ii) a set of five regression parameters that
581 estimate the effect of each environmental factor on each of the two outcomes (Figure
582 2).

583 Results of the unregistered analysis

584 The goodness of fit of the model is reported in Table 7, which shows that the model
585 had good-to-excellent fits, as indicated by the CFI values $>.94$, RMSEA values $<.06$,
586 and SRMR values $<.03$. Table 8 reports all the parameter estimates that corroborate
587 the description of the unregistered model. It contains the standardized coefficients and
588 standard deviations extracted from the measurement and the structural parts of the
589 model, expressed in terms of their bootstrapped means, as well as the bootstrap 95%
590 confidence intervals (CIs) and exact p-values.

591 *Measurement model.* The results of the measurement model were similar to those
592 reported in the registered model's description. Girls who scored high on the latent
593 language proficiency at 5-6 years also scored high in conceptualization, vocabulary,
594 verbal reasoning, non-word repetition, sentence repetition and, to a lesser extent,
595 phonological processing.

596 *Structural model.* The structural model (table 8) first supports the hypothesis of a
597 hidden mechanism mediating between age at adiposity rebound and the latent
598 variable of language proficiency at 5-6 years, as suggested by a positive residual
599 correlation between the two variables (Figure 3). More specifically, parental socio-
600 economic status (SES) is positively related to both language proficiency and BMI
601 rebound, such that the higher the parents' SES, the later the adiposity rebound and
602 the higher the language skills (Figure 2, panels A and F). A similar trend is observed
603 with the cognitive stimulation factor, which shows a positive correlation with language
604 skills and with age at adiposity rebound (Figure 2, panels B and G), although the level
605 of confidence that this latter association is actually greater than zero is closer to 90%
606 than 95% (note that the mean bootstrapped 95% CI does not include zero when only
607 data from complete cases are analyzed, see Table S16). In addition, we found that the

608 amount of physical stimulation produced by the parents was negatively related to
609 language skills, so that the more intense the physical stimulation, the lower the
610 language skills (Figure 2C). On the contrary, neither the parents' contribution to
611 satisfying the child's basic needs, nor the amount of prenatal and perinatal
612 physiological stress are related to language proficiency or adiposity rebound (Figure
613 2, panels D, E, I and J). Together, the model shows that early life environments that
614 provide the child a large amount of cognitive information, whether through the parents'
615 educational practices or their socio-economic capital, have a positive influence on
616 brain development through the acquisition of language, which slows the growth of BMI.
617

618 Discussion

619 The results of this pre-registered study are consistent with a theorized energy
620 allocation trade-off mechanism (Leonard et al., 2003; Said-Mohamed et al., 2018),
621 which suggests a prioritization of language proficiency over the investment in body
622 growth. This extends foundational theoretical and empirical research that posits a
623 competition for metabolic resources between the development of higher-order
624 cognitive functions (i.e. executive functions) and physical growth (Kuzawa & Blair,
625 2019; Blair et al., 2019; Rollins et al., 2021). Our investigation focused on the
626 association between the timing and magnitude of the infancy BMI peak, BMI inflection
627 point, BMI at adiposity rebound, with language proficiency at 5-6 years. The analyses
628 revealed no significant link between the infancy BMI peak or inflection point, and
629 language skills, but a positive association between the age at adiposity rebound and
630 language skills in girls. Specifically, girls experiencing a later adiposity rebound
631 demonstrated greater proficiency across language dimensions measured in the EDEN
632 cohort (including conceptualization, vocabulary, verbal reasoning, phonological
633 processing, non-word repetition, and sentence repetition). Importantly, this correlation
634 did not extend to non-verbal cognitive abilities such as performance IQ or processing
635 speed.

636 The absence of a correlation between body mass index and indicators of non-verbal
637 cognitive skills may reflect the specific role of language in human developmental. Yet,
638 the development of another cognitive domain, executive functions, has been linked to
639 BMI variations throughout early, middle and late childhood (Blair et al., 2019; Rollins
640 et al., 2021). This link is further supported by evidence of deficits in executive
641 functions, such as problem-solving, decision-making, and impulse control among
642 obese individuals (Yang et al., 2018). Developmental studies have consistently shown
643 that development of language and executive functions are closely intertwined
644 (Bohlmann et al., 2015; Daneri & Blair, 2017), with early language abilities significantly
645 influencing the trajectory of executive function development (Romeo et al., 2022; Slot
646 & von Suchodoletz, 2018). There remains, however, a substantial research agenda to
647 fully understand the complex interplay between body growth and cognitive
648 development. From this perspective, the elaboration of comprehensive models that
649 encapsulate multiple cognitive domains (i.e., executive functions, language skills, and
650 non-verbal cognitive abilities) could prove to be a fruitful line of inquiry.

651 Contrary to previous work (Blair et al., 2019; Farkas & Jacquet, 2023; Kuzawa et al.,
652 2014; Kuzawa & Blair, 2019; Rollins et al., 2021), our study found that the trade-off
653 between neurocognitive development and body growth was only observed in girls.
654 This result is not only statistically significant, but also of substantial magnitude. The

655 divergent developmental paths of girls and boys may reflect the role of energy trade-
656 offs in regulating differential reproductive strategy. Previous research has established
657 a link between childhood fat accumulation, including the timing of adiposity rebound,
658 and the onset of puberty (Brix et al., 2020; O’Keeffe et al., 2020; Williams & Goulding,
659 2009), potentially due to hormonal influences. Estrogens, for instance, facilitate the
660 conversion of surplus calories to fat, while leptin oversees both appetite and the
661 distribution of energy for reproductive purposes (Moschos et al., 2002; Rosenbaum &
662 Leibel, 1999). In girls, the early storage of energy reserves as adipose tissue might
663 anticipate the substantial demands of future reproductive events, such as pregnancy
664 and lactation (Kaplowitz, 2008). Conversely, the interplay between body growth and
665 reproductive physiology in boys is less clear (Kaplowitz, 2008). This disparity may
666 stem from methodological challenges in pinpointing the onset of puberty in boys,
667 alongside theoretical considerations suggesting that fat reserves play a less crucial
668 role in male reproductive functions. For example, unlike females, males do not bear
669 the energetic burdens of pregnancy and lactation, and the emergence of male
670 secondary sexual characteristics tends to rely more on the accrual of lean mass.

671 Another noteworthy finding in our study is the significant correlations between early
672 environmental factors that promote cognitive stimulation, language skills in girls and
673 the timing of adiposity rebound. Specifically, children from higher educational and
674 socio-economic backgrounds, who are exposed to language-stimulating activities at
675 ages 2-3, tend to delay adiposity rebound and express better language skills by ages
676 5-6. This echoes the patterns reported by Farkas & Jacquet (2023), where limited
677 access to various resources at age 6 was a strong predictor of later growth trajectories,
678 both somatic and cognitive. Altogether, these findings provide empirical support for
679 the hypothesis put forth in Kuzawa and Blair (2019), that an environment rich in
680 information in early life can enhance brain energy demands, thereby enhancing
681 language development.

682 Contrastingly, environmental factors less directly associated with cognitive
683 enrichment, such as parental investment in primary needs or prenatal stress levels,
684 seemingly have no bearing on the energy trade-off between body growth and brain
685 development. Additionally, our data indicate a negative correlation between physical
686 stimulation at ages 2-3 and language proficiency at ages 5-6, implying that early
687 physical activities might temporarily re-route resources from language development.
688 The observation that environmental factors promoting physical skills could impede
689 from cognitive functions as language presents an evolutionary paradox. Inhibiting
690 neurocognitive development during infancy and childhood could increase mortality
691 risks, which are notably high in the first 15 years. This could, for instance, decelerate
692 the acquisition of cognitive strategies essential for achieving efficient resource
693 productivity (see Burger et al., 2012; Gurven & Kaplan, 2007).

694 The approach we used to investigate the energy trade-off between brain development
695 and body growth could benefit from several improvements. Firstly, adding data on
696 children’s dietary habits, including the amount of nutrient-dense and processed foods
697 consumed would refine the model, given that such dietary choices can impact body
698 mass trajectories (Ip et al., 2017; Saldanha-Gomes et al., 2022). While our pre-
699 registered models partially account for dietary effects by including a covariate for
700 perinatal adversity (which captures family socioeconomic status and indirectly, dietary
701 quality, often poorer in lower-income, disadvantaged households (Fernández-Alvira et
702 al., 2015)), direct dietary measures would offer a more precise adjustment. A second
703 challenge lies in addressing genetic heritability, which significantly affects the timing

704 of adiposity rebound (Cissé et al., 2021; Couto Alves et al., 2019; Meyre et al., 2004).
705 Notably, our models that correlate social adversity and socioeconomic status with
706 cognitive development are less susceptible to genetic confounding compared to
707 models examining the relationship between adiposity rebound and cognition alone.
708 Thirdly, we might consider employing an alternative index to BMI for a nuanced
709 depiction of body composition, particularly in boys, where lean mass is a more
710 prominent contributor to BMI than in girls (Franklin, 1999; Gallagher et al., 1996;
711 Horlick, 2001; Van Eyck et al., 2021). Lastly, integrating direct measures of neural
712 activity, such as electrophysiological markers of neuronal maturation, would offer a
713 more immediate evaluation of brain development.

714 In this study, we analyzed data from a large sample and obtained result that align with
715 a trade-off mechanism between brain development and body growth. Using the BMI
716 trajectories as an indicator of body growth and language proficiency as a metric for
717 cognitive development, we also demonstrate that environmental factors promoting
718 cognitive stimulation at ages 2 and 3 concurrently influenced the timing of adiposity
719 rebound and the language skill levels measured three years later.

720 **Declarations**

721 **Ethics approval and consent to participate.** The study was approved by the ethics
722 research committee of Kremlin-Bicêtre Hospital (ID 0270 of 12 December 2012) and
723 by Data Protection Authority (CNIL, ID 902267 of 12 December 2012), and is in
724 accordance with the Declaration of Helsinki (World Medical Association, 2008). Both
725 parents gave their written informed consents.

726 **Consent for Publication.** Not applicable.

727 **Availability of data and materials**

728 *Data availability statement.* Simulated data used in this report are publicly available
729 from the Open Science Framework (<https://osf.io/8x4pm/>). Any researcher interested
730 in exploring EDEN data should contact directly the director of the EDEN mother-child
731 cohort [barbara.heude@inserm.fr] to complete a dedicated project form for evaluation
732 by the EDEN steering committee.

733 *Code availability statement.* All the codes needed to reproduce the results in the paper
734 are available on the Open Science Framework (<https://osf.io/8x4pm/>).

735 **Competing interests.** The authors declare no competing interests.

736 **Funding.** This work is funded by the Fyssen Foundation and a research grant from
737 the Fondation pour l'Audition (RD-2016-R). This research was also funded by Agence
738 Nationale de la Recherche ANR-17-EURE-0017 (PI: C.C.), ANR-22-CE28-0012-01
739 (PI: P.O.J), and ANR-21-CE28-0028 (PI: S.B.). A CC-BY public copyright license has
740 been applied by the authors to the present document and will be applied to all
741 subsequent versions up to the Author Accepted Manuscript arising from this
742 submission, in accordance with the grant's open access conditions. The funders had
743 no role in study design, data collection and analysis, decision to publish or preparation
744 of the manuscript.

745 **Author contributions.** S.B. and P.O.J. contributed the original idea of the project and
746 designed research. S.B., C.C., A.H.C., B.H. and P.O.J. designed the analysis plan and
747 drafted the Stage 1 submission. S.B. and P.O.J. analyzed the data. S.B., C.C. and

748 P.O.J. provided funding. C.C. and P.O.J. provided equipment for data analysis. S.B.
749 and P.O.J. wrote the Stage 2 manuscript with the help of C.C, A.H.C and B.H.

750 **Acknowledgments.** The authors thank the EDEN mother–child cohort study group,
751 whose members are I. Annesi-Maesano, J.Y. Bernard, M.A. Charles, P. Dargent-
752 Molina, B. de Lauzon-Guillain, P. Ducime- tière, M. de Agostini, B. Foliguet, A. Forhan,
753 X. Fritel, A. Germa, V. Goua, R. Hankard, B. Heude, M. Kaminski, B. Larroquey, N.
754 Lelong, J. Lepeule, G. Magnin, L. Marchand, C. Nabet, F Pierre, R. Slama, M.J.
755 Saurel-Cubizolles, M. Schweitzer, and O. Thiebaugeorges. We thank Franck Ramus
756 for support and useful discussions.

References

- 758 Abel, M. H., Brandlistuen, R. E., Caspersen, I. H., Aase, H., Torheim, L. E., Meltzer, H. M., &
759 Brantsaeter, A. L. (2019). Language delay and poorer school performance in children of mothers
760 with inadequate iodine intake in pregnancy: Results from follow-up at 8 years in the Norwegian
761 Mother and Child Cohort Study. *European Journal of Nutrition*, 58(8), 3047–3058.
762 <https://doi.org/10.1007/s00394-018-1850-7>
- 763 Aiello, L. C., & Wells, J. C. K. (2002). Energetics and the Evolution of the Genus HOMO. *Annual Review*
764 *of Anthropology*, 31(1), 323–338. <https://doi.org/10.1146/annurev.anthro.31.040402.085403>
- 765 Aronoff, J. E., Ragin, A., Wu, C., Markl, M., Schnell, S., Shaibani, A., Blair, C., & Kuzawa, C. W. (2022).
766 Why do humans undergo an adiposity rebound? Exploring links with the energetic costs of brain
767 development in childhood using MRI-based 4D measures of total cerebral blood flow. *International*
768 *Journal of Obesity*. <https://doi.org/10.1038/s41366-022-01065-8>
- 769 Baraldi, A. N., & Enders, C. K. (2010). An introduction to modern missing data analyses. *Journal of*
770 *School Psychology*, 48(1), 5–37. <https://doi.org/10.1016/j.jsp.2009.10.001>
- 771 Bath, K. G. (2020). Synthesizing views to understand sex differences in response to early life adversity.
772 *Trends in Neurosciences*, 43(5), 300–310. <https://doi.org/10.1016/j.tins.2020.02.004>.Synthesizing
- 773 Benjamini, Y., & Hochberg, Y. (1995). Controlling the False Discovery Rate: A Practical and Powerful
774 Approach to Multiple Testing. *Journal of the Royal Statistical Society: Series B (Methodological)*,
775 57(1), 289–300. <https://doi.org/10.1111/j.2517-6161.1995.tb02031.x>
- 776 Blair, C., Kuzawa, C. W., & Willoughby, M. T. (2019). The development of executive function in early
777 childhood is inversely related to change in body mass index: Evidence for an energetic tradeoff?
778 *Developmental Science*, 23(1), e12860. <https://doi.org/10.1111/desc.12860>
- 779 Bohlmann, N. L., Maier, M. F., & Palacios, N. (2015). Bidirectionality in Self-Regulation and Expressive
780 Vocabulary: Comparisons Between Monolingual and Dual Language Learners in Preschool. *Child*
781 *Development*, 86(4), 1094–1111. <https://doi.org/10.1111/cdev.12375>
- 782 Bradley, R. H., Caldwell, B. M., Brisby, J., Magee, M., Whiteside, L., & Rock, S. L. (1992). The HOME
783 inventory: A new scale for families of pre- and early adolescent children with disabilities. *Research*
784 *in Developmental Disabilities*, 13(4), 313–333. [https://doi.org/10.1016/0891-4222\(92\)90009-U](https://doi.org/10.1016/0891-4222(92)90009-U)
- 785 Brix, N., Ernst, A., Lauridsen, L. L. B., Parner, E. T., Arah, O. A., Olsen, J., Henriksen, T. B., & Ramlau-
786 Hansen, C. H. (2020). Childhood overweight and obesity and timing of puberty in boys and girls:
787 Cohort and sibling-matched analyses. *International Journal of Epidemiology*, 49(3), 834–844.
788 <https://doi.org/10.1093/ije/dyaa056>
- 789 Burger, O., Baudisch, A., Vaupel, J.W. (2012). Human mortality improvement in evolutionary context.
790 *Proceedings of the National Academy of Sciences USA*, 109(44), 18210-18214.
791 <https://doi.org/10.1073/pnas.1215627109>
- 792 Chugani, H. T. (1998). A critical period of brain development: Studies of cerebral glucose utilization with
793 PET. *Preventive Medicine*, 27(2), 184–188. <https://doi.org/10.1006/pmed.1998.0274>
- 794 Cissé, A. H., Lioret, S., Lauzon-Guillain, B. de, Forhan, A., Ong, K. K., Charles, M. A., & Heude, B.
795 (2021). Association between perinatal factors, genetic susceptibility to obesity and age at adiposity
796 rebound in children of the EDEN mother – child cohort. *International Journal of Obesity*, 45(8), 1802–
797 1810. <https://doi.org/10.1038/s41366-021-00847-w>
- 798 Cole, T. (2004). Children grow and horses race: Is the adiposity rebound a critical period for later
799 obesity? *BMC Pediatrics*, 4(1), 6. <https://doi.org/10.1186/1471-2431-4-6>
- 800 Couto Alves, A., De Silva, N. M. G., Karhunen, V., Sovio, U., Das, S., Taal, H. R., Warrington, N. M.,
801 Lewin, A. M., Kaakinen, M., Cousminer, D. L., Thiering, E., Timpson, N. J., Bond, T. A., Lowry, E.,
802 Brown, C. D., Estivill, X., Lindi, V., Bradfield, J. P., Geller, F., ... Early Growth Genetics (EGG)
803 Consortium. (2019). GWAS on longitudinal growth traits reveals different genetic factors influencing
804 infant, child, and adult BMI. *Science Advances*, 5(9), eaaw3095.
805 <https://doi.org/10.1126/sciadv.aaw3095>
- 806 Daneri, M. P., & Blair, C. (2017). Bidirectional relations between executive function and expressive
807 vocabulary in kindergarten and first grade. *Studies in Psychology*, 38(2), 424–450.
808 <https://doi.org/10.1080/02109395.2017.1295577>
- 809 Farah, M. J., Betancourt, L., Shera, D. M., Savage, J. H., Giannetta, J. M., Brodsky, N. L., Malmud, E.
810 K., & Hurt, H. (2008). Environmental stimulation, parental nurturance and cognitive development in
811 humans. *Developmental Science*, 11(5), 793–801. <https://doi.org/10.1111/j.1467-7687.2008.00688.x>
- 812
- 813 Farkas, B.C., Jacquet, P.O. (2023). Early life adversity jointly regulates Body-Mass Index and working
814 memory development. *Proceedings of the Royal Society of London B: Biological Sciences*. In press

- 815 Fattal-Valevski, A., Azouri-Fattal, I., Greenstein, Y. J., Guindy, M., Blau, A., & Zelnik, N. (2009). Delayed
816 language development due to infantile thiamine deficiency. *Developmental Medicine & Child*
817 *Neurology*, 51(8), 629–634. <https://doi.org/10.1111/j.1469-8749.2008.03161.x>
- 818 Fernández-Alvira, J. M., Börnhorst, C., Bammann, K., Gwozdz, W., Krogh, V., Hebestreit, A., Barba,
819 G., Reisch, L., Eiben, G., Iglesia, I., Veidebaum, T., Kourides, Y. A., Kovacs, E., Huybrechts, I.,
820 Pigeot, I., & Moreno, L. A. (2015). Prospective associations between socio-economic status and
821 dietary patterns in European children: The Identification and Prevention of Dietary- and Lifestyle-
822 induced Health Effects in Children and Infants (IDEFICS) Study. *British Journal of Nutrition*, 113(3),
823 517–525. <https://doi.org/10.1017/S0007114514003663>
- 824 Frankenhuys, W. E., Young, E. S., & Ellis, B. J. (2020). The Hidden Talents Approach: Theoretical and
825 Methodological Challenges. *Trends in Cognitive Sciences*, 24(7), 569–581.
826 <https://doi.org/10.1016/j.tics.2020.03.007>
- 827 Franklin, M. (1999). Comparison of weight and height relations in boys from 4 countries. *The American*
828 *Journal of Clinical Nutrition*, 70(1), 157S-162S. <https://doi.org/10.1093/ajcn/70.1.157s>
- 829 Gallagher, D., Visser, M., Sepulveda, D., Pierson, R. N., Harris, T., & Heymsfield, S. B. (1996). How
830 Useful Is Body Mass Index for Comparison of Body Fatness across Age, Sex, and Ethnic Groups?
831 *American Journal of Epidemiology*, 143(3), 228–239.
832 <https://doi.org/10.1093/oxfordjournals.aje.a008733>
- 833 Gentner, M. B., & Leppert, M. L. O. (2019). Environmental influences on health and development:
834 Nutrition, substance exposure, and adverse childhood experiences. *Developmental Medicine and*
835 *Child Neurology*, 61(9), 1008–1014. <https://doi.org/10.1111/dmcn.14149>
- 836 Gervain, J. (2020). Typical Language Development. In *Handbook of Clinical Neurology* (pp. 171–183).
- 837 Gurven, M., Kaplan, H. (2007). Longevity among hunter-gatherers: A cross-cultural examination.
838 *Population and Development Review*, 33(2), 321–365. <https://doi.org/10.1111/j.1728-4457.2007.00171.x>
- 840 Henry, D., Nistor, N., & Baltés, B. (2014). Examining the Relationship between Math Scores and English
841 Language Proficiency. *Journal of Educational Research and Practice*, 4(1), 11–29.
842 <https://doi.org/10.5590/JERAP.2014.04.1.02>
- 843 Heude, B., Forhan, A., Slama, R., Douhaud, L., Bedel, S., Saurel-Cubizolles, M. J., Hankard, R.,
844 Thiebaugeorges, O., De Agostini, M., Annesi-Maesano, I., Kaminski, M., Charles, M. A., & The
845 EDEN Mother-Child Cohort Study Group. (2016). Cohort Profile: The EDEN mother-child cohort on
846 the prenatal and early postnatal determinants of child health and development. *International Journal*
847 *of Epidemiology*, 45(2), 353–363. <https://doi.org/10.1093/ije/dyv151>
- 848 Holliday, M. A. (1986). Body Composition and Energy Needs during Growth. *Postnatal Growth*
849 *Neurobiology*, 101–117. https://doi.org/10.1007/978-1-4899-0522-2_5
- 850 Horlick, M. (2001). Body Mass Index in Childhood—Measuring a Moving Target. *The Journal of Clinical*
851 *Endocrinology & Metabolism*, 86(9), 4059–4060. <https://doi.org/10.1210/jcem.86.9.7948>
- 852 Hu, L.-T., & Bentler, P. M. (1999). Cutoff criteria for fit indexes in covariance structure analysis:
853 Conventional criteria versus new alternatives. *Structural Equation Modeling: A Multidisciplinary*
854 *Journal*, 6(1), 1–55. <https://doi.org/10.1080/10705519909540118>
- 855 Ip, E. H., Marshall, S. A., Saldana, S., Skelton, J. A., Suerken, C. K., Arcury, T. A., & Quandt, S. A.
856 (2017). Determinants of Adiposity Rebound Timing in Children. *The Journal of Pediatrics*, 184, 151-
857 156.e2. <https://doi.org/10.1016/j.jpeds.2017.01.051>
- 858 Kaplan, H. S., Hill, K., Lancaster, J., & Hurtado, A. M. (2000). A theory of human life history evolution:
859 Diet, intelligence, and longevity. *Evolutionary Anthropology: Issues, News, and Reviews*, 9(4), 156–
860 185. [https://doi.org/10.1002/1520-6505\(2000\)9:4<156::AID-EVAN5>3.0.CO;2-7](https://doi.org/10.1002/1520-6505(2000)9:4<156::AID-EVAN5>3.0.CO;2-7)
- 861 Kaplan, H. S., & Robson, A. J. (2002). The emergence of humans: The coevolution of intelligence and
862 longevity with intergenerational transfers. *Proceedings of the National Academy of Sciences*, 99(15),
863 10221–10226. <https://doi.org/10.1073/pnas.152502899>
- 864 Kaplowitz, P. B. (2008). Link Between Body Fat and the Timing of Puberty. *Pediatrics*,
865 121(Supplement_3), S208–S217. <https://doi.org/10.1542/peds.2007-1813F>
- 866 Kern, S., & Gayraud, F. (2010). *Inventaire Français du Développement Communicatif*. (La Cigale).
- 867 Kern, S., Langue, J., Zesiger, P., & Bovet, F. (2010). Adaptations françaises des versions courtes des
868 inventaires du développement communicatif de MacArthur-Bates. *ANAE - Approche*
869 *Neuropsychologique Des Apprentissages Chez l'Enfant*, 22(107–108), 217–228.
- 870 Kidd, E., & Donnelly, S. (2020). Individual Differences in First Language Acquisition. *Annual Review of*
871 *Linguistics*, 6, 319–340. <https://doi.org/10.1146/annurev-linguistics-011619-030326>
- 872 Kline, R. B. (2016). *Principles and practice of structural equation modeling*.
- 873 Korkman, M., Kirk, U., & Kemp, S. (2003). *Nepsy Bilan Neuropsychologique de l'enfant* (ECPA (Edit).

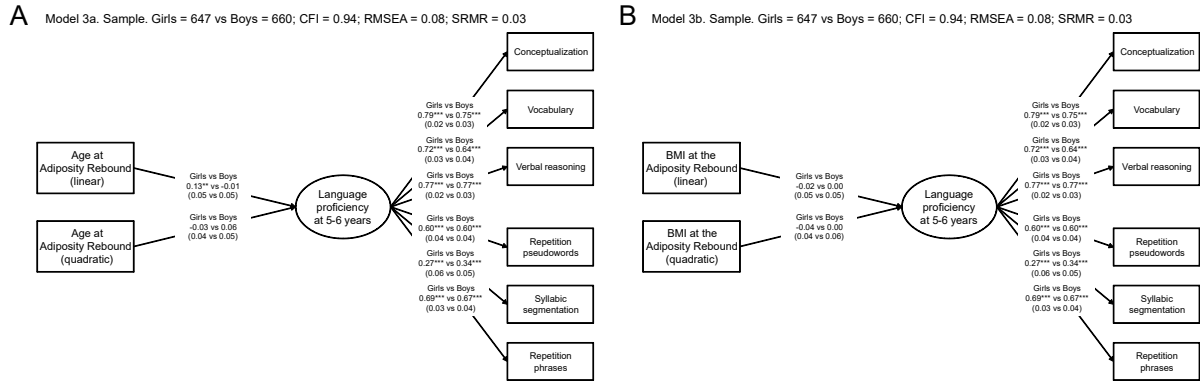
- 874 Kuzawa, C. W. (1998). Adipose Tissue in Human Infancy and Childhood: An Evolutionary Perspective.
875 *Yearbook of Physical Anthropology*, 41, 177–209. [https://doi.org/10.1002/\(sici\)1096-](https://doi.org/10.1002/(sici)1096-8644(1998)107:27+<177::aid-ajpa7>3.0.co;2-b)
876 8644(1998)107:27+<177::aid-ajpa7>3.0.co;2-b
- 877 Kuzawa, C. W., & Blair, C. (2019). A hypothesis linking the energy demand of the brain to obesity risk.
878 *Proceedings of the National Academy of Sciences of the United States of America*, 116(27), 13266–
879 13275. <https://doi.org/10.1073/pnas.1816908116>
- 880 Kuzawa, C. W., Chugani, H. T., Grossman, L. I., Lipovich, L., Muzik, O., Hof, P. R., Wildman, D. E.,
881 Sherwood, C. C., Leonard, W. R., & Lange, N. (2014). Metabolic costs and evolutionary implications
882 of human brain development. *Proceedings of the National Academy of Sciences of the United States*
883 *of America*, 111(36), 13010–13015. <https://doi.org/10.1073/pnas.1323099111>
- 884 Lee, J. (2011). Size matters: Early vocabulary as a predictor of language and literacy competence.
885 *Applied Psycholinguistics*, 32(1), 69–92. <https://doi.org/10.1017/S0142716410000299>
- 886 Leonard, W. R., Robertson, M. L., Snodgrass, J. J., & Kuzawa, C. W. (2003). Metabolic correlates of
887 hominid brain evolution. *Comparative Biochemistry and Physiology Part A: Molecular & Integrative*
888 *Physiology*, 136(1), 5–15. [https://doi.org/10.1016/S1095-6433\(03\)00132-6](https://doi.org/10.1016/S1095-6433(03)00132-6)
- 889 Lindsay, K. L., Buss, C., Wadhwa, P., & Entringer, S. (2019). The Interplay Between Nutrition and Stress
890 in Pregnancy: Implications for Fetal Programming of Brain Development. *Biological Psychiatry*,
891 85(2), 139–149. <https://doi.org/10.1016/j.biopsych.2018.06.021>
- 892 Little, R. J. A. (1988). A Test of Missing Completely at Random for Multivariate Data with Missing
893 Values. *Journal of the American Statistical Association*, 83(404), 1198–1202.
894 <https://doi.org/10.1080/01621459.1988.10478722>
- 895 Longman, D., Stock, J. T., & Wells, J. C. K. (2017). A trade-off between cognitive and physical
896 performance, with relative preservation of brain function. *Scientific Reports*, 7(1), 1–6.
897 <https://doi.org/10.1038/s41598-017-14186-2>
- 898 MacKinnon, D. P., Lockwood, C. M., & Williams, J. (2004). Confidence Limits for the Indirect Effect:
899 Distribution of the Product and Resampling Methods. *Multivariate Behavioral Research*, 39(1), 99–
900 128. https://doi.org/10.1207/s15327906mbr3901_4
- 901 Madsen, P. L., Hasselbalch, S. G., Hagemann, L. P., Olsen, K. S., Bülow, J., Holm, S., Wildschjødtz,
902 G., Paulson, O. B., & Lassen, N. A. (1995). Persistent Resetting of the Cerebral Oxygen/Glucose
903 Uptake Ratio by Brain Activation: Evidence Obtained with the Kety—Schmidt Technique. *Journal of*
904 *Cerebral Blood Flow & Metabolism*, 15(3), 485–491. <https://doi.org/10.1038/jcbfm.1995.60>
- 905 Madsen, P. L., & Vorstrup, S. (1991). Cerebral blood flow and metabolism during sleep.
906 *Cerebrovascular and Brain Metabolism Reviews*, 281–296.
- 907 Mergenthaler, P., Lindauer, U., Dienel, G. A., & Meisel, A. (2013). Sugar for the brain: The role of
908 glucose in physiological and pathological brain function. *Trends in Neurosciences*, 36(10), 587–597.
909 <https://doi.org/10.1016/j.tins.2013.07.001>
- 910 Meyre, D., Lecoq, C., Delplanque, J., Francke, S., Vatin, V., Durand, E., Weill, J., Dina, C., & Froguel,
911 P. (2004). A Genome-Wide Scan for Childhood Obesity-Associated Traits in French Families Shows
912 Significant Linkage on Chromosome 6q22.31-q23.2. *Diabetes*, 53(3), 803–811.
913 <https://doi.org/10.2337/diabetes.53.3.803>
- 914 Miller, A. B., Sheridan, M. A., Hanson, J. L., McLaughlin, K. A., Bates, J. E., Lansford, J. E., Pettit, G.
915 S., & Dodge, K. A. (2018). Dimensions of deprivation and threat, psychopathology, and potential
916 mediators: A multi-year longitudinal analysis. *Journal of Abnormal Psychology*, 127(2), 160–170.
917 <https://doi.org/10.1037/abn0000331>
- 918 Moschos, S., Chan, J. L., & Mantzoros, C. S. (2002). Leptin and reproduction: A review. *Fertility and*
919 *Sterility*, 77(3), 433–444. [https://doi.org/10.1016/S0015-0282\(01\)03010-2](https://doi.org/10.1016/S0015-0282(01)03010-2)
- 920 Muthén, B., Kaplan, D., & Hollis, M. (1987). On structural equation modeling with data that are not
921 missing completely at random. *Psychometrika*, 52(3), 431–462. <https://doi.org/10.1007/BF02294365>
- 922 Navarrete, A., Schaik, C. P. V., & Isler, K. (2011). Energetics and the evolution of human brain size.
923 *Nature*, 480(7375), 91–93. <https://doi.org/10.1038/nature10629>
- 924 Nilsson, A., Mardinoglu, A., & Nielsen, J. (2017). Predicting growth of the healthy infant using a genome
925 scale metabolic model. *Npj Systems Biology and Applications*, 3(1), 1–8.
926 <https://doi.org/10.1038/s41540-017-0004-5>
- 927 O’Keeffe, L. M., Frysz, M., Bell, J. A., Howe, L. D., & Fraser, A. (2020). Puberty timing and adiposity
928 change across childhood and adolescence: Disentangling cause and consequence. *Human*
929 *Reproduction*, 35(12), 2784–2792. <https://doi.org/10.1093/humrep/deaa213>
- 930 Pace, A., Alper, R., Burchinal, M. R., Golinkoff, R. M., & Hirsh-Pasek, K. (2018). Measuring success:
931 Within and cross-domain predictors of academic and social trajectories in elementary school. *Early*
932 *Childhood Research Quarterly*, 46, 112–125. <https://doi.org/10.1016/j.ecresq.2018.04.001>

- 933 Peyre, H., Bernard, J. Y., Forhan, A., Charles, M. A., Agostini, M. D., Heude, B., Ramus, F., & Group,
934 T. E. M.-C. C. S. (2014). Predicting changes in language skills between 2 and 3 years in the EDEN
935 mother-child cohort. *PeerJ*, 2, e335. <https://doi.org/10.7717/peerj.335>
- 936 Peyre, H., Galera, C., van der Waerden, J., Hoertel, N., Bernard, J. Y., Melchior, M., & Ramus, F.
937 (2016). Relationship between early language skills and the development of inattention/hyperactivity
938 symptoms during the preschool period: Results of the EDEN mother-child cohort. *BMC Psychiatry*,
939 16(1), 1–11. <https://doi.org/10.1186/s12888-016-1091-3>
- 940 Preacher, K. J., & Hayes, A. F. (2008). Asymptotic and resampling strategies for assessing and
941 comparing indirect effects in multiple mediator models. *Behavior Research Methods*, 40(3), 879–
942 891. <https://doi.org/10.3758/BRM.40.3.879>
- 943 Rolland-Cachera, M.-F., Deheeger, M., Bellisle, F., Sempé, M., Guillaud-Bataille, M., & Patois, E.
944 (1984). Adiposity rebound in children: A simple indicator for predicting obesity. *American Journal of*
945 *Clinical Nutrition*, 39(1), 129–135. <https://doi.org/10.1093/ajcn/39.1.129>
- 946 Rollins, B.Y., Riggs, N.R., Francis, L.A., Blair, C.B. (2021). Executive function and BMI trajectories
947 among rural, poor youth at high risk for obesity. *Obesity*, 29(2), 379–387. doi:10.1002/oby.23064
- 948 Romeo, R. R., Flournoy, J. C., McLaughlin, K. A., & Lengua, L. J. (2022). Language development as a
949 mechanism linking socioeconomic status to executive functioning development in preschool.
950 *Developmental Science*, 25(5), e13227. <https://doi.org/10.1111/desc.13227>
- 951 Rosenbaum, M., & Leibel, R. L. (1999). Role of Gonadal Steroids in the Sexual Dimorphisms in Body
952 Composition and Circulating Concentrations of Leptin. *The Journal of Clinical Endocrinology &*
953 *Metabolism*, 84(6). [https://doi.org/0021-972X/99/\\$03.00/0](https://doi.org/0021-972X/99/$03.00/0)
- 954 Rosseel, Y. (2012). Lavaan: An R package for Structural Equation Modeling. *Journal of Statistical*
955 *Software*, 48(2), 1–36.
- 956 Rowe, M. L., Raudenbush, S. W., & Goldin-Meadow, S. (2012). The Pace of Vocabulary Growth Helps
957 Predict Later Vocabulary Skill. *Child Development*, 83(2), 508–525. <https://doi.org/10.1111/j.1467-8624.2011.01710.x>
- 958
- 959 Roy, S.M., Spivack, J.G., Faith, M.S., Chesi, A., Mitchell, J.A., Kelly, A., Grant, S.F.A., McCormack,
960 S.E., Zemel, B.S. (2016). Infant BMI or weight-for-length and obesity risk in early childhood.
961 *Pediatrics*, 137(5), e20153492. <https://doi.org/10.1542/peds.2015-3492>
- 962 Said-Mohamed, R., Pettifor, J. M., & Norris, S. A. (2018). Life History theory hypotheses on child growth:
963 Potential implications for short and long-term child growth, development and health. *American*
964 *Journal of Physical Anthropology*, 165(1), 4–19. <https://doi.org/10.1002/ajpa.23340>
- 965 Saldanha-Gomes, C., Hallimat Cissé, A., Descarpentrie, A., de Lauzon-Guillain, B., Forhan, A.,
966 Charles, M.-A., Heude, B., Lioret, S., & Dargent-Molina, P. (2022). Prospective associations
967 between dietary patterns, screen and outdoor play times at 2 years and age at adiposity rebound:
968 The EDEN mother-child cohort. *Preventive Medicine Reports*, 25, 101666.
969 <https://doi.org/10.1016/j.pmedr.2021.101666>
- 970 Silverwood, R. J., De Stavola, B. L., Cole, T. J., & Leon, D. A. (2009). BMI peak in infancy as a predictor
971 for later BMI in the Uppsala Family Study. *International Journal of Obesity*, 33(8), 929–937.
972 <https://doi.org/10.1038/ijo.2009.108>
- 973 Slot, P. L., & von Suchodoletz, A. (2018). Bidirectionality in preschool children's executive functions and
974 language skills: Is one developing skill the better predictor of the other? *Early Childhood Research*
975 *Quarterly*, 42, 205–214. <https://doi.org/10.1016/j.ecresq.2017.10.005>
- 976 Stoltzfus, R. J., Kvalsvig, J. D., Chwaya, H. M., Montresor, A., Albonico, M., Tielsch, J. M., Savioli, L.,
977 & Pollitt, E. (2001). Effects of iron supplementation and anthelmintic treatment on motor and
978 language development of preschool children in Zanzibar: Double blind, placebo controlled study.
979 *BMJ*, 323(7326), 1389–1389. <https://doi.org/10.1136/bmj.323.7326.1389>
- 980 Tooley, U. A., Bassett, D. S., & Mackey, A. P. (2021). Environmental influences on the pace of brain
981 development. *Nature Reviews Neuroscience*, 22(6), 372–384. <https://doi.org/10.1038/s41583-021-00457-5>
- 982
- 983 Urlacher, S. S., Snodgrass, J. J., Dugas, L. R., Sugiyama, L. S., Liebert, M. A., Joyce, C. J., & Pontzer,
984 H. (2019). Constraint and trade-offs regulate energy expenditure during childhood. *Science*
985 *Advances*, 5(12), 1–9. <https://doi.org/10.1126/sciadv.aax1065>
- 986 Van Eyck, A., Eerens, S., Trouet, D., Lauwers, E., Wouters, K., De Winter, B. Y., van der Lee, J. H.,
987 Van Hoeck, K., & Ledeganck, K. J. (2021). Body composition monitoring in children and adolescents:
988 Reproducibility and reference values. *European Journal of Pediatrics*, 180(6), 1721–1732.
989 <https://doi.org/10.1007/s00431-021-03936-0>
- 990 Wechsler, D. (1967). *Wechsler Preschool and Primary Scale of Intelligence*. 3rd ed. (The Psycho).
- 991 Wen, X., Kleinman, K., Gillman, M. W., Rifas-Shiman, S. L., & Taveras, E. M. (2012). Childhood body
992 mass index trajectories: Modeling, characterizing, pairwise correlations and socio-demographic

993 predictors of trajectory characteristics. *BMC Medical Research Methodology*, 12.
994 <https://doi.org/10.1186/1471-2288-12-38>
995 Williams, S. M., & Goulding, A. (2009). Patterns of Growth Associated With the Timing of Adiposity
996 Rebound. *Obesity*, 17(2), 335–341. <https://doi.org/10.1038/oby.2008.547>
997 Yang, Y., Shields, G. S., Guo, C., & Liu, Y. (2018). Executive function performance in obesity and
998 overweight individuals: A meta-analysis and review. *Neuroscience & Biobehavioral Reviews*, 84,
999 225–244. <https://doi.org/10.1016/j.neubiorev.2017.11.020>

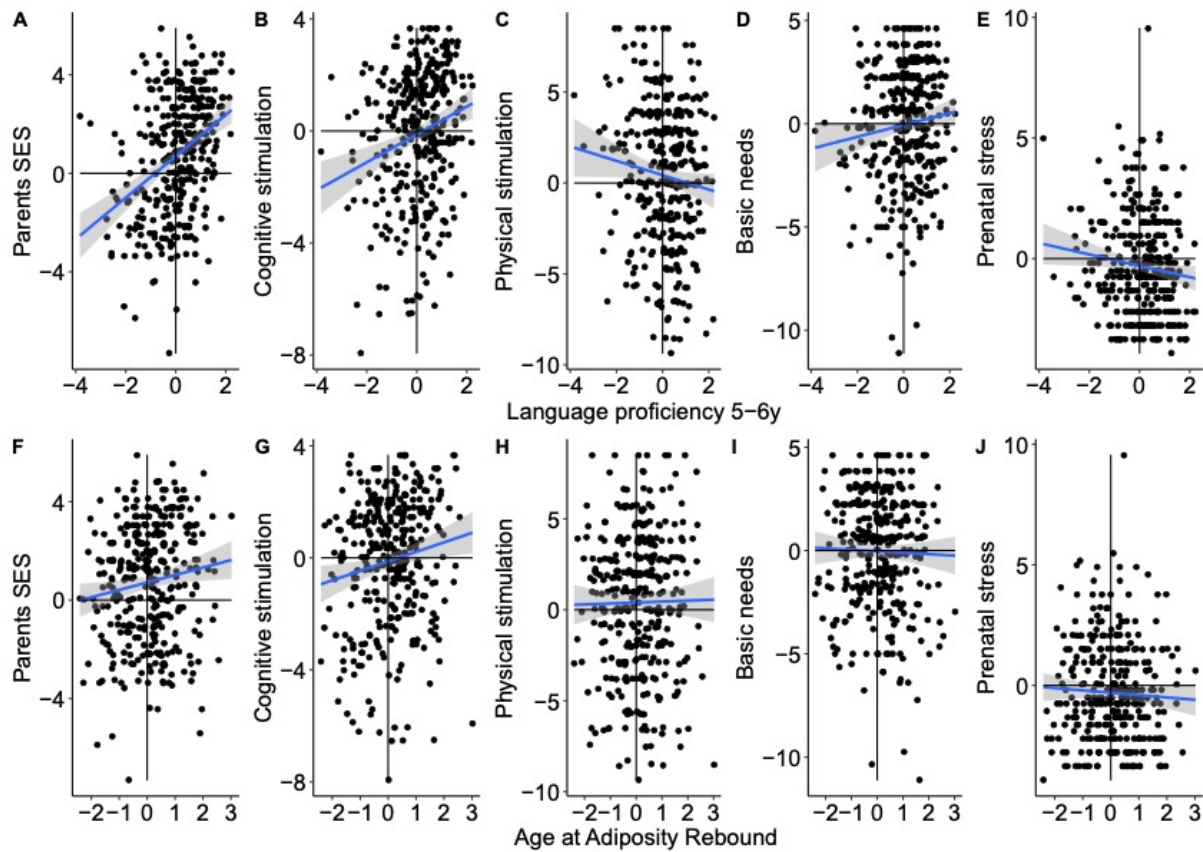
1000

Figure legends



1001

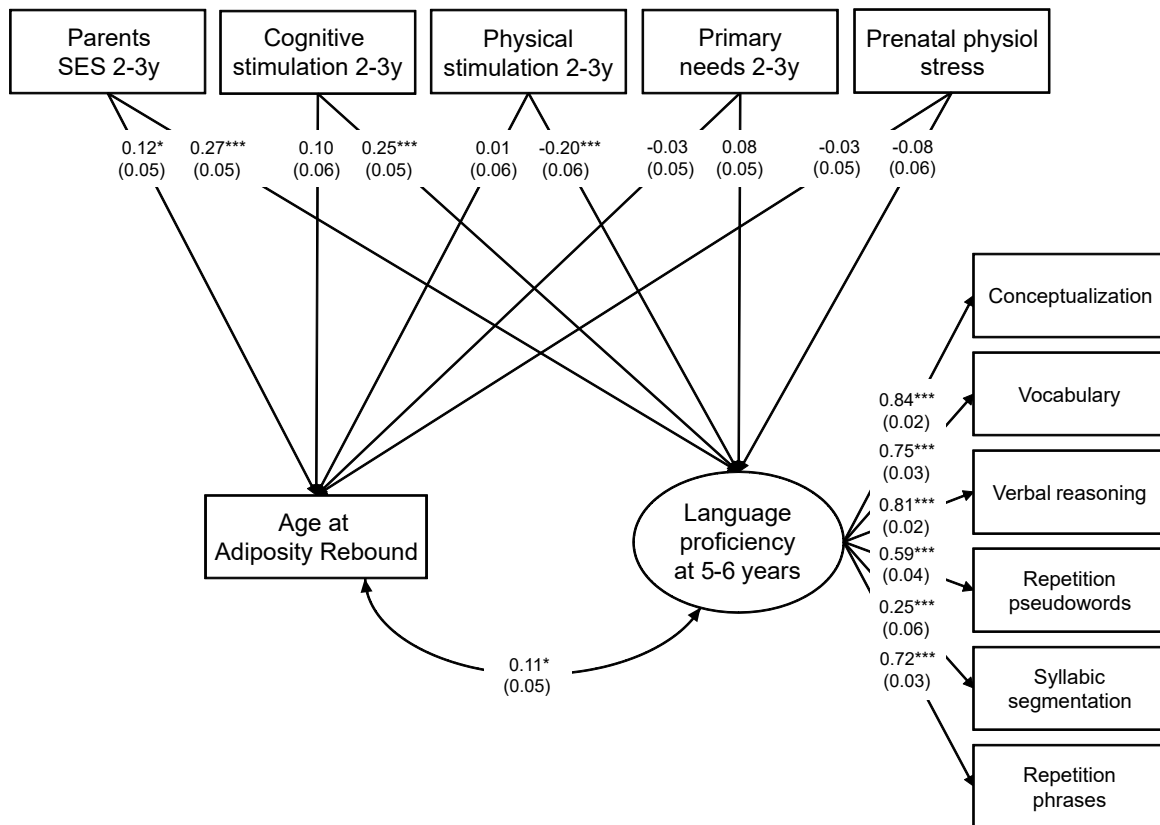
1002 **Figure 1.** Association between age at adiposity rebound and language skills at age 5-
 1003 6, estimated by the structural equation model 3a (A) and model 3b (B). Standardized
 1004 parameter values (and standard deviation reported in brackets) for the girls' sample
 1005 and the boys' sample are shown for each path. The ellipse represents the latent
 1006 variable; the rectangles represent the indicators. The paths between the indicators
 1007 and the latent variables represent factor loadings. Paths between the single composite
 1008 and the latent variable represent regressions. Significant paths are represented with
 1009 *, such that * indicates $p < .05$, ** indicates $p < .01$, *** indicates $p < .001$. We observed
 1010 that girls who reach the nadir of their body growth at a later age are more likely than
 1011 others to express better language proficiency at 5-6 years than those who reach it
 1012 earlier.



1014

1015 **Figure 2.** Scatterplots of environmental factors (column) according to language
 1016 proficiency score (top row) or age at adiposity rebound (bottom row) in girls. Five
 1017 environmental factors are used in this analysis: cognitive stimulation, physical
 1018 stimulation, basic needs, prenatal stress and perinatal SES. To ensure comparability
 1019 of the indicators, all scores were transformed into z-scores. We found that the amount
 1020 of cognitive and physical stimulation provided by parents, as well as their socio-
 1021 economic status, were positively related to language proficiency at age 5-6. In
 1022 contrast, neither the parents' contribution to meeting the child's basic physiological
 1023 needs nor the extent of prenatal and perinatal physiological stress were related to
 1024 language proficiency scores. We observed that among the 5 early life environmental
 1025 factors, only the parental socio-economic status is related to the age of the child at the
 1026 time of adiposity rebound, so that the highest the SES, the more the adiposity rebound
 1027 is delayed.

Unregistered model. Girl sample. N = 442; CFI = 0.95; RMSEA = 0.06; SRMR = 0.03



1028

1029

1030

1031

1032

1033

1034

1035

1036

1037

1038

1039

1040

Figure 3. Results of the unregistered model, estimating whether environmental factors are associated with the relationship between age at adiposity rebound and language proficiency at age 5-6, in girls. Standardized parameter values (and standard deviation in brackets) for the sample of girls are shown for each path. The ellipse represents the latent variable; the rectangles represent the indicators. The paths between the indicators and the latent variables represent factor loadings. Paths between the single composite and the latent variable represent regressions. Significant paths are represented by *, such that * indicates $p < .05$, ** indicates $p < .01$, *** indicates $p < .001$. Among the 5 early life environmental factors, we found a significant positive association between parents' socio-economic status and both the age at adiposity rebound and language skills, and between cognitive stimulation at 2-3 years and language skills at 5-6 years.