# Daily Energy Expenditure through the Human Life Course

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# see supplementary materials

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**Abstract:** Total daily energy expenditure ("total expenditure", MJ/d) reflects daily energy needs and is a critical variable in human health and physiology, yet it is unclear how daily expenditure changes over the life course. Here, we analyze a large, globally diverse database of total expenditure measured by the doubly labeled water method for males and females aged 8 days to 95 yr. We show that total expenditure is strongly related to fat free mass in a power-law manner and identify four distinct metabolic life stages. Fat free mass-adjusted daily expenditure accelerates rapidly in neonates (0-1yr) to ~46% above adult values at ~1 yr, declines slowly throughout childhood and adolescence (1-20 yr) to adult levels at ~20 yr, remains stable in adulthood (20-60 yr) even during pregnancy, and declines in older adults (60+ yr). These changes in total expenditure shed new light on human development and aging and should help shape nutrition and health strategies across the lifespan.

**One Sentence Summary:** Expenditure varies as we age, with four distinct metabolic life stages reflecting changes in behavior, anatomy, and tissue metabolism.

**Main Text:** All of life's essential tasks, from development and reproduction to maintenance and movement, require energy. Total expenditure is thus fundamental to understanding both daily nutritional requirements and the body's investment among activities. Yet we know surprisingly little about the determinants of total expenditure in humans or how it changes over the lifespan. Most large (n>1,000) analyses of human energy expenditure have been limited to basal expenditure, the metabolic rate at rest (*1*), which accounts for only a portion (usually ~50-70%) of total expenditure, or have estimated total expenditure from basal expenditure and daily physical activity (*2-5*). Measurements of total expenditure in humans during daily life, outside of

142     the laboratory, became possible in the 1980's with the advancement of the doubly labeled water

143     method , but doubly labeled water studies to date have been limited in sample size (n < 600),

144     geographic and socioeconomic representation, and/or age (*6-9*).

145         Body composition, size, and physical activity change over the life course, often in

146     concert, making it difficult to parse the determinants of energy expenditure. Total expenditure

147     increases with age as children grow (*10*), but the relative effects of increasing physical activity

148     (*11-13*) and age-related changes in tissue-specific metabolic rates, as have been reported for the

149     brain (*14*), are unclear. Total and basal expenditure increase from childhood through puberty, but

150     much of this increase is attributable to increased fat free mass, and the role of endocrine or other

151     effects is uncertain (*15*). The decline in total expenditure beginning in the sixth decade of life

152     corresponds with a decline in fat free mass (*9*) and "physical activity level", PAL (the ratio of

153     total/basal expenditure), but may also reflect age-related reductions in organ metabolism.

154         We investigated the effects of age, body composition, and sex on total expenditure and its

155     components, using a large (n = 6,421; 64% female), geographically and economical diverse (n =

156     29 countries) database of doubly labeled water measurements for subjects aged eight days to 95

157     years  (*16*), calculating total expenditure from isotopic measurements using a single, validated

158     equation for all subjects (*17*). Basal expenditure, measured *via* indirect calorimetry, was

159     available for a n = 2,008 subjects, and we augmented the dataset with additional published

160     meaures of basal expenditure in neonates and doubly labeled water-mesaured total expenditure in

161     pregnant and post-partum women (Methods; Table S1).

162         We found that both total and basal expenditure increased with fat free mass in a power-

163     law manner (TEE= $0.677FFM^{0.708}$, $r^2$=0.83 Figures 1, S1, S2, Table S1). Thus, body size,

164     particularly fat free mass, accounted for most (83%) of the variation in daily expenditure,

165     requiring us to adjust for body size in subsequent analyses of expenditure across subjects and

166     cohorts to isolate potential effects of age, sex, and other factors. Notably, analyses indicated an

167     exponent <1, meaning that the ratio of energy expenditure/mass does not adequately control for

168     body size because the ratio inherently trends lower for larger individuals (Figure S1 (*18*)).

169     Instead, we used regression analysis to control for body size (*18*). A general linear model with

170     *ln*-transformed values of energy expenditure (total or basal), fat free mass, and fat mass in adults

171     20 – 60 y (Table S2) was used to calculate residual energy expenditures for each subject. We

172     converted these residuals to "adjusted" expenditures for clarity in discussing age-related

173     changes: 100% indicates an expenditure that matches the expected value given the subject's fat

174     free mass and fat mass, 120% indicates an expenditure 20% above expected, *etc*. (Methods).

175     Using this approach, we also calculated the portion of adjusted total expenditure attributed to

176     basal expenditure (Figure 2D; Methods). Segmented regression analysis of (Methods) revealed

177     four distinct phases of adjusted (or residual) total and basal expenditure over the lifespan.

178     *Neonates (0 to 1 y)*: Neonates in the first month of life had size-adjusted energy expenditures

179     similar to adults, with adjusted total expenditure of 99.0 ± 17.2% (n = 35) and adjusted basal

180     expenditure of 78.1 ± 15.0% (n = 34; Figure 2). Both measures increased rapidly in the first year.

181     In segmented regression analysis, adjusted total expenditure rose 84.7 ± 7.2% per year from birth

182     to a break point at 0.7 years (95% CI: 0.6, 0.8); a similar rise (75.5 ± 5.6%) and break point (1.0

183     y, 95% CI: 0.9, 1.1) were evident in adjusted basal expenditure (Table S4). For subjects between

184     9 and 15 months, adjusted total and basal expenditures were nearly ~50% elevated compared to

185     adults (Figure 2).

186     *Juveniles (1 to 20 y)*: Total and basal expenditure, along with fat free mass, continued to increase

187     with age throughout childhood and adolescence (Figure 1), but body size-adjusted expenditures

188    steadily declined. Adjusted total expenditure declined at a rate of -2.8 ± 0.1% per year from

189    147.8 ± 22.6% for subjects 1 – 2 y (n = 102) to 102.7 ± 18.1% for subjects 20 – 25 y (n = 314;

190    Tables S2, S4). Segmented regression analysis identified a breakpoint in adjusted total

191    expenditure at 20.5 y (95% CI: 19.8, 21.2), after which it plateaued at adult levels (Figure 2). A

192    similar decline (-3.8 ± 0.2% per year) and break point (18.0 y, 95% CI: 16.8, 19.2) were evident

193    in adjusted basal expenditure (Figure 2, Text S1, Table S4). No pubertal increases in adjusted

194    total or basal expenditure were evident among subjects 10 – 15 y. In multivariate regression for

195    subjects 1 to 20 y, males had a higher total expenditure and adjusted total expenditure (Tables

196    S2, S3), but sex had no detectable effect on the rate of decline in adjusted total expenditure with

197    age (sex:age interaction p=0.30).

198    *Adults (20 to 60 y)*: Total and basal expenditure and fat free mass were all stable from age 20 to

199    60 (Figure 1, 2; Tables S1, S2; Text S1). Sex had no effect on total expenditure in multivariate

200    models with fat free mass and fat mass, nor in analyses of adjusted total expenditure (Tables S2,

201    S4). Adjusted total and basal expenditures were stable even during pregnancy, the elevation in

202    unadjusted expenditures matching those expected from the gain in mothers' fat free mass and fat

203    mass (Figure 2C). Segmented regression analysis identified a break point at 63.0 y (95% CI:

204    60.1, 65.9), after which adjusted TEE begins to decline. This break point was somewhat earlier

205    for adjusted basal expenditure (46.5, 95% CI: 40.6, 52.4), but the relatively small number of

206    basal measures for 45 – 65 y (Figure 2D) reduces our precision in determining this break point.

207    *Older adults (>60 y)*: At ~60 y, total and basal expenditure begin to decline, along with fat free

208    mass and fat mass (Figures 1, S3, Table S1). Declines in expenditure are not only a function of

209    reduced fat free mass and fat mass, however. Adjusted total expenditure declined by -0.7 ± 0.1%

210   per year, and adjusted basal expendiure fell at a similar rates (Figure 2, Figure S3, Text S1, Table

211   S4). For subjects in their nineties, adjusted TEE was ~26% below that of middle-aged adults.

212      In addition to providing empirical measures and predictive equations for total expenditure

213   from infancy to old age (Tables S1, S2), our analyses bring to light major changes in metabolic

214   rate across the life course. To begin, we can infer fetal metabolic rates from maternal measures

215   during pregnancy: if body size-adjusted expenditures were elevated in the fetus, then adjusted

216   expenditures for pregnant mothers, particularly late in pregnancy when the fetus accounts for a

217   substantial portion of a mother's weight, would be likewise elevated. Instead, the stability of

218   adjusted total and basal expenditures at ~100% during pregnancy (Figure 2B) indicates that the

219   growing fetus maintains a fat free mass- and fat mass-adjusted metabolic rate similar to adults,

220   which is consistent with adjusted expenditures of neonates (both ~100%; Figure 2) in the first

221   weeks after birth. Total and basal expenditures, both absolute and size-adjusted values, then

222   accelerate rapidly over the first year. This early period of metabolic acceleration corresponds to a

223   critical period in early development in which growth often falters in nutritionally-stressed

224   populations (19). Increasing energy demands could be a contributing factor.

225      After rapid acceleration in total and basal expenditure during the first year, adjusted

226   expenditures progressively decline thereafter, reaching adult levels at ~20 yr. Elevated adjusted

227   expenditures in this life stage may reflect the metabolic demands of growth and development.

228   Adult expenditures, adjusted for body size and composition, are remarkably stable, even during

229   pregnancy and post-partum. Declining metabolic rates in older adults could increase the risk of

230   weight gain. However, neither fat mass nor percentage increased in this period (Figure S3),

231   consistent with the hypothesis that energy intake is coupled to expenditure (20).

232     Following previous studies (*21-25*), we calculated the effect of organ size on basal

233     expenditure over the lifespan (Methods). At rest, the tissue-specific metabolic rates (Watts/gram)

234     of the heart, liver, brain, and kidneys are much greater than those of the muscles and other lean

235     tissue or fat (*21-25*). Organs with a high tissue-specific metabolic rate, particularly the brain and

236     liver, account for a greater proportion of fat free mass in young individuals, and thus organ-based

237     basal expenditure, estimated from organ size and tissue-specific metabolic rate, follows a power-

238     law relationship with fat free mass, roughly consistent with observed basal expenditures

239     (Methods, Figure S6). Still, observed basal expenditure exceeded organ-based estimates by

240     ~30% in early life (1 – 20 y) and was ~20% lower than organ-based estimates in subjects over 60

241     y (Figure S6), consistent with previous work indicating that tissue-specific metabolic rates are

242     elevated in children and adolescents (*22, 24*) and reduced in older adults (*21, 23, 25*).

243     We investigated the contributions of daily physical activity and changes in tissue-specific

244     metabolic rate to total and basal expenditure using a simple model with two components: activity

245     and basal expenditure (Figure 3; Meethods). Activity expenditure was modeled as a function of

246     physical activity and body mass, assuming activity costs are proportional to weight, and could

247     either remain constant at adult levels over the lifespan or follow the trajectory of daily physical

248     activity measured *via* accelerometry, peaking at 5 – 10 y and declining thereafter (*11, 26, 27*)

249     (Figure 3). Similarly, basal expenditure was modeled as a power function of fat free mass

250     (consistent with organ-based BEE estimates; Methods) multiplied by a "tissue specific

251     metabolism" term, which could either remain constant at adult levels across the lifespan or

252     follow the trajectory observed in adjusted basal expenditure (Figure 2). For each scenario, total

253     expenditure was modeled as the sum of activity and basal expenditure (Methods).

254    Models that hold physical activity or tissue-specific metabolic rates constant over the

255    lifespan do not reproduce the observed patterns of age-related change in absolute or adjusted

256    measures of total or basal expenditure (Figure 3). Only when age-related changes in physical

257    activity and tissue-specific metabolism are included does model output match observed

258    expenditures, indicating that variation in both physical activity and tissue-specific metabolism

259    contribute to total expenditure and its components across the lifespan. Elevated tissue-specific

260    metabolism in early life may be related to growth or development (*22, 24*). Conversely, reduced

261    expenditures in later life may reflect a decline in organ level metabolism (*23, 25, 28*).

262    Metabolic models of life history commonly assume continuity in tissue-specific

263    metabolism over the life course, with cellular metabolic rates increasing in a power-law manner

264    (Energy = $a$Mass$^b$) and the energy available for growth during the juvenile period made available

265    for reproduction in adults (*29, 30*). Measures of humans here challenge this view, with size

266    adjusted metabolism elevated ~50% in childhood compared to adults (including pregnant

267    females), and ~25% lower in the oldest subjects. It remains to be determined whether these

268    fluctuations occur in other species. In addition to affecting energy balance, nutritional needs, and

269    body weight, these metabolic changes present a potential target for clinical investigation into the

270    kinetics of disease, pharmaceutical activity, and healing, processes intimately related to

271    metabolic rate. Further, there is considerable metabolic variation among individuals, with TEE

272    and its components varying more than ± 20% even when controlling for fat free mass, fat mass,

273    sex, and age (Figure 1, 2, Table S2). Elucidating the processes underlying metabolic changes

274    across the life course and variation among individuals may help reveal the roles of metabolic

275    variation in health and disease.

**Conflict of interest**

The authors have no conflicts of interest to declare.

**Data Availability**

All data used in these analyses is freely available via the IAEA Doubly Labelled Water Database

(https://doubly-labelled-water-database.iaea.org/home or https://www.dlwdatabase.org/).

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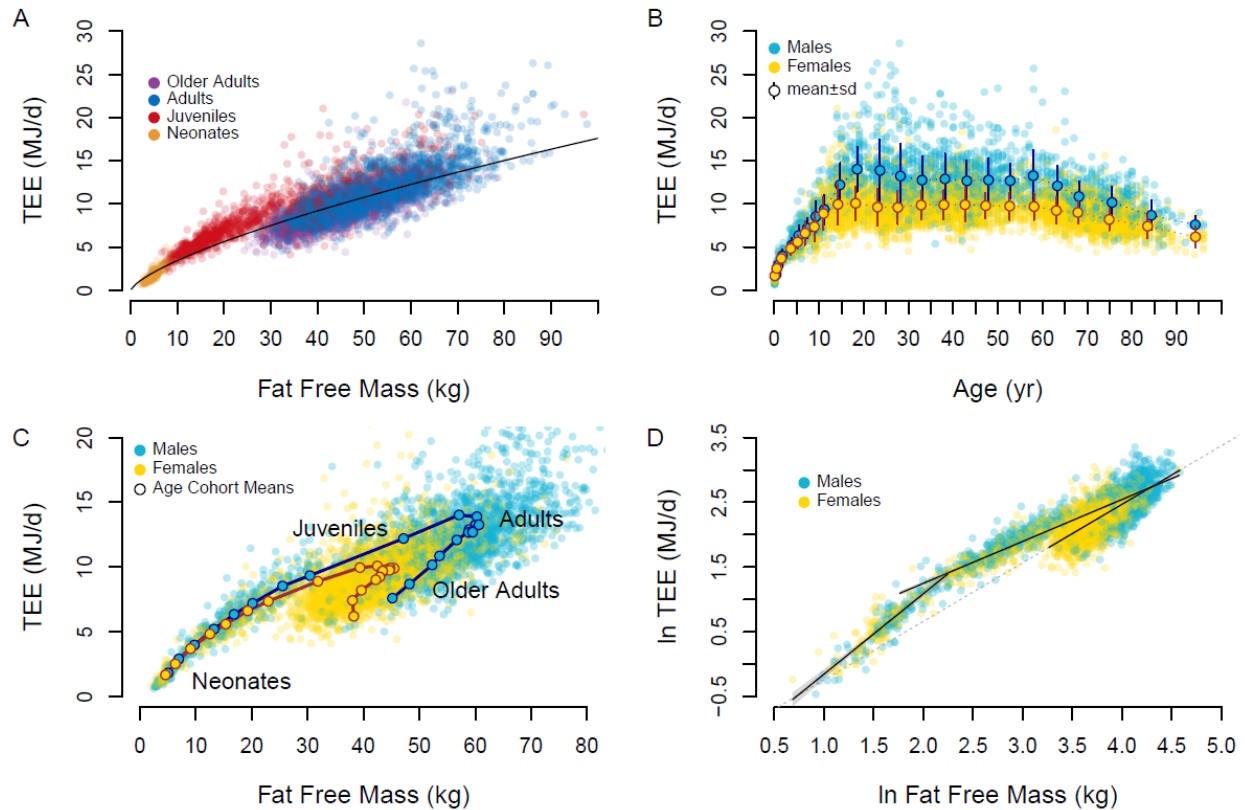
Figure 1. **A.** Total expenditure (TEE) increases with fat free mass in a power-law manner, but age groups cluster about the trend line differently. **B.** Total expenditure rises in childhood, is stable through adulthood, and declines in older adults. Means±sd for age-sex cohorts are shown. **C.** Age-sex cohort means show a distinct progression of total expenditure and fat free mass over the life course. **D.** Neonate, juveniles, and adults exhibit distinct relationships between fat free mass and expenditure. The dashed line, extrapolated from the regression for adults, approximates the regression used to calculate adjusted total expenditure.
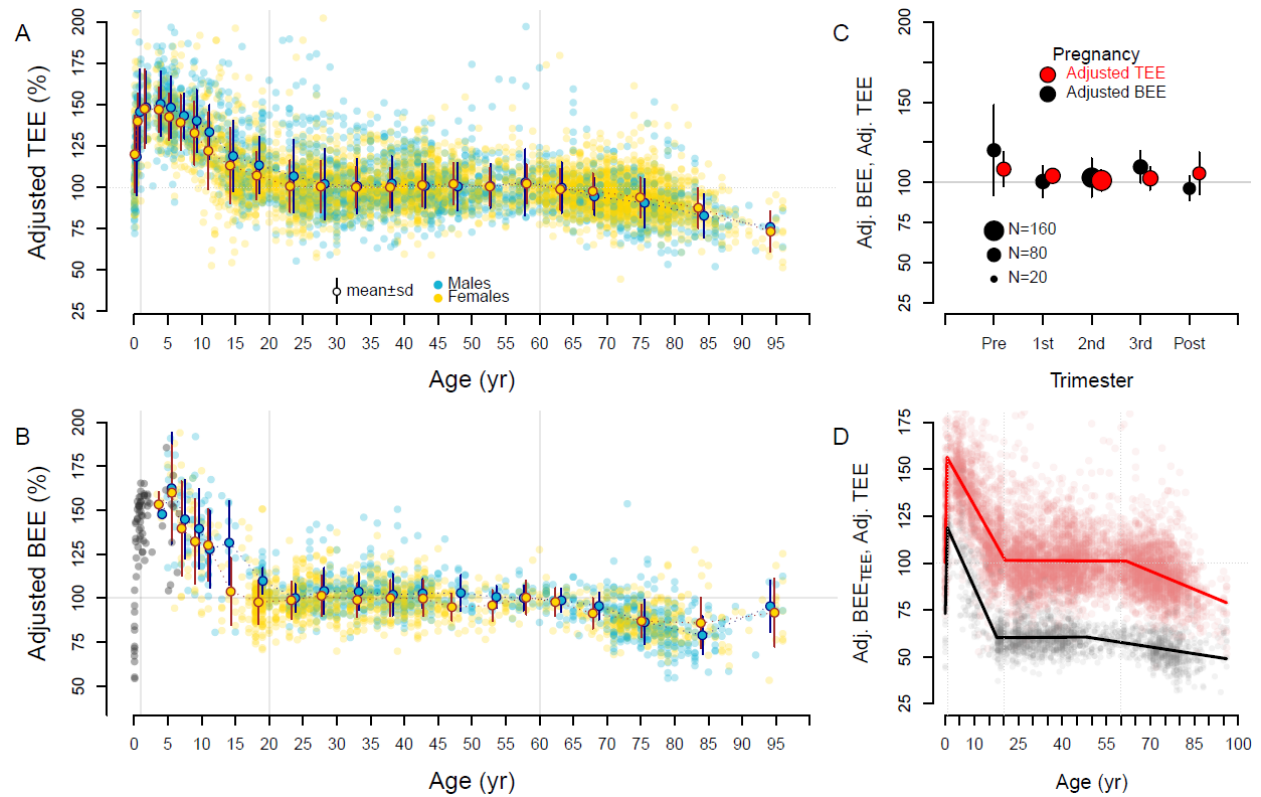
**Figure 2.** Fat free mass- and fat mass-adjusted expenditures over the life course. Individual subjects and age-sex cohort mean ± SD are shown. For both total (Adj. TEE) (**A**) and basal (Adj. BEE) expenditure (**B**), adjusted expenditures begin near adult levels (~100%) but quickly climb to ~150% in the first year. Adjusted expenditures decline to adult levels ~20y, then decline again in older adults. Basal expenditures for infants and children not in the doubly labeled water database are shown in gray. **C.** Pregnant mothers exhibit adjusted total and basal expenditures similar to non-reproducing adults (Pre: prior to pregnancy; Post: 27 weeks post-partum). **D**. Segmented regression analysis of adjusted total (red) and adjusted basal expenditure (calculated as a portion of total; Adj. BEE$_{TEE}$; black) indicates a peak at ~1 y, adult levels at ~20 y, and decline at ~60 y (see text).

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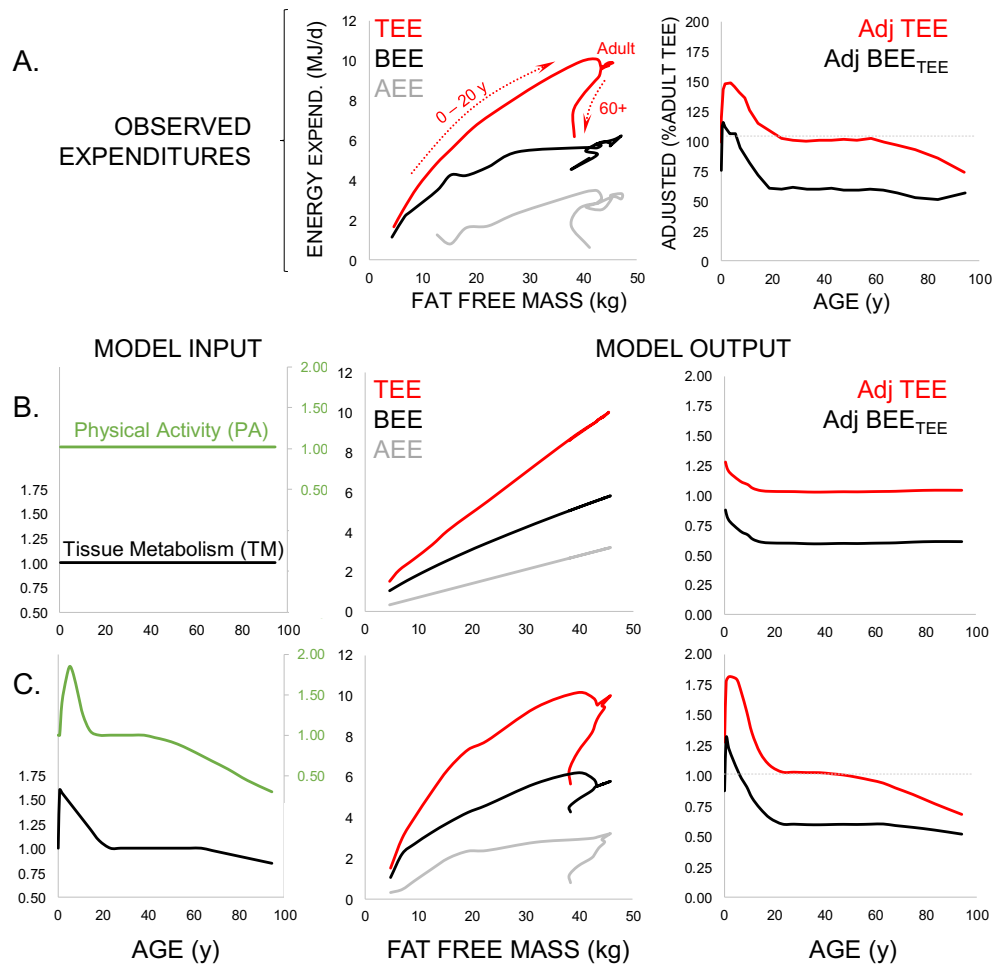
**Figure 3.** Modeling the contribution of physical activity and tissue-specific metabolism to daily expenditures.

**A.** Observed total (TEE, red), basal (BEE, black), and activity (AEE, gray) expenditures (Table S1) show age-related variation with respect to fat free mass (see Figure 1C) that is also evident in adjusted values (Table S3; see Figure 2D). **B.** These age effects do not emerge in models assuming constant physical activity (PA, green) and tissue-specific metabolic rate (TM, black) across the life course. **C.** When physical activity and tissue-specific metabolism follow the life course trajectories evident from accelerometry and adjusted basal expenditure, respectively, model output is similar to observed expenditures.

431     **Supplementary Materials:**

432     Pontzer et al. *Daily Energy Expenditure through the Human Life Course*

433     **Contents:**

446     **Material and Methods**

447     1.  <u>Doubly Labeled Water Database</u>

448         Data were taken from IAEA Doubly Labelled Water (DLW) Database, version 3.1,

449     completed April, 2020 (*16*). This version of the database comprises 6,743 measurements of total

450     expenditure using the doubly labeled water method. Of these, a total of 6,421 had valid data for

451     total expenditure, fat free mass, fat mass, sex, and age. These 6,421 measurements were used in

452     this analysis. This dataset was augmented with published basal expenditure measurements for

453     n=136 neonates and infants (*31-36*) that included fat free mass and fat mass. Malnourished or

454 preterm infants were excluded. For sources that provided cohort means rather than individual

455 subject measurements (*33, 36*) means were entered as single values into the dataset without

456 reweighting to reflect sample size. This approach resulted in 77 measures of basal expenditure,

457 fat free mass, and fat mass for n=136 subjects. We also added to the dataset published basal and

458 total expenditure measurements of n=141 women before, during, and after pregnancy (*37-39*)

459 that included fat free mass and fat mass. These measurements were grouped as pre-pregnancy, 1st

460 trimester, 2nd trimester, 3rd trimester, and post-partum for analysis.

461      In the doubly labeled water method (*5*), subjects were administered a precisely measured

462 dose of water enriched in $^2H_2O$ and $H_2^{18}O$. The subject's body water pool is thus enriched in

463 deuterium ($^2H$) and $^{18}O$. The initial increase in body water enrichment from pre-dose values is

464 used to calculate the size of the body water pool, measured as the dilution space for deuterium

465 ($N_d$) and $^{18}O$ ($N_o$). These isotopes are then depleted from the body water pool over time: both

466 isotopes are depleted *via* water loss, whereas $^{18}O$ is also lost *via* carbon dioxide production.

467 Subtracting the rate (%/d) of deuterium depletion ($k_d$) from the rate of $^{18}O$ depletion ($k_o$), and

468 multiplying the size of the body water pool (derived from $N_d$ and $N_o$) provided the rate of carbon

469 doxide production, $rCO_2$. Entries in the DLW database include the original k and N values for

470 each subject, which were then used to calculate $CO_2$ using a common equation that has been

471 validated in subjects across the lifespan (*17*). The rate of $CO_2$ production, along with each

472 subject's reported food quotient, was then used to calculate energy expenditure (MJ/d) using the

473 Weir equation (*40*). We used the food quotients reported in the original studies to calculate total

474 energy expenditure from $rCO_2$ for each subject.

475      The size of the body water pool, determined from $N_d$ and $N_o$, was used to establish FFM,

476 using hydration constants for fat free mass taken from empirical studies. Other anthropometric

477  variables (age, height, body mass, sex) were measured using standard protocols. Fat mass was

478  calculated as (body mass) – (fat free mass).

479  2.  <u>Basal Expenditure, Activity Expenditure, and Physical Activityl Level (PAL)</u>

480      A total of 2,008 subjects in the database had associated basal expenditure, measured *via*

481  respirometry. For these subjects, we analyzed basal expenditure, activity expenditure, and

482  "physical activity level" (PAL). Activity expenditure was calculated as [0.9(total expenditure) –

483  (basal expenditure)] which subtracts basal expenditure and the assumed thermic effect of food

484  [estimated at 0.1(total expenditure)] from total expenditure. The PAL ratio was calculated as

485  (total expenditure)/(basal expenditure). As noted above, the basal expenditure dataset was

486  augmented with measurements from neonates and infants, but these additional measures do not

487  have associated total expenditure and could not be used to calculate activity expenditure or PAL.

488  3.  <u>Predictive Models for Total, Basal, and Activity Expenditures and PAL</u>

489      We used general linear models to regress measures of energy expenditure against

490  anthropometric variables. We used the base package in R version 4.0.3 (*41*) for all analyses.

491  General linear models were implemented using the `lm` function. These models were used to

492  develop predictive equations for total expenditure for clinical and research applications, and to

493  determine the relative contribution of different variables to total expenditure and its components.

494  Given the marked changes in metabolic rate over the lifespan (Figure 1, Figure 2) we calculated

495  these models separately for each life history stage: infants (0 – 1 y), juveniles (1 – 20 y), adults

496  (20 – 60 y), and older adults (60+ y). These age ranges were identified using segmented

497  regression analysis. Results of these models are shown in Table S2.

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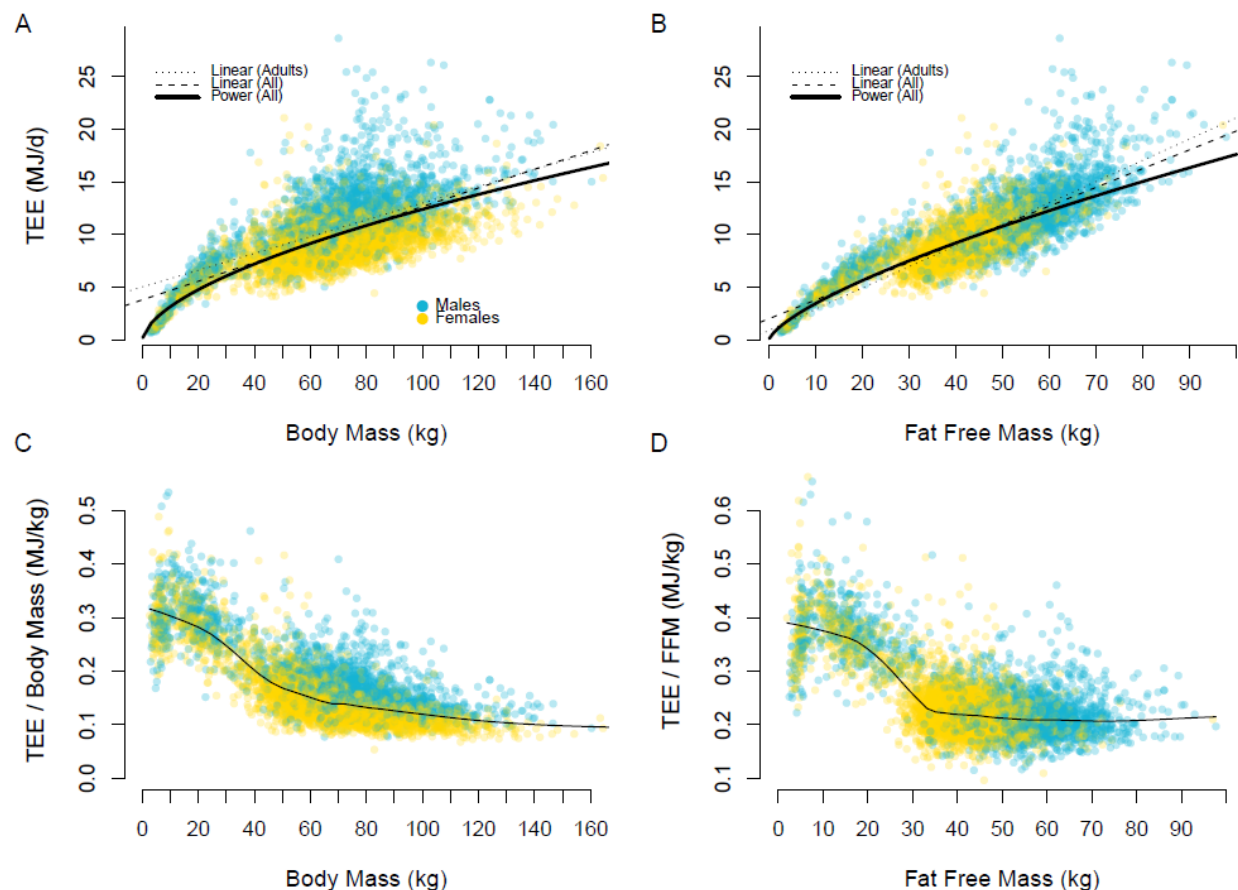
**Figure S1.** Total expenditure (TEE) increases with body size in a power-law manner. For the entire dataset (n = 6,407): **A.** the power-law regression for total body mass (*ln*TEE = 0.593 ± 0.004 *ln*Mass − 0.214 ± 0.018, p < 0.001, adj. $r^2$ = 0.73, model std. err. = 0.223, df = 6419) is less predictive than the regression for **B.** fat free mass (*ln*TEE = 0.708 ± 0.004 *ln*FFM − 0.391 ± 0.015, p < 0.001, adj. $r^2$ = 0.83, model std. err. = 0.176, df = 6419). For both body mass and fat free mass regressions, power-law regressions outperform linear models, particularly at the smallest body sizes. For all models, for both body mass and fat free mass, children have elevated total expenditure, clustering above the trend line. Children also exhibit elevated basal and activity expenditures (Figure S2). Power-law regressions have an exponent < 1.0, and linear regressions (dashed: linear regression through all data; dotted: linear regression through adults only) have a positive intercept, indicating that simple ratios of **C.** (total expenditure)/(body mass) or **D.** (total expenditure)/(fat free mass) do not adequately control for differences in body size (*18*) as smaller individuals will tend to have higher ratios. Lines in **C** and **D** are lowess with span 1/6. In body mass regressions (panel **A**, power and linear models) and the ratio of (total expenditure)/(body mass) (**C**), adult males cluster above the trend line while females cluster below due to sex differences in body composition. In contrast, males and females fit the fat free mass regressions (**B**) and ratio (**D**) equally well.

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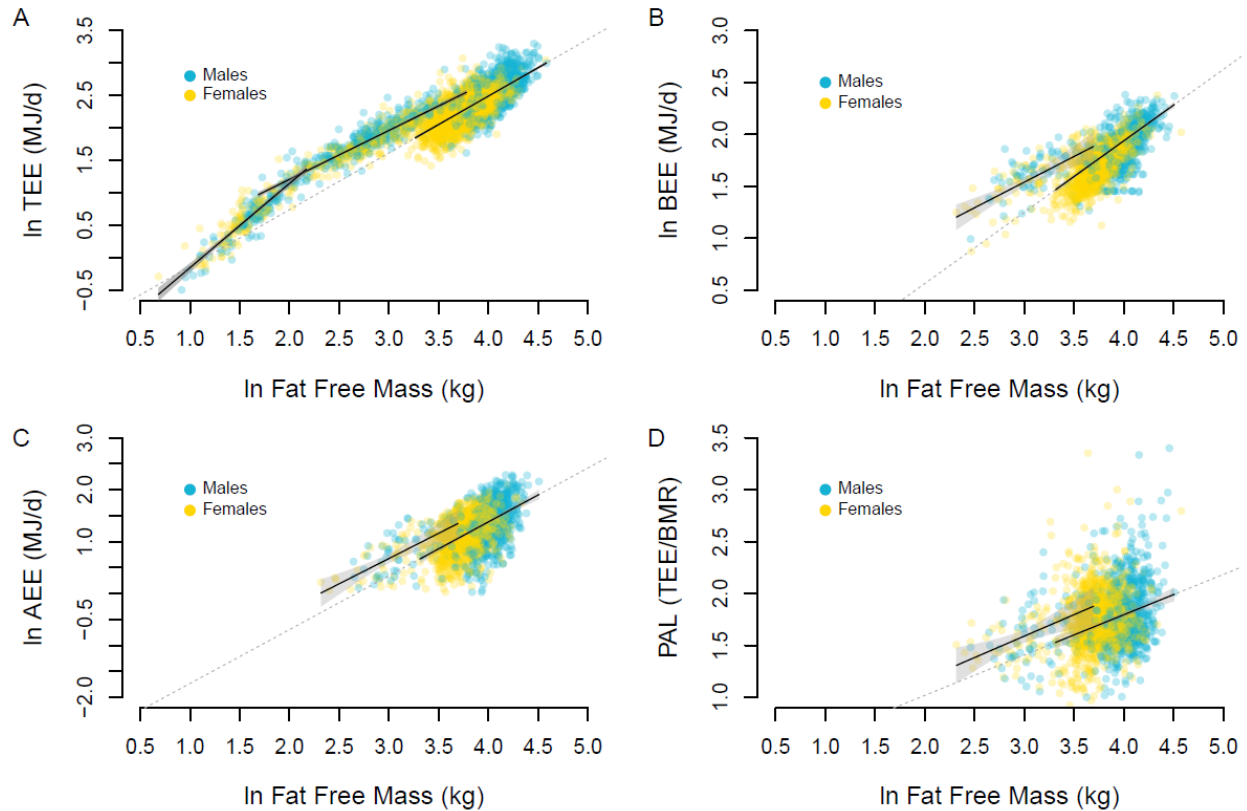
**Figure S2.** Infants and children exhibit different relationships between fat free mass and expenditure and the PAL ratio. **A:** For total expenditure (TEE), regressions for infants (age <1 y, left regression line) and adults (right regression line) intersect for neonates, at the smallest body size. However, the slopes differ, with the infants' regression and 95% CI (gray region) falling outside of that for adults (age 20 – 60 y, extrapolated dashed line). Juvelines (age 1 – 20 y, middle regression line) are elevated, with a regression outside the 95% CI of adults. Juvenile (1 – 20 y) regressions (with 95%CI) are also elevated for basal expenditure (BEE) (**B**), activity expenditure (AEE) (**C**), and PAL (**D**) compared to adults (20 – 60 y). Sex differences in expenditure (**A-D**) are attributable to differences in fat free mass. Note that total and basal expenditures are measured directly. Activity expenditure is calculated as (0.9TEE – BEE), and PAL is calculated as (TEE/BEE); see Methods.

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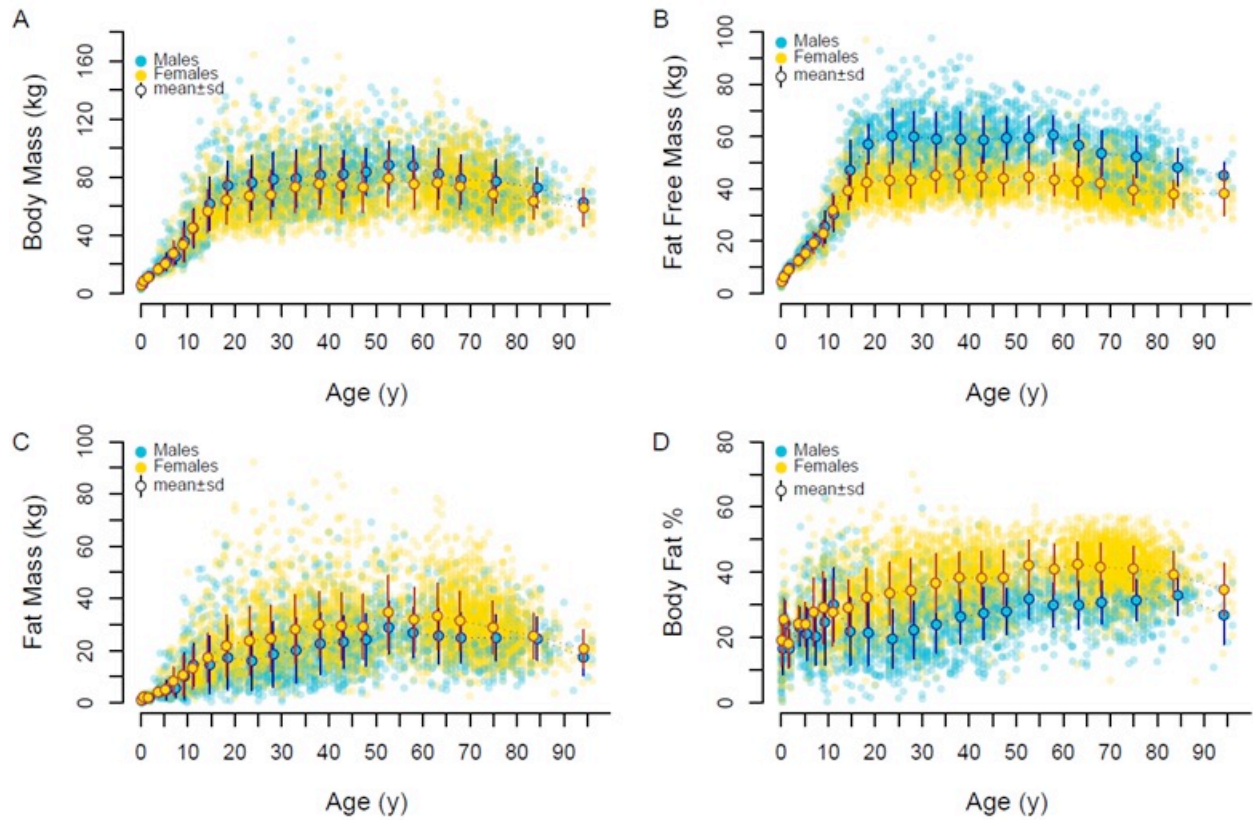
**Figure S3.** Changes in body composition over the lifespan: **A.** Body mass; **B.** Fat free mass; **C.** Fat Mass;

527    and **D.** Body fat percentage.

528    4.  Adjusted Expenditures

529        We used general linear models with fat free mass and fat mass in adults (20 – 60 y) to

530    calculate adjusted total expenditure and adjusted basal expenditure. ==The 20 – 60 y age range was==

531    ==used as the basis for analyses because segmented regression analysis consistently identified this==

532    ==period as stable with respect to size-adjusted total expenditure (see below).==

533        We used models 2 and 5 in Table S2, which have the form $ln$(Expenditure)~$ln$(FFM) +

534    $ln$(Fat Mass) and were implemented using the `lm` function in base R version 4.0.3 (*41*). We

535    used $ln$-transformed variables due to the inherent power-law relationship between body size and

536    both  total and basal expenditure (ref. *2*; see Figure 1, Figure S1). Predicted values for each

537    subject, given their fat free mass and fat mass, were calculated from the model using the

538    `pred()` function; these $ln$-transformed values were converted back into MJ as exp(Predicted).

539    Residuals for each subject were calculated as (Observed – Predicted) expenditure, and were then

540    used to calculate adjusted expenditures as:

541        Adjusted Expenditure = 1 + Residual / Predicted                    [1]

542    The advantage of expressing residuals as a percentage of the predicted value is that it allows us

543    to compare residuals across the range of age and body size in the dataset. Raw residuals (MJ) do

544    not permit direct comparison because the relationship between size and expenditure is

545    heteroscedastic; the magnitude of residuals increases with size (see Figure S1). Ln-transformed

546    residuals ($ln$MJ) avoid this problem but are more difficult to interpret. Adjusted expenditures,

547    used here, provide an easily interpretable measure of deviation from expected values. An

548    adjusted expenditure value of 100% indicates that a subject's observed total or basal expenditure

549    matches the value predicted for their fat free mass and fat mass, based on the general linear

550    model derived for adults. An adjusted expenditure of 120% indicates an observed total or basal

551    expenditure value that exceeds the predicted value for their fat free mass and fat mass by 20%.

552    Similarly, an adjusted expenditure of 80% means the subject's measured expenditure was 20%

553    lower than predicted for their fat free mass and fat mass using the adult model. Adjusted total

554    expenditure and adjusted basal expenditure values for each age-sex cohort are given in Table S3.

555    Within each metabolic life history stage we used general linear models (lm function in R) to

556    investigate the effects of sex and age on adjusted total and basal expenditure.

557    This same approach was used to calculate adjusted basal expenditure as a proportion of

558    total expenditure (Figure 2D), hereafter termed adjusted $BEE_{TEE}$. $Residual_{BEE-TEE}$, the deviation

559    of observed basal expenditure from the adult total expenditure regression (eq. 2 in Table S2),

560    was calculated as (Observed Basal Expenditure – Predicted Total Expenditure) and then used to

561    calculate adjusted $BEE_{TEE}$ as

562    Adjusted $BEE_{TEE}$ = 1 + $Residual_{BEE-TEE}$ / Predicted Total Expenditure        [2]

563    When adjusted $BEE_{TEE}$ = 80%, observed basal expenditure is equal to 80% of predicted total

564    expenditure given the subject's fat free mass and fat mass. Adjusted $BEE_{TEE}$ is equivalent to

565    adjusted basal expenditure (Figure S4) but provides some analytical advantages. The derivation

566    of adjusted $BEE_{TEE}$ approach applies identical manipulations to observed total expenditure and

567    observed basal expenditure and therefore maintains them in directly comparable units. The ratio

568    of (adjusted total expenditure)/(adjusted basal expenditure) is identical to the PAL ratio of (total

569    expenditure)/(basal expenditure), and the difference (0.9adjusted total expenditure– adjusted

570    basal expenditure) is proportional to activity expenditure (Figure S4). Plotting adjusted total

571    expenditure and adjusted $BEE_{TEE}$ over the lifespan (Figure 2D) therefore shows both the relative

572    magnitudes of total and basal expenditure and their relationship to one another in comparable

573    units.
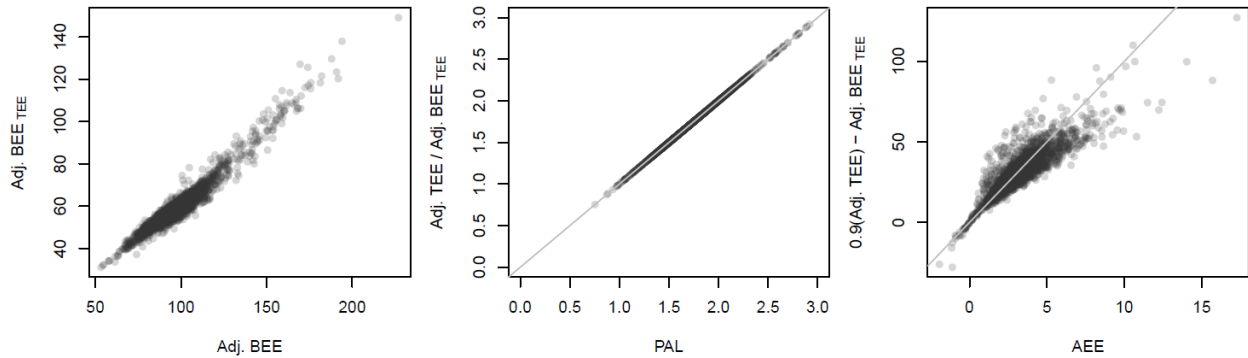
**Figure S4.** <u>Left:</u> Adjusted BEE$_{TEE}$ corresponds strongly to adjusted basal expenditure (Adj. BEE). <u>Center:</u> The ratio of adjusted total expenditure (adj. TEE) to adjusted BEE$_{TEE}$ is identical to the PAL ratio. <u>Right:</u> The difference (0.9adjusted total expenditure – adjusted BEE$_{TEE}$) is proportional to activity energy expenditure (AEE). Gray lines: center panel: y = x, right panel: y = 10x.

5.  <u>Segmented Regression Analysis</u>

We used segmented regression analysis to determine the change points in the relationship between adjusted expenditure and age. We used the Segmented (version 1.1-0) package in R (*42*). For adjusted total expenditure, we examined a range of models with 0 to 5 change points, using the `npsi=` term in the `segmented()` function. This approach does not specify the location or value of change points, only the number of them. Each increase in the number of change points from 0 to 3 improved the model adj. $R^2$ and standard error considerably. Increasing the number of change points further to 4 or 5 did not improve the model, and the additional change points identifed by the `segmented()` function fell near the change points for the 3-change point model. We therefore selected the 3-change point model as the best fit for adjusted total expenditure in this dataset. Segmented regression results are shown in Table S4. A similar 3-change point segmented regression approach was conducted for adjusted basal expenditure (Figure S4) and adjusted BEE$_{TEE}$ (Figure 2D). We note that the decline in adjusted basal expenditure and adjusted BEE$_{TEE}$ in older adults begins earlier (as identified by segmented

593    regression analysis) than does the decline in adjusted total expenditure among older adults.

594    However, this difference may reflect the relative paucity of basal expenditure measurements for

595    subjects 40 – 60 y. Additional measurements are needed to determine whether the decline in

596    basal expenditure does in fact begin earlier than the decline in total expedinture. Here, we view

597    the timing as essentially coincident and interpret the change point in adjusted total expenditure

598    (~60 y), which is determined with a greater number of measurements, as more accurate and

599    reliable.

600        Having established that 3 break points provided the best fit for this dataset, we examined

601    whether changes in the age range used to calculate adjusted total energy expenditure affected the

602    age break-points identified by segmented regression. When the age range used to calculate

603    adjusted expenditure was set at 20 – 60 y, the set of break point (95% CI) was: 0.69 (0.61-0.76),

604    20.46 (19.77-21.15), 62.99 (60.14-65.85). When the age range was expanded to 15 – 70 y, break

605    points determined through segmented regression were effectively unchanged: 0.69 (0.62 – 0.76),

606    21.40 (20.60-22.19), 61.32 (58.60-64.03). Break points were also unchanged when the initial age

607    range for adjusted expenditure was limited to 30 – 50 y: 0.69 (0.62-0.77), 20.56 (19.84-21.27),

608    62.85 (59.97-65.74).

609　**A**　　　　　　　　　　　　　　　　　　　　**B**



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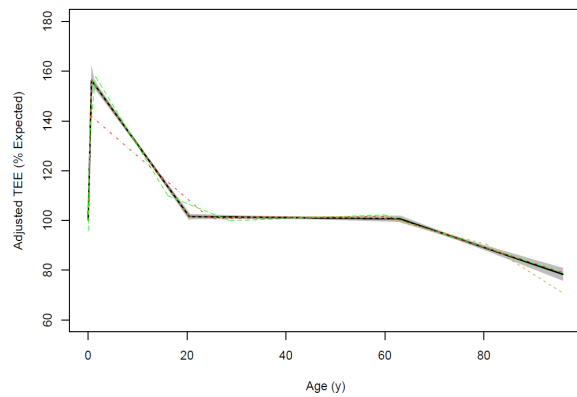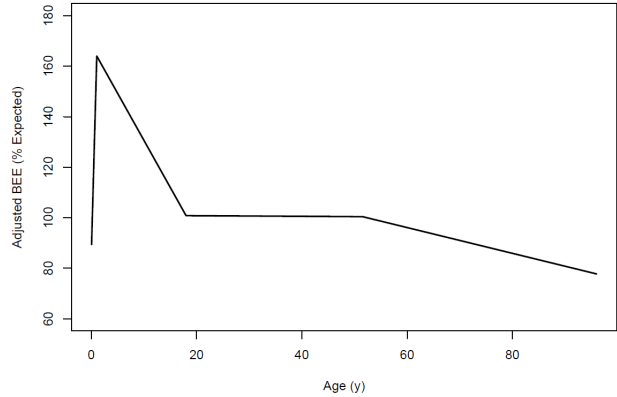
611　**Figure S5.** Segmented regression analysis of adjusted TEE (**A**) and adjusted BEE (**B**). In both panels, the

612　black line and gray shaded confidence region depicts the 3 change-point regression. For adjusted TEE,

613　segmented regressions are also shown for 2 change points (red), 4 change points (yellow), and 5 change

614　points (green). Segmented regression statistics are given in Table S4.

615    6.   Organ Size and Basal Expenditure

616        Measuring the metabolic rate of individual organs is notoriously challenging, and the

617    available data come from only a small number of studies. The available data indicate that organs

618    differ markedly in their mass-specific metabolic rates at rest (*43*). The heart (1848 kJ kg$^{-1}$ d$^{-1}$),

619    liver (840 kJ kg$^{-1}$ d$^{-1}$), brain (1008 kJ kg$^{-1}$ d$^{-1}$), and kidneys (1848 kJ kg$^{-1}$ d$^{-1}$) have much greater

620    mass-specific metabolic rates at rest than do muscle (55 kJ kg$^{-1}$ d$^{-1}$), other lean tissue (50 kJ kg$^{-1}$

621    d$^{-1}$), and fat (19 kJ kg$^{-1}$ d$^{-1}$). Consequently, the heart, liver, brain, and kidneys combined account

622    for ~60% of basal expenditure in adults (*21, 22, 44, 45*). In infants and children, these

623    metabolically active organs constitute a larger proportion of body mass. The whole body mass-

624    specific basal expenditure [i.e., (basal expenditure)/(body mass), or (basal expenditure)/(fat free

625    mass)] for infants and children is therefore expected to be greater than adults' due to the greater

626    proportion of metabolically active organs early in life adults (*21, 22, 44, 45*). Similarly, reduced

627    organ sizes in elderly subjects may result in declining basal expenditure (*21*).

628        To examine this effect of organ size on basal expenditure in our dataset, we used

629    published references for organ size to determine the mass of the metabolically active organs

630    (heart, liver, brain, and kidneys) as a percentage of body mass or fat free mass for subjects 0 – 12

631    y (*22, 44-46*), 15 to 60 y (*21, 22*), and 60 to 100 y (*21, 47*). We used these relationships to

632    estimate the combined mass of the metabolically active organs (heart, liver, brain, kidneys) for

633    each subject in our dataset. We then subtracted the mass of the metabolically active organs from

634    measured fat free mass to calculate the mass of "other fat free mass". These two measures, along

635    with measured fat mass, provided a three-compartment model for each subject: metabolically

636    active organs, other fat free mass, and fat (Figure S6A).

637     Following previous studies (*21-25*), we assigned mass-specific metabolic rates to each

638     compartment and estimated basal expenditure for each subject. We used reported mass-specific

639     metabolic rates for the heart, liver, brain, and kidneys (see above; (*43*)) and age-related changes

640     in the proportions of these organs for subjects 0 – 12 y (*22, 46*), 15 to 60 y (*21-25*), and 60 to 100

641     y (*21, 23, 25, 47*) to calculate an age-based weighted mass-specific metabolic rate for the

642     metabolically active organ compartment. We averaged the mass-specific metabolic rates of

643     resting muscle and other lean tissue (see above; (*21, 22*)) and assigned a value of 52.5 kJ kg$^{-1}$ d$^{-1}$

644     to "other fat free mass", and we used a mass-specific metabolic rate of 19 kJ kg$^{-1}$ d$^{-1}$ for fat.

645     Results are shown in Figure S6. Due to the greater proportion of metabolically active

646     organs in early life, the estimated basal expenditure from the three-compartment model follows a

647     power-law relationship with FFM (using age cohort means, BEE= 0.38 FFM$^{0.75}$; Figure S6B)

648     that is similar to that calculated from observed basal expenditure in our dataset (see Table S2 and

649     *7. Modeling the Effects of Physical Activity and Tissue Specific Metabolism*, below). Estimated

650     BEE from the three-compartment model produced mass-specific metabolic rates that are

651     considerably higher for infants and children than for adults and roughly consistent with observed

652     age-related changes in (basal expenditure)/(fat free mass) (Figure S6C). Thus, changes in organ

653     size can account for much of the variation in basal expenditure across the lifespan observed in

654     our dataset.

655     Nonetheless, observed basal expenditure was ~30% greater early in life, and ~20% lower

656     in older adults, than estimated basal expenditure from the three-compartment model (Figure

657     S6D). The departures from estimated basal expenditure suggest that the mass-specific metabolic

658     rates of one or more organ compartments are considerably higher early in life, and lower late in

659     life, than they are in middle-aged adults, consistent with previous assessments (*21-25*). It is

660    notable, in this context, that observed basal expenditure for neonates is nearly identical to basal

661    expenditure estimated from the three-comparment model, which assumes adult-like tissue

662    metabolic rates (Figure S6B,C,D). Observed basal expenditure for neonates is thus consistent

663    with the hypothesis that the mass-specific metabolic rates of their organs are similar to those of

664    other adults, specifically the mother.



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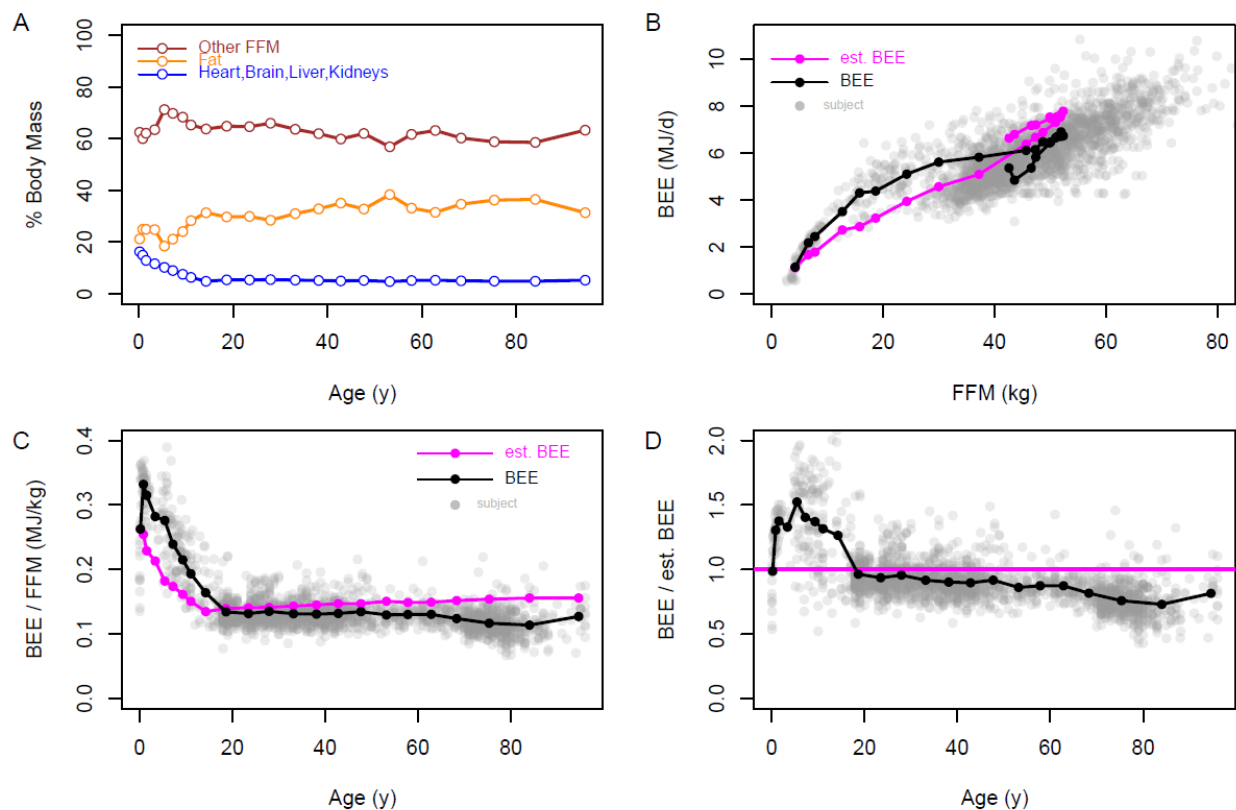
**Figure S6. Organ sizes and BEE. A.** The relative proportions of metabolically active organs (heart, brain, liver, kidneys), other fat free mass (FFM), and fat changes over the life course. Age cohort means are shown. **B.** Consequently, estimated basal expenditure (BEE) from the three-compartment model increases with fat free mass (FFM) in a manner similar to observed basal expenditure, with **C.** greater whole body mass-specific basal expenditure (BEE/FFM) early in life. **D.** Observed basal expenditure is ~30% greater early in life, and ~20% lower after age 60 y, than estimated basal expenditure from the three-compartment model (shown as the ratio of BEE/est.BEE). In panels **B**, **C**, and **D**, age-cohort means for observed (black) and estimated (magenta) basal expenditure are shown.

674    7.   Modeling the Effects of Physical Activity and Tissue Specific Metabolism

675         We constructed two simple models to examine the contributions of physical activity and

676    variation in tissue metabolic rate to total and basal expenditure. In the simplest version, we used

677    the observed relationship between basal expenditure and tat free mass for all adults 20 – 60 y

678    determined from linear regression of $ln$(basal expenditure) and $ln$(fat free mass) (untransformed

679    regression equation: basal expenditure = 0.32 (fat free mass)$^{0.75}$, adj. $r^2$ = 0.60, df = 1684, p <

680    0.0001) to model basal expenditure as

681         Basal expenditure = 0.32 $TM_{age}$ (fat free mass)$^{0.75}$          [3]

682    The $TM_{age}$ term is tissue metabolic rate, a multiplier between 0 and 2 reflecting a relative

683    increase ($TM_{age}$ > 1.0) or decrease ($TM_{age}$ < 1.0) in organ metabolic rate relative that expected

684    from the power-law regression for adults. Note that, even when $TM_{age}$ = 1.0, smaller individuals

685    are expected to exhibit greater mass-specific basal expenditure (that is, a greater basal

686    expenditure per kg body weight) due to the power-law relationship between basal expenditure

687    and fat free mass. Further, we note that the power-law relationship between basal expenditure

688    and fat free mass for adults is similar to that produced when estimating basal expenditure from

689    organ sizes (see *Organ Size and Basal Expenditure*, above). Thus, variation in $TM_{age}$ reflects

690    modeled changes in tissue metabolic rate *in addition* to power-law scaling effects, and also, in

691    effect, in addition to changes in basal expenditure due to age-related changes in organ size and

692    proportion. To model variation in organ activity over the lifespan, we either 1) maintained $TM_{age}$

693    at adult levels ($TM_{age}$ = 1.0) over the entire lifespan, or 2) had $TM_{age}$ follow the trajectory of

694    adjusted basal expenditure with age (Figure S8).

695        To incorporate effects of fat mass into the model, we constructed a second version of the

696    model in which basal expenditure was modeled following the observed relationship with FFM

697    and fat mass for adults 20 – 60 y,

698        Basal expenditure = 0.32 $TM_{age}$ (fat free mass)$^{0.7544}$ (fat mass)$^{0.0003}$    [4]

699    As with the fat free mass model (eq. 3), we either maintained $TM_{age}$ at 1.0 over the life span or

700    modeled it using the trajectory of adjusted basal expenditure.

701        Activity expenditure was modeled as a function of physical activity and body mass

702    assuming larger indivduals expend more energy during activity. We began with activity

703    expenditure, calculated as [0.9(total expenditure) – (basal expenditure)] as described above. The

704    observed ratio of (activity expenditure)/(fat free mass) for adults 20 – 60 y was 0.07 MJ d$^{-1}$ kg$^{-1}$.

705    We therefore modeled activity expenditure as

706        Activity expenditure = 0.07 $PA_{age}$ (fat free mass)    [5]

707    To incorporate effects of fat mass, we constructed a second version using the ratio of (activity

708    expenditure)/(body weight) for adults 20 – 60y,

709        Activity expenditure = 0.04 $PA_{age}$ (body weight)    [6]

710    In both equations, $PA_{age}$ represents the level of physical activity relative to the mean value for 20

711    – 60 y adults. $PA_{age}$ could either remain constant at adult levels ($PA_{age}$=1.0) over the lifespan or

712    follow the trajectory of physical activity measured *via* accelerometry, which peaks between 5 –

713    10 y, declines rapidly through adolescence, and then declines more slowly beginning at ~40 y

714    (*11-13, 26, 27, 48-51*). Different measures of physical activity (*e.g.*, moderate and vigorous PA,

715    mean counts per min., total accelerometry counts) exhibit somewhat different trajectories over

716    the lifespan, but the patterns are strongly correlated; all measures show the greatest activity at 5-

717    10 y and declining activity in older adults (Figure S7). We chose total accelerometry counts (*11,*

718    *26*), which sum all movement per 24-hour period, to model age-related changes in PA$_{age}$. We

719    chose total counts because activity energy expenditure should reflect the summed cost of all

720    activity, not only activity at moderate and vigorous intensities. Further, the amplitude of change

721    in moderate and vigorous activity over the lifespan is considerably larger than the observed

722    changes in adjusted  total expenditure or adjusted activity expenditure (Figure S10). Determining

723    the relative contributions of different measures of physical activity to total expenditure is beyond

724    the scope of the simple modeling approach here and remains an important task for future

725    research.

726



727    **A.**                                                                                              **B.**
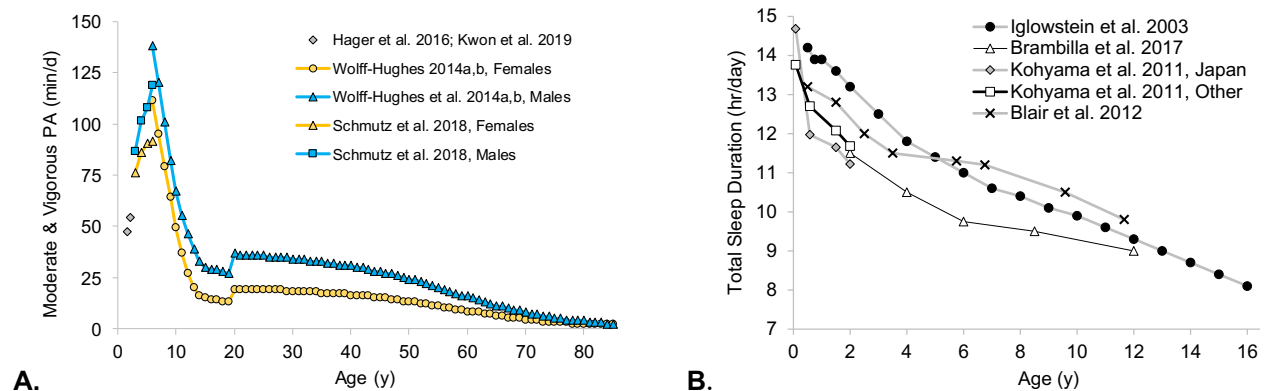
728    **Figure S7.** Modeling physical activity across the lifespan. **A.** Across studies and countries, accelerometer-

729    measured physical activity rises through infancy and early childhood, peaking between 5 and 10y before

730    declining to adult levels in the teenage years (*11-13, 26, 27, 48-51*). Physical activity declines again,

731    more slowly, in older adults. The onset of decline in older adults varies somewhat across studies, beginning

732    between ~40 y and ~60 y. Here, physical activity is shown as minutes/day of moderate and vigorous

733    physical activity. Other measures (*e.g.*, total accelerometer counts; mean counts/min, vector magnitude)

734    follow a similar pattern of physical activity over the life span (*11, 26*). **B.** The increase in physical activity

735    from 0 to ~10 y is mirrored by the steady decline in total daily sleep duration during this period (*52-55*).

736
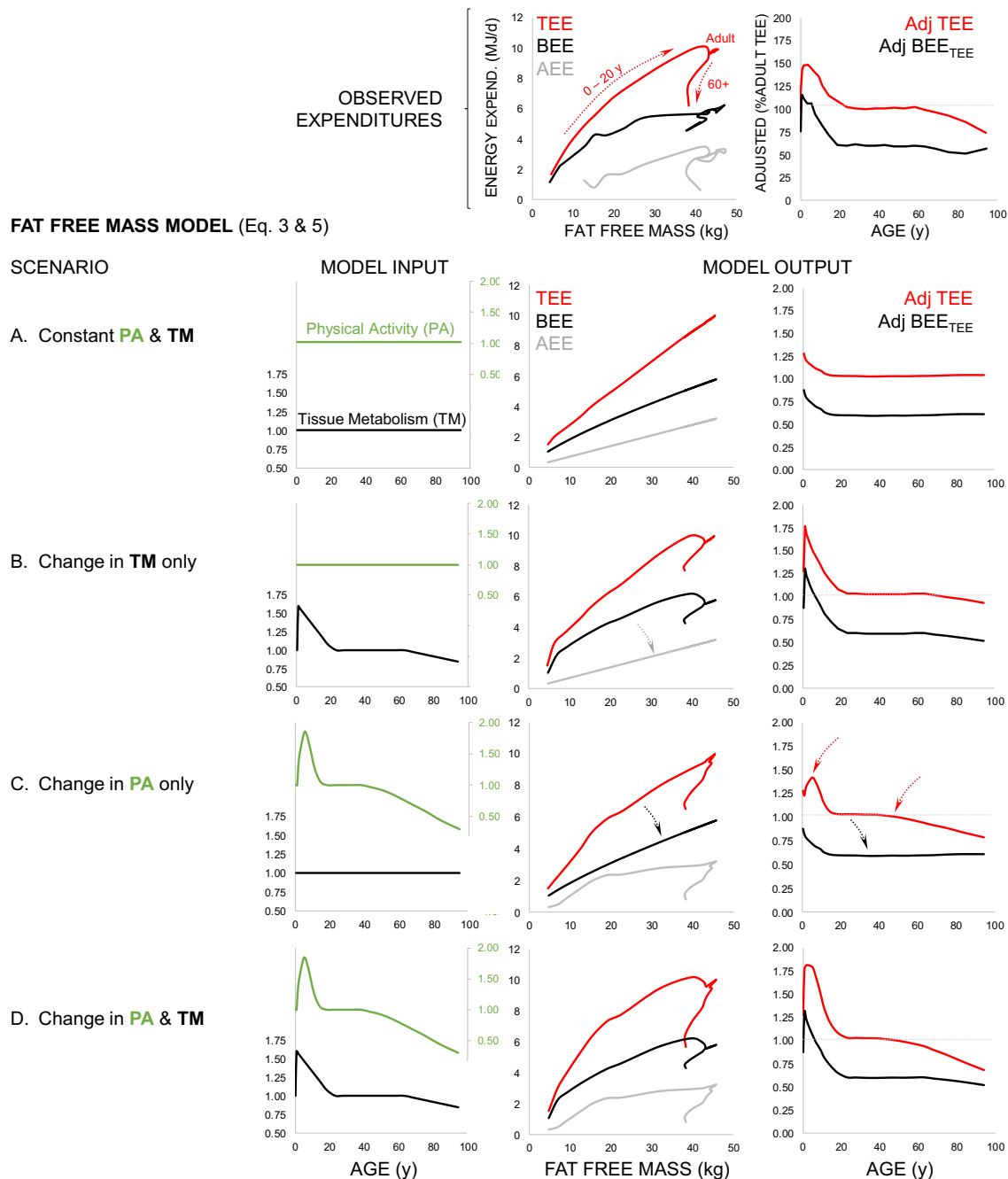
**Figure S8.** Results of the fat free mass model. Observed expenditures exhibit a marked age effect on the relationship between expenditure and fat free mass that is evident in both absolute (Figure 1C) and adjusted (Figure 2D) measures. **A.** If physical activity (PA) and cellular metabolism (TM) remain constant at adult levels, age effects do not emerge from the model. **B.** When only TM varies, age effects emerge for total expenditure (TEE) and basal expenditure (BEE), but not activity expenditure (AEE; gray arrow). **C.** Conversely, if only physical activity varies age effects emerge for AEE and TEE but not BEE (black arrows). Adjusted TEE also peaks later in childhood and declines earlier in adulthood (red arrows) than observed. **D.** Varying both PA and TM gives model outputs similar to observed expenditures.

745
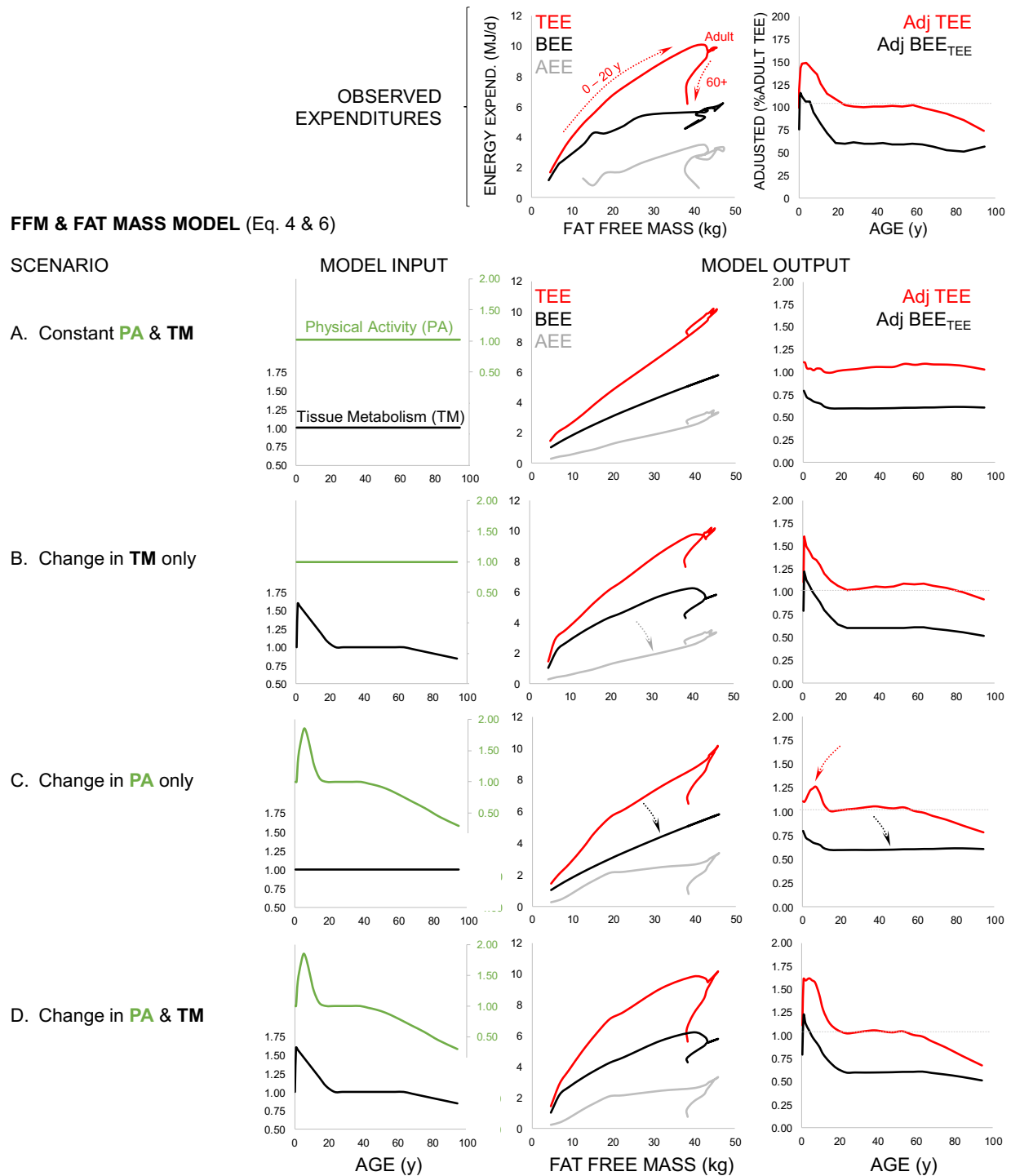
**Figure S9.** Results of the fat free mass and fat mass model. Model outputs are similar to those of the fat

free mass model (Figure S8). The scenario that best matches the observed relationships between fat free

mass, age, and expenditure is D, in which AEE is influenced by age-related variation in both physical activity

and cellular metabolism. Abbreviations as in Fig S8.

750      8. Physical Activity, Activity Expenditure and PAL

751           To further interrogate our simple model of expenditure and the contribution of physical

752      activity, we examined the agreement between accelerometery-measured physical activity,

753      adjusted activity expenditure, and modeled PAL over the lifespan. First, as noted in our

754      discussion of the simple expenditure model (see above; Figures 3, S8, S9), moderate and

755      vigorous physical activity and total accelerometry counts show a similar shape profile when

756      plotted against age, but moderate and vigorous physical activity shows a greater amplitude of

757      change over the lifespan (Figure S10). Moderate and vigorous physical activity reach a peak ~4-

758      times greater than the mean values observed for 20 – 30 y men and women, far greater than the

759      amplitude of change in adjusted total expenditure.

760           We used adjusted total and basal expenditures to model activity expenditure and PAL

761      over the lifespan for comparison with published accelerometry measures of physical activity.

762      Modeling activity expenditure and PAL was preferable because our dataset has no subjects less

763      than 3 y with measures of both total and basal expenditure, and only 4 subjects under the age of 6

764      y with both measures (Table S1). Using values of adjusted total expenditure and adjusted

765      $BEE_{TEE}$ (basal expenditure expressed as a percentage of total expenditure) for age cohorts from

766      Table S3 enabled us to model activity expenditure and PAL for this critical early period of

767      development, in which both physical activity and expenditure change substantially. We modeled

768      adjusted activity expenditure as [(adjusted total expenditure) – (adjusted $BEE_{TEE}$)] and PAL as

769      [(adjusted total expenditure) / (adjusted $BEE_{TEE}$)], which as we show in Figure S4 corelate

770      strongly with unadjusted measures of activity expenditure and PAL, respectively.

771           Modeled adjusted activity expenditure and PAL showed a somewhat different pattern of

772      change over the lifecoure than either total counts or moderate and vigorous activity measured via

773    accelerometry (Figure S10). Modeled activity expenditure was most similar to total counts, rising

774    through childhood, peaking between 10 and 20 y before falling to a stable adult level; the adult

775    level was stable from ~30 – 75 y before declining (Figure S10). Modeled PAL rose unevenly

776    from birth through age 20, then remained largely stable thereafter.

777          The agreement, and lack thereof, between the pattern of accelerometry-measured physical

778    activity and modeled activity expenditure and PAL must be assessed with caution. These

779    measures are from different samples; we do not have paired accelerometry and energy

780    expenditure measures in the present dataset. The life course pattern of accelerometry-measured

781    physical activity, particularly total counts, is broadly consistent with that of modeled activity

782    expenditure. However, more work is clearly needed to determine the effects of physical activity

783    and other factors to variation in activity expenditure and PAL over the lifecourse.

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**9.IAEA DLW database consortium**

This group authorship contains the names of people whose data were contributed into the database by the analysis laboratory but they later could not be traced, or they did not respond to emails to assent inclusion among the authorship. The list also includes some researchers who did not assent inclusion because they felt their contribution was not sufficient to merit authorship

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A



B



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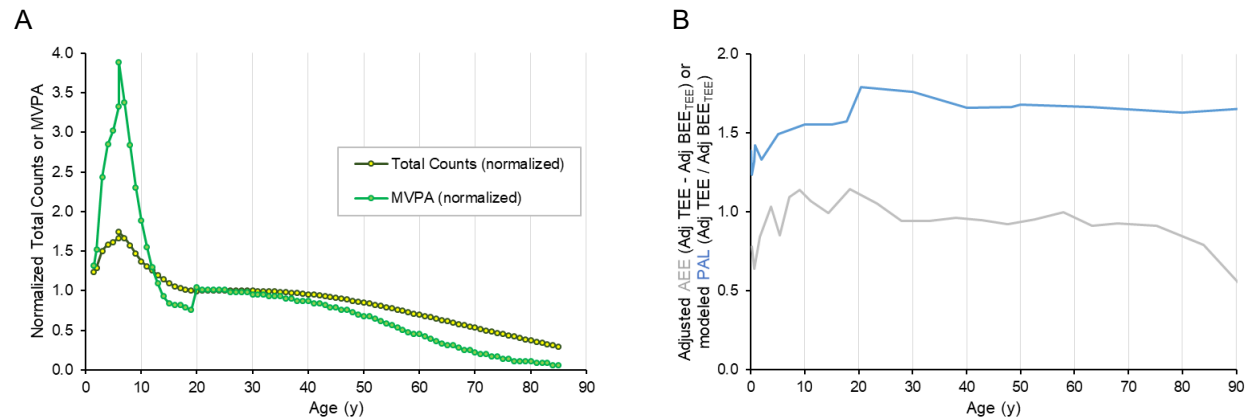
891    **Figure S10. A.** Physical activity measured via accelerometry from published analyses (*11-13, 26, 27,*
892    *48-51*) and **B.** modeled activity expenditure and PAL calculated from cohort means for adjusted total
893    expenditure and adjusted BEE$_{TEE}$ in Table S3. Accelerometry measures and modeled activity expenditure
894    are normalized to mean values for 20 – 30 y subjects.

**Table S1.** Key characteristics by age-sex cohort for A. Total expenditure (TEE) from the DLW database and B. subjects with basal expenditure (BEE) measurements. Activity expenditure (AEE) = 0.9TEE - BEE. *Infant data from the literature, males and females pooled. N values for infant BEE (0 to 2 years) indicate number of entries and (number of individuals). See Methods.

**A.**

| Age group | N F | N M | Age (y) F mean | sd | Age M mean | sd | Height (cm) F mean | sd | M mean | sd | Mass (kg) F mean | sd | M mean | sd | BMI F mean | sd | M mean | sd | Fat Free Mass (kg) F mean | sd | M mean | sd | Fat Mass (kg) F mean | sd | M mean | sd | Fat% F mean | sd | M mean | sd | TEE (MJ/d) F mean | sd | M mean | sd |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (0,0.5) | 102 | 93 | 0.24 | 0.13 | 0.24 | 0.13 | 59.7 | 4.6 | 60.4 | 5.4 | 5.71 | 1.28 | 6.12 | 1.52 | 15.8 | 1.6 | 16.4 | 1.9 | 4.56 | 0.87 | 5.03 | 1.09 | 1.14 | 0.63 | 1.09 | 0.66 | 19.2 | 7.7 | 16.6 | 7.8 | 1.68 | 0.46 | 1.83 | 0.58 |
| (0.5,1) | 18 | 23 | 0.68 | 0.18 | 0.72 | 0.20 | 69.1 | 4.3 | 71.8 | 4.6 | 8.54 | 1.40 | 9.17 | 1.33 | 17.8 | 2.1 | 17.7 | 1.3 | 6.32 | 0.91 | 6.94 | 1.18 | 2.23 | 0.80 | 2.23 | 0.65 | 25.6 | 6.4 | 24.3 | 6.7 | 2.53 | 0.36 | 2.90 | 0.78 |
| (1,2) | 33 | 35 | 1.70 | 0.46 | 1.64 | 0.48 | 82.3 | 5.0 | 83.2 | 5.9 | 11.06 | 1.41 | 11.69 | 1.65 | 16.3 | 1.0 | 16.8 | 1.0 | 9.04 | 1.32 | 9.74 | 1.41 | 2.02 | 0.87 | 1.96 | 0.76 | 18.1 | 7.5 | 16.7 | 5.7 | 3.70 | 0.64 | 3.99 | 0.74 |
| (2,4) | 54 | 48 | 3.81 | 0.28 | 3.78 | 0.31 | 101.2 | 4.6 | 102.1 | 6.1 | 16.66 | 3.38 | 17.38 | 3.03 | 15.9 | 1.7 | 16.6 | 2.4 | 12.51 | 1.85 | 13.24 | 1.85 | 4.15 | 1.91 | 4.14 | 1.69 | 24.2 | 5.5 | 23.2 | 5.8 | 4.84 | 0.70 | 5.21 | 0.89 |
| (4,6) | 99 | 121 | 5.34 | 0.63 | 5.31 | 0.68 | 112.7 | 6.7 | 113.7 | 7.5 | 20.41 | 3.86 | 21.74 | 5.73 | 16.0 | 2.0 | 16.6 | 2.4 | 15.34 | 2.31 | 16.83 | 2.92 | 5.06 | 2.43 | 4.91 | 3.55 | 21.1 | 8.0 | 21.1 | 8.6 | 5.59 | 1.18 | 6.35 | 1.18 |
| (6,8) | 42 | 43 | 7.03 | 0.65 | 7.25 | 0.62 | 122.5 | 10.2 | 125.2 | 8.8 | 27.62 | 8.49 | 25.71 | 5.49 | 18.2 | 4.5 | 16.2 | 2.4 | 19.28 | 3.97 | 20.14 | 2.75 | 8.34 | 5.33 | 5.57 | 3.62 | 27.8 | 10.3 | 20.3 | 8.7 | 6.62 | 1.36 | 7.20 | 1.13 |
| (8,10) | 79 | 75 | 9.10 | 0.48 | 9.14 | 0.53 | 133.5 | 9.3 | 136.9 | 10.0 | 33.62 | 13.69 | 35.76 | 13.69 | 18.2 | 4.5 | 18.4 | 4.8 | 22.96 | 5.01 | 25.53 | 6.09 | 10.66 | 7.74 | 10.23 | 8.76 | 29.1 | 10.9 | 24.7 | 13.1 | 7.36 | 1.67 | 8.54 | 1.77 |
| (10,12) | 69 | 34 | 11.14 | 0.58 | 11.01 | 0.47 | 148.5 | 8.0 | 143.7 | 9.6 | 45.15 | 11.65 | 44.91 | 13.45 | 20.3 | 4.1 | 21.2 | 4.4 | 30.42 | 6.63 | 31.85 | 6.35 | 14.50 | 8.25 | 13.30 | 7.90 | 30.1 | 11.2 | 28.0 | 10.3 | 8.90 | 1.88 | 9.35 | 1.68 |
| (12,16) | 227 | 129 | 14.53 | 1.14 | 14.53 | 1.18 | 160.6 | 8.4 | 168.4 | 12.1 | 56.72 | 14.67 | 61.73 | 16.34 | 21.9 | 4.8 | 21.4 | 4.4 | 39.37 | 7.27 | 47.15 | 11.42 | 17.34 | 9.25 | 14.50 | 8.25 | 29.2 | 8.3 | 21.5 | 10.4 | 9.96 | 2.35 | 10.22 | 2.53 |
| (16,20) | 211 | 103 | 18.32 | 0.99 | 18.37 | 1.11 | 163.9 | 7.4 | 177.9 | 7.7 | 64.31 | 16.34 | 74.36 | 16.73 | 23.9 | 8.8 | 23.5 | 4.9 | 42.49 | 7.26 | 57.11 | 7.58 | 21.82 | 11.76 | 17.25 | 12.26 | 29.2 | 8.3 | 21.5 | 10.0 | 10.08 | 1.95 | 14.02 | 2.59 |
| (20,25) | 257 | 128 | 23.23 | 1.40 | 23.48 | 1.38 | 164.6 | 7.4 | 176.6 | 9.3 | 67.08 | 17.92 | 76.35 | 18.60 | 24.8 | 6.4 | 24.1 | 4.9 | 43.26 | 6.97 | 60.29 | 10.53 | 23.82 | 13.08 | 16.06 | 11.14 | 19.6 | 8.9 | 21.5 | 10.0 | 9.64 | 2.12 | 13.88 | 3.56 |
| (25,30) | 281 | 186 | 27.77 | 1.48 | 28.05 | 1.40 | 164.1 | 6.9 | 177.4 | 8.9 | 67.99 | 16.72 | 78.56 | 18.51 | 25.2 | 5.9 | 24.9 | 4.8 | 43.36 | 6.81 | 59.97 | 9.63 | 24.63 | 12.51 | 18.58 | 12.54 | 22.3 | 8.6 | 23.2 | 8.6 | 9.60 | 1.94 | 13.24 | 3.75 |
| (30,35) | 238 | 149 | 32.99 | 1.36 | 32.88 | 1.41 | 164.5 | 6.2 | 177.2 | 8.0 | 73.39 | 17.78 | 79.14 | 19.56 | 27.2 | 6.3 | 25.1 | 5.4 | 45.20 | 6.63 | 59.07 | 10.23 | 28.18 | 12.96 | 20.07 | 12.18 | 24.0 | 8.7 | 24.0 | 8.7 | 9.88 | 1.65 | 12.76 | 2.79 |
| (35,40) | 232 | 167 | 38.05 | 1.45 | 38.01 | 1.42 | 164.2 | 6.5 | 176.7 | 7.6 | 75.50 | 17.68 | 81.55 | 19.88 | 27.5 | 7.6 | 26.0 | 5.4 | 45.47 | 6.82 | 58.91 | 10.51 | 30.03 | 12.59 | 22.64 | 13.22 | 24.0 | 9.0 | 24.0 | 8.7 | 9.90 | 1.68 | 12.92 | 2.92 |
| (40,45) | 301 | 165 | 42.81 | 1.36 | 42.92 | 1.37 | 163.7 | 7.2 | 176.3 | 7.7 | 74.23 | 18.78 | 82.12 | 18.78 | 27.6 | 6.3 | 26.4 | 4.3 | 44.76 | 7.56 | 58.79 | 8.91 | 29.47 | 12.78 | 23.33 | 9.38 | 27.4 | 7.9 | 27.4 | 7.9 | 9.92 | 1.94 | 12.68 | 2.39 |
| (45,50) | 172 | 144 | 47.43 | 1.46 | 47.76 | 1.46 | 164.6 | 6.1 | 176.8 | 7.2 | 73.18 | 17.40 | 76.21 | 15.81 | 27.4 | 6.3 | 27.2 | 4.3 | 44.02 | 6.44 | 59.52 | 8.15 | 29.15 | 12.40 | 24.21 | 13.91 | 28.0 | 7.1 | 28.0 | 7.1 | 9.80 | 1.48 | 12.77 | 2.47 |
| (50,55) | 105 | 93 | 52.80 | 1.48 | 52.59 | 1.48 | 163.5 | 5.9 | 177.1 | 6.7 | 79.37 | 19.42 | 79.37 | 16.51 | 29.7 | 7.0 | 28.4 | 4.8 | 44.66 | 6.51 | 59.54 | 8.29 | 34.72 | 14.08 | 28.84 | 10.08 | 42.2 | 7.8 | 31.8 | 6.1 | 9.75 | 1.59 | 12.69 | 2.03 |
| (55,60) | 111 | 76 | 57.76 | 1.38 | 57.16 | 1.55 | 163.6 | 6.2 | 177.3 | 7.6 | 75.35 | 17.07 | 76.21 | 18.34 | 28.3 | 5.7 | 28.3 | 3.7 | 43.42 | 6.06 | 56.64 | 10.52 | 31.93 | 12.22 | 28.04 | 9.42 | 41.0 | 7.7 | 30.0 | 6.7 | 9.70 | 1.54 | 13.27 | 2.97 |
| (60,65) | 252 | 90 | 63.22 | 1.47 | 63.16 | 1.55 | 161.5 | 7.1 | 174.5 | 7.4 | 73.67 | 15.55 | 78.50 | 16.64 | 29.3 | 6.8 | 27.2 | 4.5 | 44.23 | 6.83 | 56.70 | 8.07 | 33.29 | 12.58 | 25.64 | 10.52 | 42.5 | 6.7 | 29.9 | 7.4 | 9.24 | 1.54 | 12.09 | 2.36 |
| (65,70) | 387 | 90 | 68.04 | 1.47 | 67.98 | 1.37 | 161.4 | 6.7 | 172.4 | 7.3 | 73.67 | 15.55 | 78.50 | 16.64 | 28.3 | 5.7 | 26.2 | 4.5 | 42.20 | 5.85 | 53.61 | 8.62 | 31.47 | 11.13 | 24.89 | 9.55 | 41.6 | 7.2 | 30.8 | 6.4 | 9.02 | 1.32 | 10.86 | 1.79 |
| (70,80) | 682 | 232 | 75.05 | 2.79 | 75.40 | 2.92 | 159.4 | 6.7 | 171.3 | 8.0 | 66.50 | 14.42 | 77.19 | 14.92 | 26.9 | 5.2 | 26.2 | 4.2 | 39.62 | 5.65 | 52.29 | 7.86 | 28.88 | 8.74 | 24.90 | 8.74 | 41.1 | 6.7 | 31.4 | 6.3 | 8.21 | 1.30 | 10.17 | 1.80 |
| (80,90) | 149 | 66 | 83.65 | 2.40 | 84.20 | 2.50 | 157.5 | 7.2 | 168.7 | 7.5 | 63.61 | 12.29 | 72.76 | 13.80 | 25.7 | 4.7 | 25.5 | 4.2 | 38.02 | 5.22 | 48.22 | 7.07 | 25.59 | 8.70 | 24.53 | 8.24 | 39.3 | 7.0 | 32.9 | 6.2 | 7.43 | 1.36 | 8.69 | 1.70 |
| (90,100) | 22 | 8 | 94.36 | 1.79 | 94.00 | 1.85 | 158.0 | 9.1 | 168.8 | 3.0 | 58.98 | 12.81 | 62.60 | 9.47 | 23.6 | 4.1 | 22.0 | 3.4 | 38.26 | 8.50 | 45.18 | 4.93 | 20.72 | 7.23 | 17.42 | 6.93 | 34.7 | 7.9 | 26.9 | 8.9 | 6.20 | 1.20 | 7.60 | 1.03 |

**B.**

| Age Group | N F | N M | Age (y) F mean | sd | M mean | sd | Mass (kg) F mean | sd | M mean | sd | Fat Free Mass (kg) F mean | sd | M mean | sd | Fat Mass (kg) F mean | sd | M mean | sd | Fat% F mean | sd | M mean | sd | BEE (MJ/d) F mean | sd | M mean | sd | AEE (MJ/d) F mean | sd | M mean | sd | PAL (TEE/BEE) F mean | M mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (0,0.5)* | 22 (111) | 20 (88) | 0.21 | 0.17 | 0.17 | 0.17 | 5.45 | 1.6 | | | 4.17 | 0.87 | | | 1.3 | 0.80 | | | 21.21 | 8.94 | | | 1.14 | 0.52 | | | | | | | | |
| (0.5,1)* | 18 (86) | | 0.85 | 0.14 | 0.74 | | 8.76 | 1.2 | | | 6.55 | 0.70 | | | 2.2 | 0.53 | | | 24.97 | 3.75 | | | 2.17 | 0.29 | | | | | | | | |
| (1,2)* | | | 1.56 | 0.32 | 1.73 | | 10.33 | 1.73 | | | 7.72 | 1.12 | | | 2.6 | 0.69 | | | 24.96 | 3.27 | | | 2.44 | 0.44 | | | | | | | | |
| (2,4) | 3 | 1 | 3.80 | 0.35 | 4.00 | NA | 21.6 | 8.3 | 18.0 | NA | 14.87 | 4.25 | 14.96 | NA | 6.7 | 4.0 | 3.0 | NA | 29.54 | 6.26 | 16.91 | NA | 4.07 | 0.67 | 3.93 | NA | 1.27 | 0.45 | 1.37 | NA | 1.45 | 1.50 |
| (4,6) | 9 | 11 | 5.74 | 0.34 | 5.41 | 0.47 | 19.1 | 2.9 | 19.9 | 3.7 | 15.16 | 2.78 | 16.81 | 2.61 | 3.9 | 1.8 | 3.1 | 1.5 | 20.41 | 8.91 | 15.04 | 4.77 | 4.26 | 0.82 | 4.69 | 1.05 | 1.16 | 0.60 | 1.34 | 0.21 | 1.34 | 1.41 |
| (6,8) | 18 | 13 | 7.19 | 0.58 | 7.38 | 0.72 | 24.5 | 6.5 | 24.7 | 4.6 | 18.07 | 3.75 | 20.01 | 2.50 | 6.4 | 4.4 | 4.6 | 3.8 | 17.41 | 10.59 | 17.41 | 10.59 | 4.24 | 0.85 | 4.71 | 0.59 | 2.04 | 1.22 | 1.54 | 0.26 | 1.54 | 1.61 |
| (8,10) | 22 | 21 | 9.19 | 0.64 | 9.49 | 0.61 | 31.6 | 13.0 | 35.6 | 12.9 | 22.19 | 4.08 | 26.32 | 6.07 | 9.4 | 10.4 | 9.2 | 7.8 | 25.80 | 13.92 | 22.26 | 13.20 | 4.67 | 0.87 | 5.53 | 0.95 | 2.74 | 1.25 | 1.54 | 0.26 | 1.54 | 1.68 |
| (10,12) | 5 | 18 | 11.12 | 0.61 | 11.07 | 0.28 | 36.2 | 6.3 | 45.3 | 13.9 | 27.77 | 3.42 | 30.56 | 6.44 | 8.4 | 4.4 | 14.7 | 8.5 | 22.44 | 8.25 | 29.96 | 10.88 | 5.43 | 0.87 | 5.66 | 0.65 | 2.74 | 1.24 | 1.62 | 0.21 | 1.62 | 1.66 |
| (12,16) | 18 | 11 | 14.47 | 1.33 | 13.95 | 0.87 | 65.8 | 26.5 | 44.0 | 14.0 | 32.51 | 7.19 | 32.61 | 7.19 | 25.7 | 16.8 | 11.5 | 7.5 | 35.77 | 12.72 | 24.17 | 8.02 | 5.65 | 1.18 | 5.66 | 0.65 | 2.34 | 1.51 | 1.80 | 0.34 | 1.67 | 1.55 |
| (16,20) | 154 | 41 | 18.57 | 0.83 | 18.92 | 0.75 | 63.7 | 15.9 | 74.8 | 12.5 | 42.43 | 7.32 | 57.96 | 7.28 | 21.1 | 11.2 | 16.9 | 8.2 | 31.95 | 8.30 | 21.65 | 8.25 | 7.86 | 0.90 | 6.10 | 1.08 | 3.43 | 1.83 | 1.82 | 0.25 | 1.82 | 1.93 |
| (20,25) | 135 | 42 | 23.41 | 1.40 | 23.70 | 1.37 | 66.4 | 19.2 | 77.5 | 19.3 | 43.32 | 7.03 | 58.82 | 9.21 | 23.1 | 13.7 | 17.4 | 11.0 | 32.62 | 9.55 | 21.25 | 8.61 | 5.77 | 0.81 | 7.34 | 1.24 | 4.99 | 2.39 | 1.86 | 0.32 | 1.86 | 1.93 |
| (25,30) | 114 | 71 | 27.90 | 1.46 | 27.98 | 1.44 | 65.9 | 17.4 | 75.5 | 20.9 | 42.37 | 7.04 | 58.82 | 9.21 | 23.5 | 12.9 | 16.7 | 15.1 | 33.50 | 10.86 | 20.50 | 8.21 | 5.83 | 0.87 | 7.34 | 1.24 | 4.62 | 2.92 | 1.65 | 0.27 | 1.80 | 1.86 |
| (30,35) | 95 | 71 | 33.18 | 1.34 | 33.10 | 1.47 | 74.8 | 20.3 | 77.5 | 18.3 | 45.46 | 6.95 | 58.52 | 9.23 | 29.3 | 14.6 | 18.9 | 11.8 | 36.97 | 9.70 | 23.09 | 8.65 | 6.03 | 0.94 | 7.50 | 1.17 | 4.40 | 2.21 | 1.71 | 0.22 | 1.71 | 1.80 |
| (35,40) | 112 | 87 | 38.17 | 1.45 | 38.10 | 1.41 | 78.5 | 20.6 | 80.1 | 20.2 | 46.96 | 7.57 | 59.28 | 9.50 | 31.5 | 14.9 | 20.0 | 12.3 | 38.29 | 9.00 | 25.86 | 8.49 | 7.32 | 1.17 | 7.50 | 1.17 | 4.40 | 1.79 | 1.67 | 0.34 | 1.67 | 1.77 |
| (40,45) | 99 | 53 | 42.92 | 1.33 | 42.57 | 1.29 | 80.8 | 22.2 | 82.3 | 18.5 | 47.08 | 8.20 | 59.28 | 9.50 | 33.8 | 15.3 | 23.0 | 12.5 | 39.94 | 8.82 | 26.35 | 9.81 | 6.24 | 1.02 | 7.99 | 1.16 | 4.46 | 2.03 | 1.72 | 0.24 | 1.72 | 1.78 |
| (45,50) | 37 | 30 | 47.19 | 1.27 | 48.20 | 1.37 | 75.5 | 20.7 | 77.8 | 19.3 | 45.01 | 7.42 | 63.72 | 6.48 | 30.5 | 14.5 | 29.1 | 13.7 | 38.08 | 10.35 | 29.89 | 8.78 | 5.73 | 0.78 | 7.50 | 1.09 | 4.99 | 2.39 | 1.82 | 0.32 | 1.72 | 1.83 |
| (50,55) | 32 | 13 | 53.16 | 1.57 | 53.46 | 1.20 | 80.5 | 20.7 | 87.0 | 10.2 | 45.18 | 5.96 | 61.65 | 7.44 | 35.3 | 15.7 | 25.3 | 7.2 | 41.92 | 8.73 | 31.98 | 7.19 | 5.84 | 0.81 | 7.64 | 0.96 | 5.06 | 1.99 | 1.75 | 0.17 | 1.75 | 1.83 |
| (55,60) | 22 | 23 | 58.18 | 1.40 | 57.52 | 1.24 | 66.7 | 10.1 | 79.9 | 12.6 | 56.76 | 5.89 | 61.72 | 6.29 | 23.2 | 8.2 | 28.2 | 8.2 | 38.09 | 5.81 | 28.68 | 5.83 | 5.49 | 0.82 | 7.56 | 0.72 | 4.49 | 1.39 | 1.71 | 0.16 | 1.71 | 1.75 |
| (60,65) | 22 | 37 | 63.11 | 1.66 | 62.50 | 1.44 | 71.2 | 16.3 | 76.4 | 15.1 | 42.61 | 5.96 | 53.98 | 9.37 | 28.6 | 11.7 | 22.4 | 7.3 | 38.16 | 4.80 | 28.22 | 6.25 | 5.92 | 0.83 | 7.02 | 0.79 | 4.16 | 1.43 | 1.68 | 0.23 | 1.68 | 1.70 |
| (65,70) | 40 | 29 | 68.05 | 1.64 | 68.66 | 1.45 | 67.1 | 14.6 | 71.2 | 16.3 | 42.61 | 5.96 | 53.98 | 9.37 | 28.78 | 5.58 | 22.4 | 7.3 | 38.78 | 5.58 | 28.78 | 5.58 | 5.30 | 0.61 | 6.53 | 0.93 | 4.35 | 1.50 | 1.72 | 0.20 | 1.72 | 1.70 |
| (70,80) | 187 | 192 | 75.42 | 2.87 | 75.25 | 2.96 | 67.1 | 14.6 | 80.2 | 14.0 | 39.22 | 6.23 | 53.83 | 7.24 | 32.14 | 6.27 | 27.9 | 10.0 | 38.96 | 7.67 | 32.14 | 6.27 | 4.76 | 0.71 | 5.91 | 1.00 | 3.37 | 1.21 | 1.73 | 0.20 | 1.73 | 1.75 |
| (80,90) | 46 | 46 | 84.02 | 2.58 | 83.96 | 2.31 | 63.3 | 12.9 | 75.6 | 14.3 | 37.66 | 5.74 | 49.76 | 7.38 | 33.49 | 5.41 | 39.58 | 7.41 | 40.59 | 6.78 | 39.58 | 7.41 | 4.55 | 0.81 | 5.10 | 0.85 | 3.30 | 1.37 | 1.72 | 0.28 | 1.56 | 1.75 |
| (90,100) | 14 | 8 | 94.93 | 1.44 | 94.00 | 1.85 | 62.4 | 12.2 | 62.6 | 9.5 | 45.18 | 4.93 | 45.18 | 4.93 | 21.4 | 7.0 | 21.4 | 6.9 | 33.97 | 8.06 | 33.49 | 5.41 | 4.55 | 0.81 | 5.10 | 0.85 | 2.88 | 1.26 | 1.29 | 0.32 | 1.29 | 1.35 |

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**Table S2.** Model parameters for Total, Basal, and Activity Expenditure and PAL (p<0.0001 for all models)

### Total Expenditure (TEE)

| Model | Factors | Neonates (0 - 1y) β | std.err | t-value | p | Juveniles (1 - 20y) β | std.err | t-value | p | Adults (20 - 60y) β | std.err | t-value | p | Older Adults (60+ y) β | std.err | t-value | p |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. TEE~Body Mass+Sex+Age | Intercept (MJ/d) | 0.255 | 0.111 | 2.304 | 0.022 | 2.592 | 0.118 | 22.032 | 0.000 | 5.984 | 0.197 | 30.427 | 0.000 | 10.917 | 0.375 | 29.130 | 0.000 |
| | Body Mass (kg) | 0.205 | 0.025 | 8.061 | 0.000 | 0.080 | 0.004 | 22.494 | 0.000 | 0.065 | 0.002 | 30.274 | 0.000 | 0.048 | 0.002 | 24.701 | 0.000 |
| | Sex(M) | 0.090 | 0.046 | 1.953 | 0.052 | 1.436 | 0.095 | 15.145 | 0.000 | 2.669 | 0.081 | 33.036 | 0.000 | 1.659 | 0.070 | 23.672 | 0.000 |
| | Age (y) | 0.951 | 0.205 | 4.632 | 0.000 | 0.183 | 0.015 | 11.832 | 0.000 | -0.025 | 0.004 | -6.635 | 0.000 | -0.080 | 0.004 | -18.451 | 0.000 |
| | *model* (N, SEE, df, adjR2) | 235 | 0.343 | 231 | 0.733 | 1403 | 1.719 | 1399 | 0.726 | 2805 | 2.032 | 2801 | 0.482 | 1978 | 1.311 | 1974 | 0.509 |
| 2. ln(TEE)~ln(FFM)+ln(FM) | Intercept (MJ/d) | -1.270 | 0.074 | -17.130 | 0.000 | -0.121 | 0.028 | -4.259 | 0.000 | -1.102 | 0.050 | -22.038 | 0.000 | -0.773 | 0.062 | -12.403 | 0.000 |
| | ln(Fat Free Mass; kg) | 1.163 | 0.046 | 25.311 | 0.000 | 0.696 | 0.011 | 60.758 | 0.000 | 0.916 | 0.013 | 71.248 | 0.000 | 0.797 | 0.018 | 44.723 | 0.000 |
| | ln(Fat Mass; kg) | 0.053 | 0.014 | 3.862 | 0.000 | -0.041 | 0.007 | -5.714 | 0.000 | -0.030 | 0.005 | -5.986 | 0.000 | -0.016 | 0.009 | -1.828 | 0.068 |
| | *model* | 235 | 0.160 | 232 | 0.796 | 1403 | 0.154 | 1400 | 0.842 | 2805 | 0.142 | 2802 | 0.646 | 1978 | 0.139 | 1975 | 0.533 |
| 3. ln(TEE)~ln(FFM)+ln(FM)+Sex+Age | Intercept (MJ/d) | -1.122 | 0.089 | -12.619 | 0.000 | -0.348 | 0.044 | -7.956 | 0.000 | -1.118 | 0.069 | -16.129 | 0.000 | 0.092 | 0.089 | 1.032 | 0.302 |
| | ln(Fat Free Mass; kg) | 1.025 | 0.067 | 15.215 | 0.000 | 0.784 | 0.021 | 38.119 | 0.000 | 0.920 | 0.020 | 45.942 | 0.000 | 0.736 | 0.025 | 29.883 | 0.000 |
| | ln(Fat Mass; kg) | 0.034 | 0.015 | 2.294 | 0.023 | -0.019 | 0.007 | -2.622 | 0.009 | -0.032 | 0.006 | -5.149 | 0.000 | -0.030 | 0.010 | -3.118 | 0.002 |
| | Sex(M) | -0.014 | 0.021 | -0.644 | 0.520 | 0.067 | 0.009 | 7.592 | 0.000 | -0.002 | 0.009 | -0.249 | 0.803 | 0.011 | 0.010 | 1.042 | 0.298 |
| | Age (y) | 0.254 | 0.082 | 3.104 | 0.002 | -0.012 | 0.002 | -6.630 | 0.000 | 0.000 | 0.000 | 0.765 | 0.444 | -0.008 | 0.000 | -19.038 | 0.000 |
| | *model* | 235 | 0.157 | 230 | 0.804 | 1403 | 0.147 | 1398 | 0.857 | 2805 | 0.142 | 2800 | 0.646 | 1978 | 0.128 | 1973 | 0.606 |

### Basal Expenditure (BEE)

| Model | Factors | Juveniles (1 - 20y) β | std.err | t-value | p | Adults (20 - 60y) β | std.err | t-value | p | Older Adults (60+ y) β | std.err | t-value | p |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4. BEE~Body Mass+Sex+Age | Intercept (MJ/d) | 2.965 | 0.158 | 18.785 | 0.000 | 3.649 | 0.104 | 34.943 | 0.000 | 5.905 | 0.379 | 15.571 | 0.000 |
| | Body Mass (kg) | 0.034 | 0.003 | 11.004 | 0.000 | 0.036 | 0.001 | 32.494 | 0.000 | 0.031 | 0.002 | 14.277 | 0.000 |
| | Sex(M) | 1.185 | 0.101 | 11.733 | 0.000 | 1.263 | 0.045 | 27.915 | 0.000 | 0.724 | 0.066 | 10.939 | 0.000 |
| | Age (y) | 0.033 | 0.015 | 2.212 | 0.028 | -0.008 | 0.002 | -3.487 | 0.001 | -0.041 | 0.004 | -9.501 | 0.000 |
| | *model* | 345 | 0.848 | 341 | 0.581 | 1036 | 0.694 | 1032 | 0.682 | 621 | 0.761 | 617 | 0.520 |
| 5. ln(BEE)~ln(FFM)+ln(FM) | Intercept (MJ/d) | 0.055 | 0.078 | 0.706 | 0.480 | -0.954 | 0.059 | -16.176 | 0.000 | -0.923 | 0.099 | -9.350 | 0.000 |
| | ln(Fat Free Mass; kg) | 0.535 | 0.028 | 19.103 | 0.000 | 0.707 | 0.016 | 45.353 | 0.000 | 0.656 | 0.027 | 24.640 | 0.000 |
| | ln(Fat Mass; kg) | -0.095 | 0.014 | -6.784 | 0.000 | 0.019 | 0.006 | 3.408 | 0.001 | 0.028 | 0.015 | 1.819 | 0.069 |
| | *model* | 345 | 0.153 | 342 | 0.573 | 1036 | 0.103 | 1033 | 0.688 | 621 | 0.135 | 618 | 0.530 |
| 6. ln(BEE)~ln(FFM)+ln(FM)+Sex+Age | Intercept (MJ/d) | -0.270 | 0.100 | -2.704 | 0.007 | -0.497 | 0.079 | -6.281 | 0.000 | -0.089 | 0.151 | -0.587 | 0.557 |
| | ln(Fat Free Mass; kg) | 0.663 | 0.044 | 15.167 | 0.000 | 0.561 | 0.023 | 24.008 | 0.000 | 0.549 | 0.040 | 13.663 | 0.000 |
| | ln(Fat Mass; kg) | -0.054 | 0.014 | -4.005 | 0.000 | 0.054 | 0.007 | 7.809 | 0.000 | 0.042 | 0.016 | 2.619 | 0.009 |
| | Sex(M) | 0.090 | 0.019 | 4.780 | 0.000 | 0.086 | 0.010 | 8.297 | 0.000 | 0.037 | 0.016 | 2.288 | 0.022 |
| | Age (y) | -0.018 | 0.003 | -5.102 | 0.000 | -0.001 | 0.000 | -2.124 | 0.034 | -0.006 | 0.001 | -8.814 | 0.000 |
| | *model* | 345 | 0.137 | 340 | 0.658 | 1036 | 0.100 | 1031 | 0.708 | 621 | 0.128 | 616 | 0.582 |

### Activity Expenditure (AEE)

| Model | Factors | Juveniles (1 - 20y) β | std.err | t-value | p | Adults (20 - 60y) β | std.err | t-value | p | Older Adults (60+ y) β | std.err | t-value | p |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 7. AEE~Body Mass+Sex+Age | Intercept (MJ/d) | -0.481 | 0.237 | -2.030 | 0.043 | 1.822 | 0.252 | 7.231 | 0.000 | 5.835 | 0.604 | 9.663 | 0.000 |
| | Body Mass (kg) | 0.032 | 0.005 | 6.774 | 0.000 | 0.023 | 0.003 | 8.870 | 0.000 | 0.014 | 0.003 | 4.111 | 0.000 |
| | Sex(M) | 0.999 | 0.152 | 6.581 | 0.000 | 1.308 | 0.109 | 11.983 | 0.000 | 0.661 | 0.105 | 6.264 | 0.000 |
| | Age (y) | 0.113 | 0.022 | 5.133 | 0.000 | -0.012 | 0.006 | -2.216 | 0.027 | -0.058 | 0.007 | -8.354 | 0.000 |
| | *model* | 345 | 1.275 | 341 | 0.476 | 1036 | 1.675 | 1032 | 0.201 | 621 | 1.212 | 617 | 0.219 |
| 8. ln(AEE)~ln(FFM)+ln(FM) | Intercept (MJ/d) | -3.330 | 0.231 | -14.447 | 0.000 | -4.124 | 0.248 | -16.627 | 0.000 | -2.556 | 0.401 | -6.381 | 0.000 |
| | ln(Fat Free Mass; kg) | 1.301 | 0.082 | 15.776 | 0.000 | 1.476 | 0.065 | 22.614 | 0.000 | 0.952 | 0.108 | 8.807 | 0.000 |
| | ln(Fat Mass; kg) | -0.099 | 0.041 | -2.414 | 0.016 | -0.142 | 0.023 | -6.130 | 0.000 | -0.042 | 0.062 | -0.685 | 0.494 |
| | *model* | 338 | 0.445 | 335 | 0.550 | 1023 | 0.423 | 1020 | 0.333 | 612 | 0.546 | 609 | 0.116 |
| 9. ln(AEE)~ln(FFM)+ln(FM)+Sex+Age | Intercept (MJ/d) | -3.437 | 0.332 | -10.366 | 0.000 | -5.194 | 0.248 | -15.187 | 0.000 | 0.222 | 0.625 | 0.355 | 0.723 |
| | ln(Fat Free Mass; kg) | 1.349 | 0.145 | 9.295 | 0.000 | 1.816 | 0.100 | 18.079 | 0.000 | 0.674 | 0.165 | 4.088 | 0.000 |
| | ln(Fat Mass; kg) | -0.093 | 0.044 | -2.097 | 0.037 | -0.221 | 0.029 | -7.598 | 0.000 | -0.010 | 0.066 | -0.151 | 0.880 |
| | Sex(M) | 0.006 | 0.062 | 0.090 | 0.928 | -0.198 | 0.044 | -4.480 | 0.000 | 0.079 | 0.067 | 1.181 | 0.238 |
| | Age (y) | -0.005 | 0.011 | -0.474 | 0.636 | 0.002 | 0.001 | 1.162 | 0.246 | -0.025 | 0.003 | -7.852 | 0.000 |
| | *model* | 338 | 0.446 | 333 | 0.547 | 1023 | 0.420 | 1018 | 0.345 | 612 | 0.521 | 607 | 0.195 |

### PAL (TEE/BEE)

| Model | Factors | Juveniles (1 - 20y) β | std.err | t-value | p | Adults (20 - 60y) β | std.err | t-value | p | Older Adults (60+ y) β | std.err | t-value | p |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10. PAL~Body Mass+Sex+Age | Intercept (MJ/d) | 1.290 | 0.048 | 26.913 | 0.000 | 1.668 | 0.041 | 40.739 | 0.000 | 2.209 | 0.144 | 15.348 | 0.000 |
| | Body Mass (kg) | 0.002 | 0.001 | 2.093 | 0.037 | 0.001 | 0.000 | 2.058 | 0.040 | 0.000 | 0.001 | -0.239 | 0.811 |
| | Sex(M) | 0.050 | 0.031 | 1.641 | 0.102 | 0.094 | 0.018 | 5.312 | 0.000 | 0.058 | 0.025 | 2.298 | 0.022 |
| | Age (y) | 0.022 | 0.004 | 4.933 | 0.000 | -0.001 | 0.001 | -1.260 | 0.208 | -0.007 | 0.002 | -4.142 | 0.000 |
| | *model* | 345 | 0.258 | 341 | 0.234 | 1036 | 0.272 | 1032 | 0.032 | 621 | 0.289 | 617 | 0.032 |
| 11. PAL~ln(FFM)+ln(FM) | Intercept (MJ/d) | 0.420 | 0.129 | 3.252 | 0.001 | 0.174 | 0.148 | 1.178 | 0.239 | 1.215 | 0.212 | 5.736 | 0.000 |
| | ln(Fat Free Mass; kg) | 0.386 | 0.046 | 8.348 | 0.000 | 0.477 | 0.039 | 12.221 | 0.000 | 0.201 | 0.057 | 3.524 | 0.000 |
| | ln(Fat Mass; kg) | -0.019 | 0.023 | -0.817 | 0.415 | -0.098 | 0.014 | -6.999 | 0.000 | -0.085 | 0.033 | -2.605 | 0.009 |
| | *model* | 345 | 0.253 | 342 | 0.263 | 1036 | 0.257 | 1033 | 0.137 | 621 | 0.291 | 618 | 0.021 |
| 12. PAL~ln(FFM)+ln(FM)+Sex+Age | Intercept (MJ/d) | 0.528 | 0.185 | 2.860 | 0.005 | -0.744 | 0.200 | -3.714 | 0.000 | 1.841 | 0.340 | 5.417 | 0.000 |
| | ln(Fat Free Mass; kg) | 0.338 | 0.081 | 4.179 | 0.000 | 0.777 | 0.059 | 13.140 | 0.000 | 0.164 | 0.090 | 1.814 | 0.070 |
| | ln(Fat Mass; kg) | -0.026 | 0.025 | -1.034 | 0.302 | -0.164 | 0.021 | -9.442 | 0.000 | -0.087 | 0.036 | -2.405 | 0.016 |
| | Sex(M) | -0.009 | 0.035 | -0.250 | 0.803 | -0.174 | 0.026 | -6.645 | 0.000 | 0.000 | 0.037 | 0.007 | 0.995 |
| | Age (y) | 0.006 | 0.006 | 0.873 | 0.384 | 0.000 | 0.001 | 0.497 | 0.619 | -0.006 | 0.002 | -3.818 | 0.000 |
| | *model* | 345 | 0.253 | 340 | 0.261 | 1036 | 0.252 | 1031 | 0.171 | 621 | 0.288 | 616 | 0.040 |

**Table S3.** Adjusted total expenditure (TEE), Adjusted basal expenditure (BEE), and Adjusted BEE$_{TEE}$. *Infant data from the literature, males and females pooled. N values for infant BEE (0 to 2 years) indicate number of entries and (number of individuals).

| | Adjusted TEE - Female & Male Cohorts | | | | | | | | Adjusted BEE and Adjusted BEE$_{TEE}$ | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Adjusted TEE | | | | | | | | Adjusted BEE | | | | Adjusted BEE$_{TEE}$ | | | |
| Age | N | | mean Age | | F | | M | | N | | mean Age | | F | | M | | F | | M | |
| Cohort | F | M | F | M | mean | sd | mean | sd | F | M | F | M | mean | sd | mean | sd | mean | sd | mean | sd |
| (0,0.5] | 103 | 93 | 0.2 | 0.2 | 120.0 | 23.2 | 118.4 | 23.2 | 22 (111)* | | 0.2 | | | | 100.47 | 33.89 | 86.03 | 28.9 | | |
| (0.5,1] | 18 | 23 | 0.7 | 0.7 | 139.8 | 17.0 | 145.5 | 25.7 | 20 (88)* | | 0.9 | | | | 142.89 | 11.62 | 115.47 | 9.2 | | |
| (1,2] | 33 | 35 | 1.7 | 1.6 | 147.4 | 23.9 | 148.2 | 21.6 | 18 (86)* | | 1.6 | | | | 142.02 | 13.52 | 111.94 | 9.6 | | |
| (2,4] | 54 | 48 | 3.8 | 3.8 | 147.0 | 13.4 | 150.3 | 19.6 | 3 | 1 | 3.8 | 4.0 | 150.2 | 6.0 | 144.3 | NA | 108.6 | 7.4 | 100.7 | NA |
| (4,6] | 99 | 121 | 5.3 | 5.3 | 142.5 | 14.0 | 148.2 | 18.5 | 9 | 5 | 5.7 | 5.4 | 156.4 | 26.3 | 158.8 | 30.9 | 110.1 | 19.9 | 108.1 | 19.9 |
| (6,8] | 42 | 42 | 7.0 | 7.2 | 139.2 | 16.7 | 143.2 | 13.6 | 18 | 12 | 7.2 | 7.4 | 136.9 | 25.8 | 141.9 | 21.8 | 94.6 | 17.7 | 94.6 | 15.1 |
| (8,10] | 79 | 75 | 9.1 | 9.1 | 132.8 | 19.2 | 140.2 | 18.7 | 22 | 16 | 9.2 | 9.5 | 130.0 | 23.4 | 137.3 | 21.8 | 87.2 | 15.2 | 88.8 | 14.2 |
| (10,12] | 68 | 34 | 11.1 | 11.0 | 122.0 | 23.4 | 133.4 | 16.3 | 5 | 5 | 11.1 | 11.1 | 128.3 | 19.9 | 126.3 | 21.2 | 82.6 | 12.3 | 81.8 | 15.0 |
| (12,16] | 229 | 128 | 14.4 | 14.5 | 113.1 | 22.9 | 118.9 | 21.4 | 18 | 16 | 14.4 | 13.9 | 103.1 | 18.6 | 130.0 | 23.3 | 64.9 | 12.2 | 82.4 | 15.7 |
| (16,20] | 209 | 103 | 18.3 | 18.4 | 107.1 | 14.4 | 113.3 | 17.1 | 155 | 148 | 18.5 | 18.9 | 97.5 | 12.9 | 109.3 | 7.5 | 60.2 | 8.1 | 62.9 | 5.3 |
| (20,25] | 252 | 123 | 23.2 | 23.5 | 100.6 | 15.5 | 106.7 | 21.9 | 135 | 116 | 23.4 | 23.8 | 98.3 | 10.5 | 99.6 | 8.1 | 60.6 | 7.1 | 57.0 | 5.2 |
| (25,30] | 280 | 182 | 27.8 | 28.0 | 100.5 | 15.3 | 102.0 | 21.2 | 115 | 104 | 27.9 | 27.9 | 100.8 | 11.5 | 104.0 | 13.4 | 62.5 | 7.8 | 59.6 | 8.3 |
| (30,35] | 235 | 146 | 33.0 | 32.8 | 100.0 | 11.9 | 100.7 | 16.5 | 96 | 94 | 33.2 | 33.1 | 98.7 | 9.7 | 103.3 | 10.4 | 60.9 | 6.3 | 59.7 | 7.0 |
| (35,40] | 231 | 165 | 38.0 | 38.0 | 100.0 | 11.9 | 102.3 | 16.3 | 112 | 110 | 38.1 | 38.2 | 99.7 | 10.2 | 101.6 | 11.7 | 61.4 | 6.9 | 59.1 | 7.2 |
| (40,45] | 301 | 165 | 42.8 | 42.9 | 101.3 | 12.6 | 100.8 | 13.2 | 100 | 96 | 42.9 | 42.6 | 99.8 | 10.4 | 102.9 | 9.1 | 61.6 | 6.9 | 59.7 | 6.1 |
| (45,50] | 171 | 144 | 47.4 | 47.8 | 102.0 | 12.4 | 100.5 | 14.3 | 42 | 41 | 47.3 | 48.1 | 99.0 | 14.7 | 108.1 | 14.6 | 61.4 | 9.6 | 62.7 | 8.9 |
| (50,55] | 105 | 93 | 52.8 | 52.6 | 100.5 | 11.4 | 100.8 | 13.2 | 33 | 33 | 53.1 | 53.4 | 96.1 | 9.1 | 103.1 | 9.2 | 59.8 | 5.5 | 60.3 | 5.9 |
| (55,60] | 111 | 76 | 58.2 | 57.8 | 102.2 | 11.7 | 102.9 | 20.0 | 23 | 23 | 58.1 | 57.5 | 100.3 | 9.5 | 100.0 | 7.1 | 62.5 | 6.1 | 57.9 | 4.5 |
| (60,65] | 252 | 90 | 63.2 | 63.2 | 98.8 | 12.4 | 99.8 | 15.3 | 23 | 21 | 62.4 | 63.1 | 99.5 | 12.8 | 99.2 | 8.5 | 62.6 | 8.3 | 58.3 | 5.2 |
| (65,70] | 387 | 90 | 68.0 | 68.0 | 97.6 | 10.9 | 94.4 | 11.1 | 40 | 40 | 68.0 | 68.7 | 91.0 | 8.6 | 95.2 | 7.6 | 56.9 | 5.9 | 56.4 | 4.8 |
| (70,80] | 681 | 232 | 75.1 | 75.4 | 93.9 | 12.1 | 90.6 | 14.6 | 188 | 173 | 75.2 | 75.4 | 86.8 | 9.9 | 86.4 | 12.9 | 55.2 | 6.6 | 51.5 | 8.0 |
| (80,90] | 149 | 66 | 83.6 | 84.2 | 87.6 | 12.2 | 82.8 | 13.0 | 47 | 38 | 84.1 | 84.0 | 86.5 | 16.0 | 78.6 | 10.8 | 55.3 | 10.8 | 47.6 | 6.8 |
| (90,100] | 22 | 8 | 94.4 | 94.0 | 73.2 | 12.4 | 76.0 | 9.6 | 14 | 5 | 94.9 | 94.0 | 91.2 | 19.1 | 94.8 | 14.6 | 57.1 | 12.9 | 57.3 | 8.6 |

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898 **Table S4.** Segmented Regression Analyses

| adjTEE | Segments | | | | Break Points | | |
|---|---|---|---|---|---|---|---|
| | *beta* | *SE* | *CI_lower* | *CI_upper* | *Estimate* | *CI_lower* | *CI_upper* |
| | 84.70 | 7.15 | 70.69 | 98.71 | 0.69 | 0.61 | 0.76 |
| | -2.77 | 0.07 | -2.91 | -2.63 | 20.46 | 19.77 | 21.15 |
| | -0.02 | 0.02 | -0.07 | 0.03 | 62.99 | 60.13 | 65.85 |
| | -0.68 | 0.06 | -0.79 | -0.57 | | | |

| adjBEE | Segments | | | | Break Points | | |
|---|---|---|---|---|---|---|---|
| | *beta* | *SE* | *CI_lower* | *CI_upper* | *Estimate* | *CI_lower* | *CI_upper* |
| | 75.51 | 5.59 | 64.55 | 86.46 | 1.04 | 0.94 | 1.14 |
| | -3.75 | 0.22 | -4.17 | -3.33 | 18.00 | 16.82 | 19.18 |
| | 0.02 | 0.05 | -0.07 | 0.12 | 46.46 | 40.57 | 52.35 |
| | -0.45 | 0.04 | -0.53 | -0.37 | | | |

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