Extreme energy lability in human children:

An overlooked and central aspect of human biology

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Preprint of related ideas   http://is.gd/gjFKw

This talk is concerned with human biology and human exceptionality

humans 100,000-200,000 years BP

Approach to topic of the talk

- Key jigsaw piece in understanding
- new and unappreciated facts about human biology
- Diverse types of biological phenomena- balkanization
- Seeing familiar things in unfamiliar ways
- mathematical modeling opportunities
- Juvenility=childhood + adolescence (the period following infancy before adulthood)

Extreme energy lability of human juveniles

Energy – energy demands of the human brain

Lability – the risk of disruption to its functioning (and survival) if no matching energy supply

Juveniles – that this disruption risk is particularly extreme for children and to a lesser degree adolescents

Extreme – that is a determining aspect of human biology

Lability is “two sided”

Lability depends upon both utilization and supply

On the utilization side is the brain’s functional vulnerability to disruption in supply of energy

On the supply side are adaptations that ensure that energy is always available that matches the brain’s needs

Why the brain faces lability

low glycogen reserves

brain 6–12 μmol g^{-1}
liver 100–500 μmol g^{-1}
skeletal muscle 300–350 μmol g^{-1} Brown and Ransom 2007

high energy use

brain 13 W kg^{-1}
heart 21 W kg^{-1}
skeletal muscle 24 W kg^{-1} Elia 1992

no “off” state

11%-28%↓ sleep Nofzinger 2002; Boyle 1994
40-fold active vs rest (24 W kg^{-1} vs 0.6 W kg^{-1})

glucose specialist –not an energy “omnivore”

What will be detailed

Why on the brain side of human biology creates the risk for lability – particularly for juveniles

The exceptionality of the human brain

Infant/juvenile malnutrition risk and a ceiling upon brain size

Human juveniles show physiological adaptations to minimize energy lability

Human juveniles exist because of human behavior that pools food with juveniles and their mothers and does so in an egalitarian manner – the human exceptionality of nutritional homogeneity

Food pooling/nutritional homogeneity depends upon a ring indirect reciprocally -- adult cognition -- neuromaturation

Human brain exceptionally high energy use

brain body energy ratio ≈ 5% nearly all vertebrates Mink et al 1981

Does not vary with size Basal Metabolic Rate ≈ Body size[1]

Same ratio in cold blooded (4.8 ±0.6%)
as in warm blooded (5.5±0.7%)

primates (all over 10%)

humans 20%

Primate and human molecular adaptations

electron carrier molecule cytochrome c. This “underwent two periods of increase amino acid replacement: the first occurred early in vertebrate evolution and the second occurred at the stem of the anthropoid primates” Grossman et al 2004

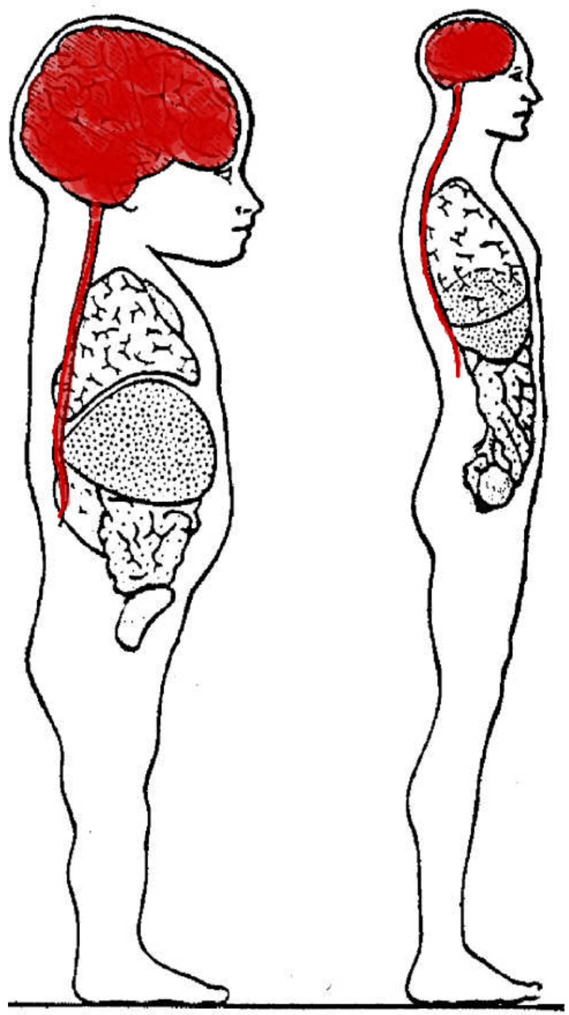
human cytochrome c gene is expressed at a higher level in human cerebral tissue than in chimpanzees or gorillas Uddin et al 2008

Suzana Herculano-Houzel Primates scale up brain size near linearly with increase in neuron numbers

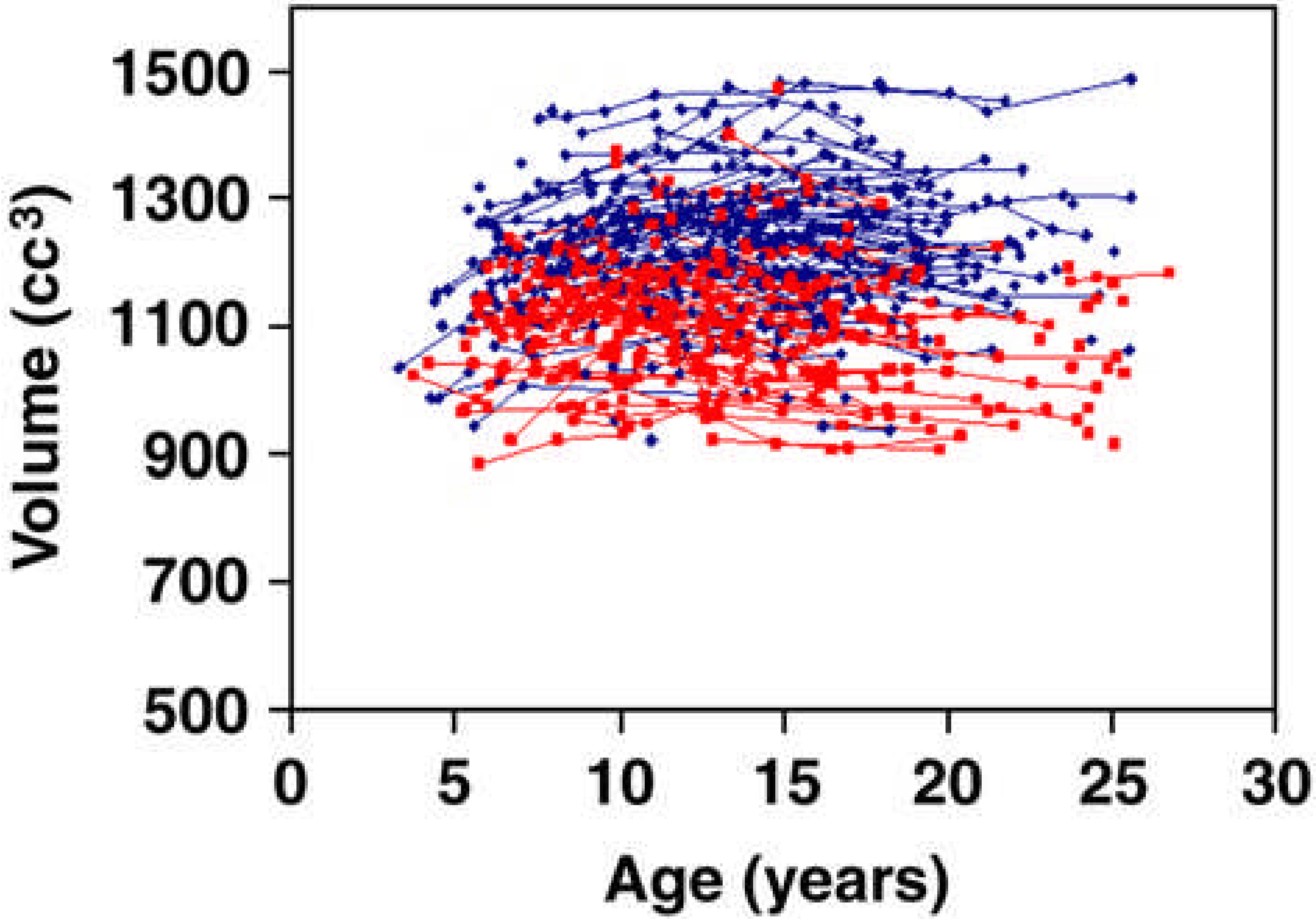
A human with rodent scaling would have a brain 43 kg

juveniles have a very large brain body ratio

Newborn adult brain size difference
24%-31% humans Vinicius 2005

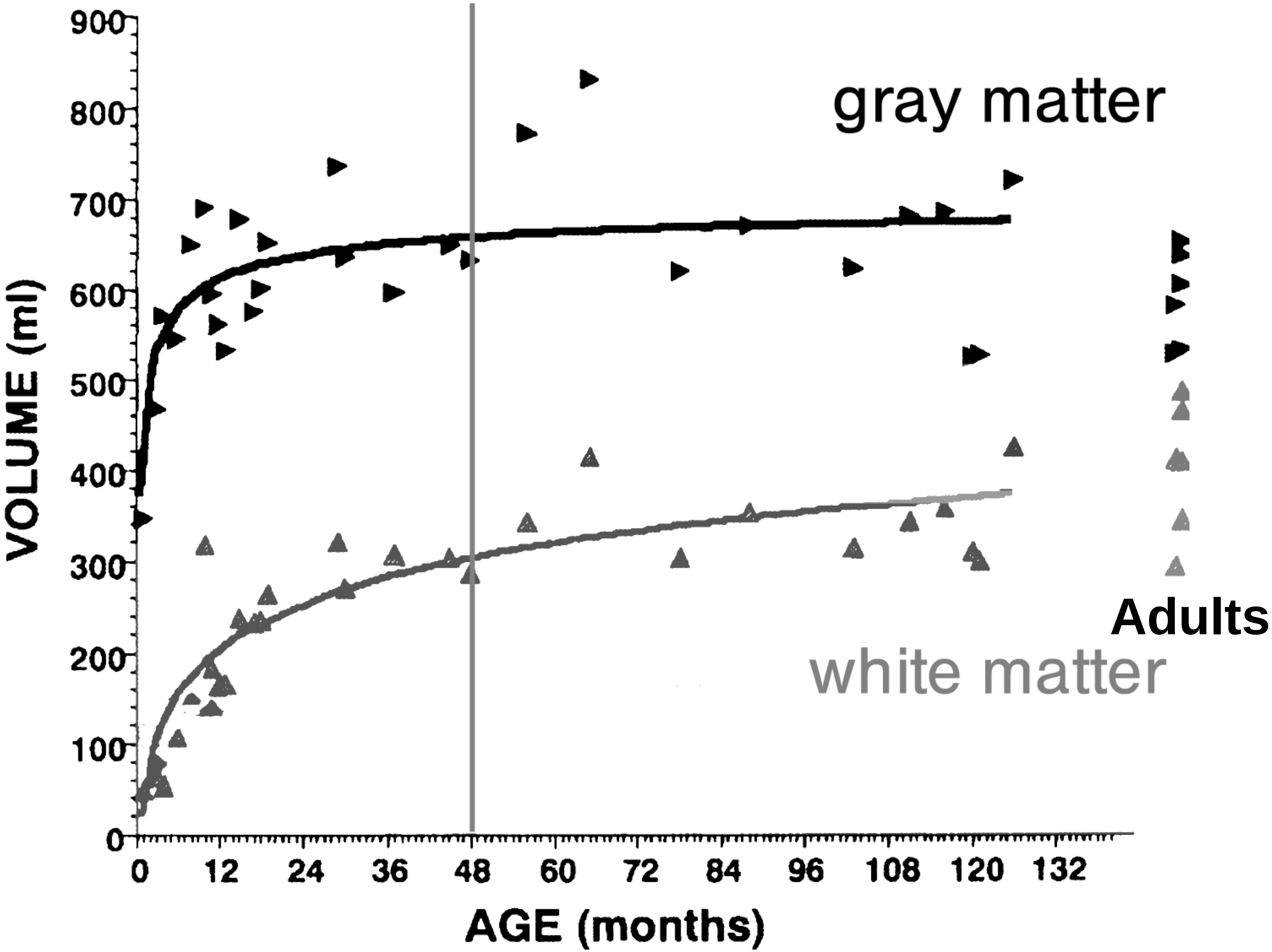


Human brains are nearly full size by four



Blue = male red = female Lenroot et al 2007

Infant gray matter adult size or larger



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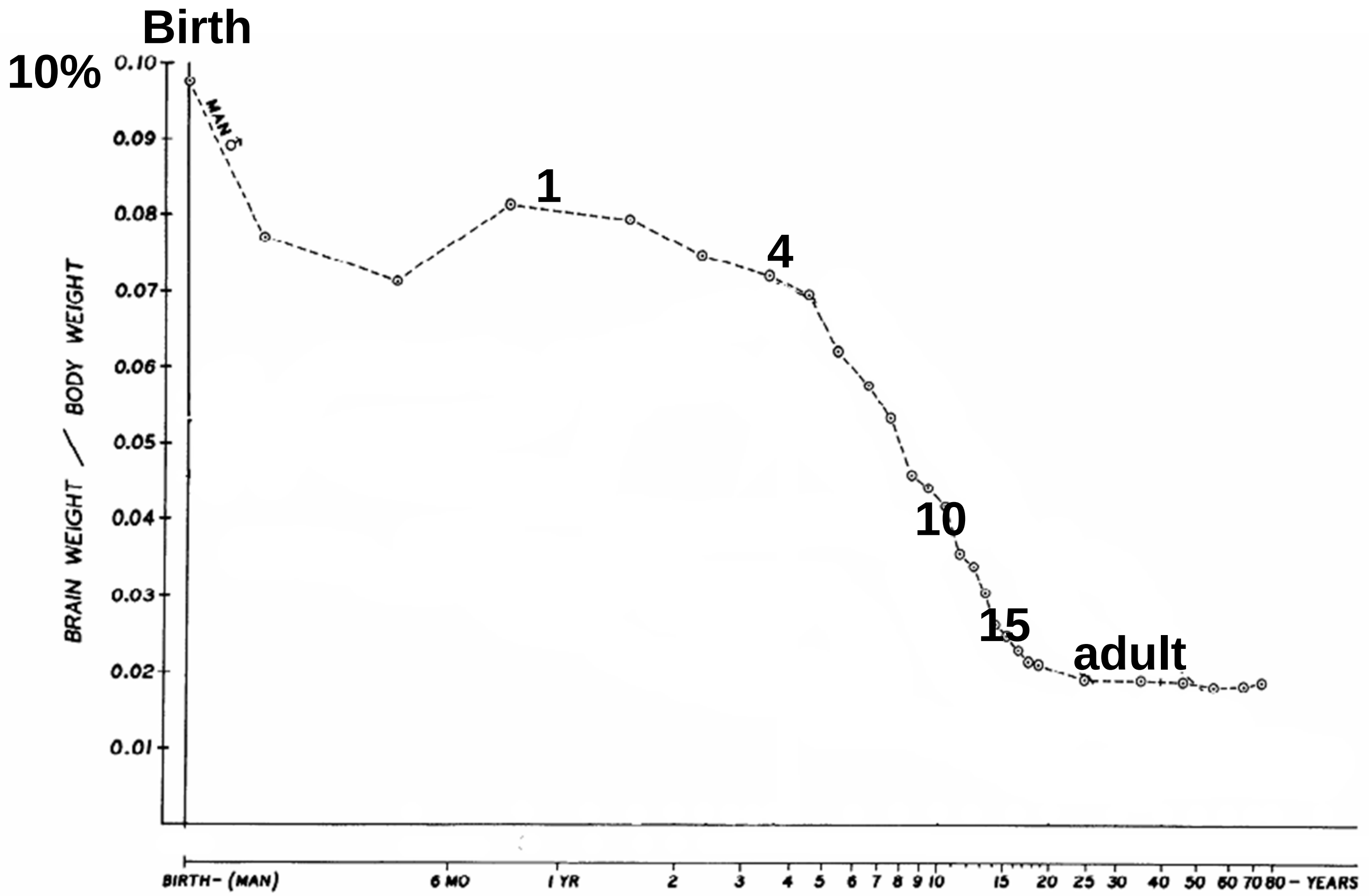
Brain body percentage change



Kobayashi 1963

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Brain body % in nonhumans

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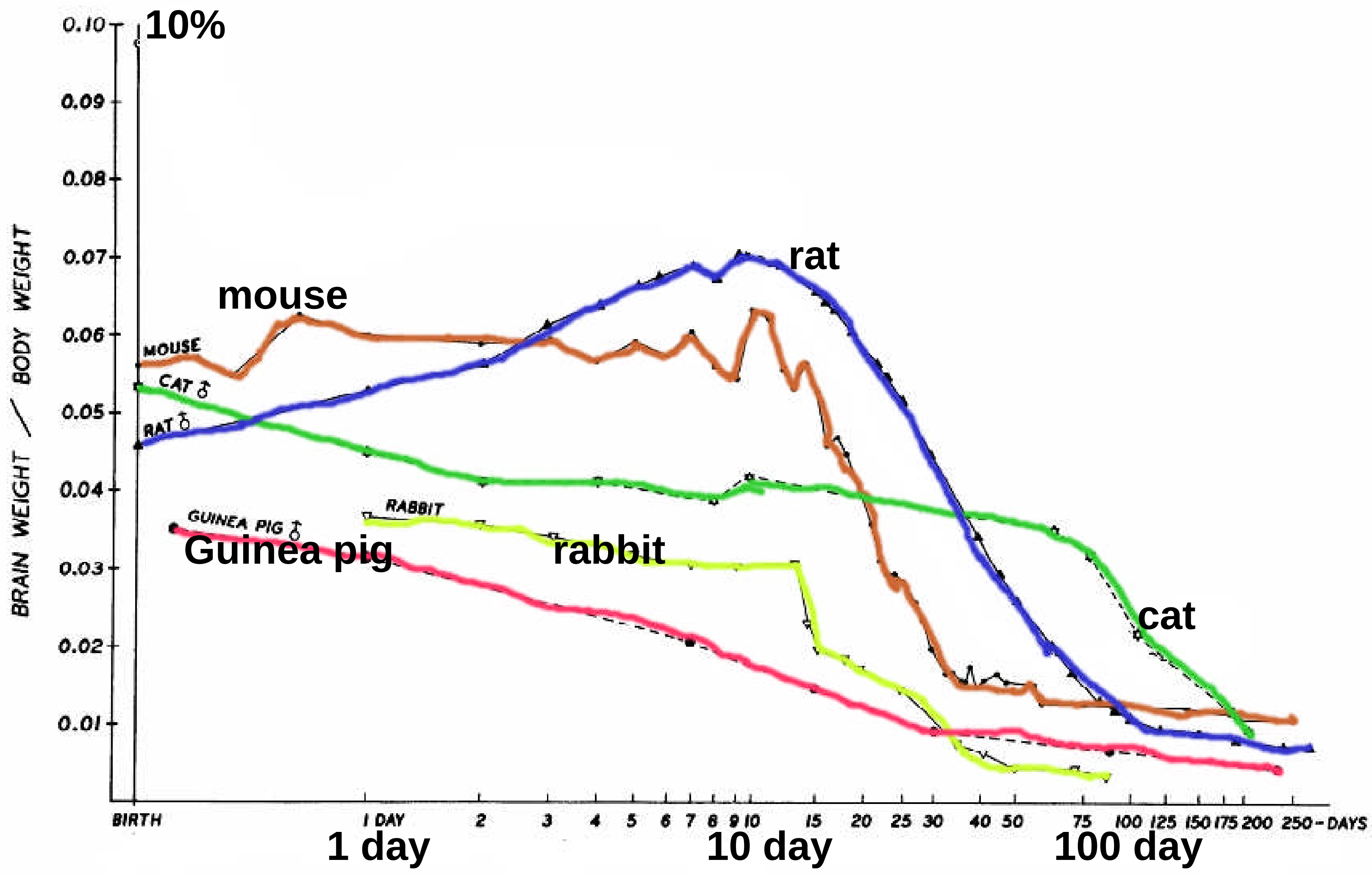
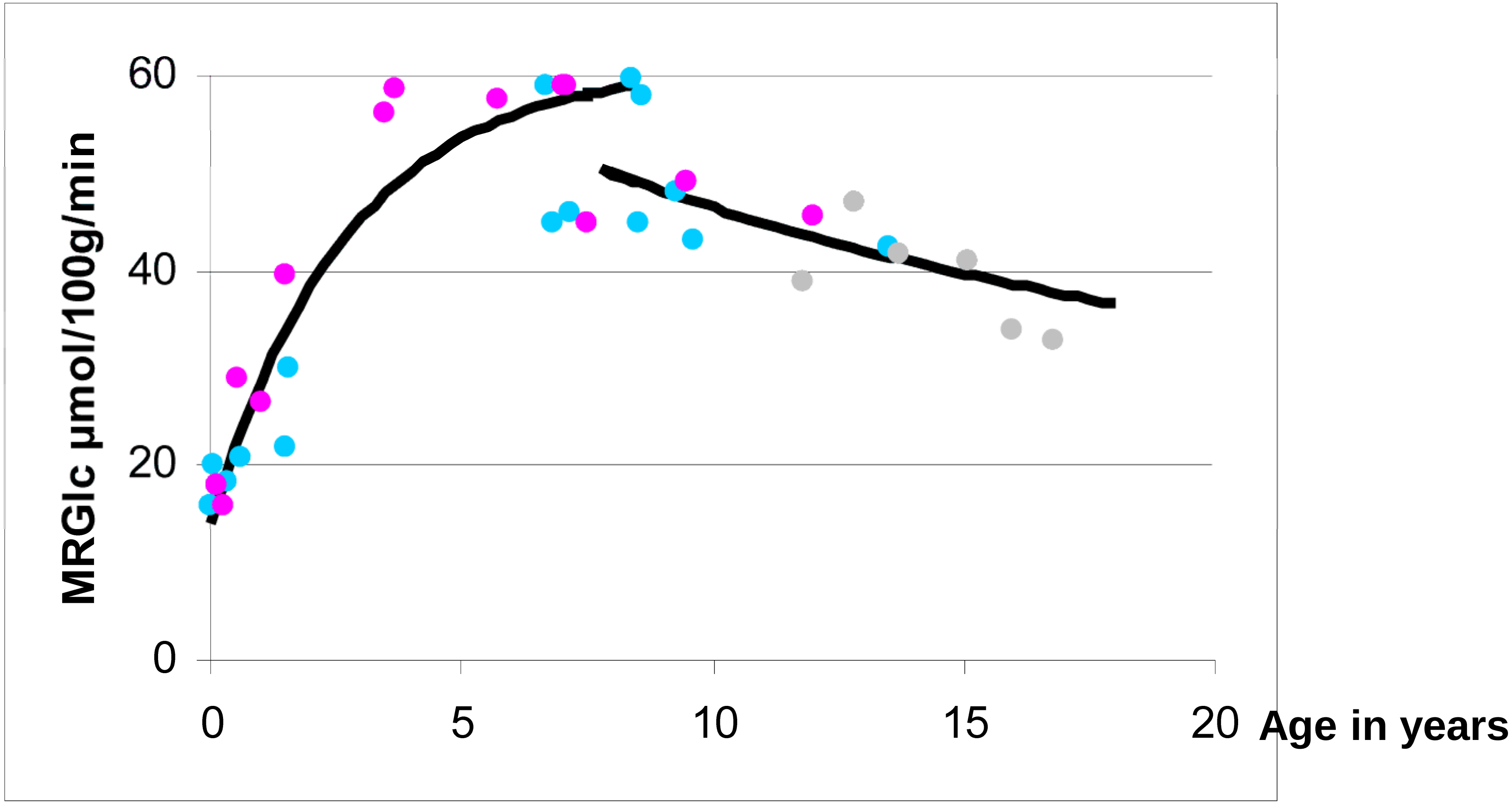


Kobayashi 1963

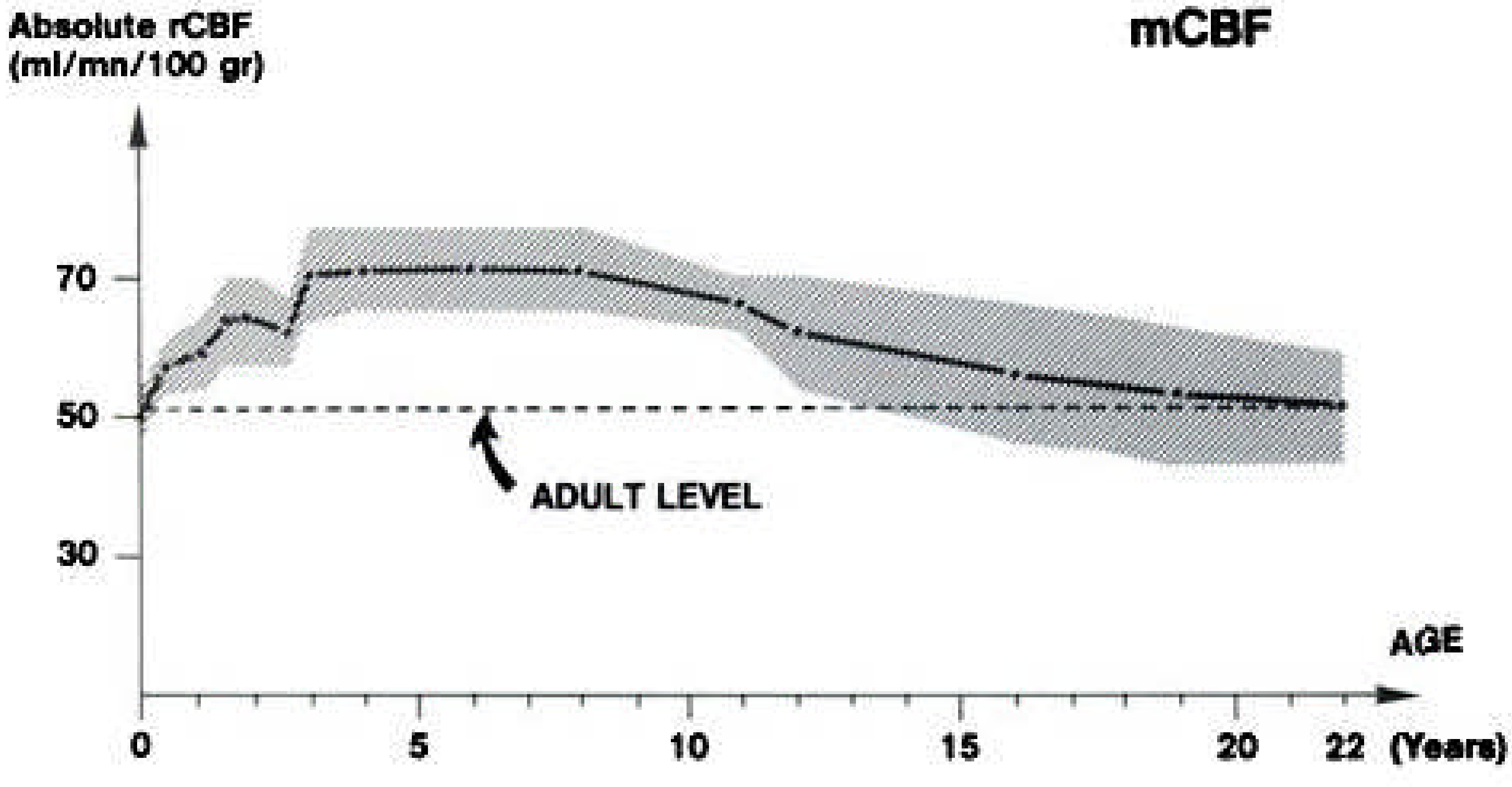
Juvenile gray matter inverted U metabolic rate



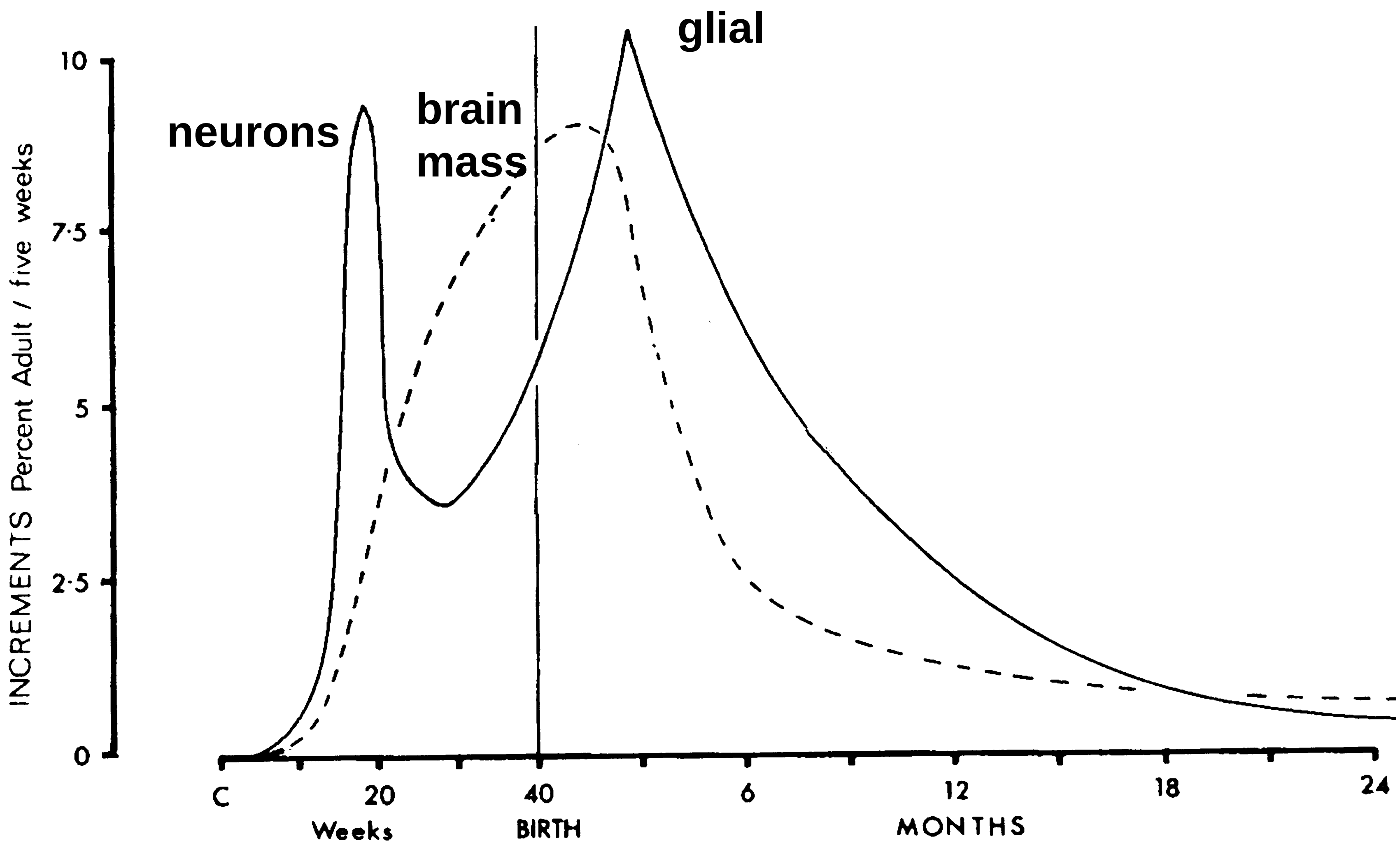
(Chugani et al 1987 Muzik et al 1999

Inverted U in blood flow parallels energy use

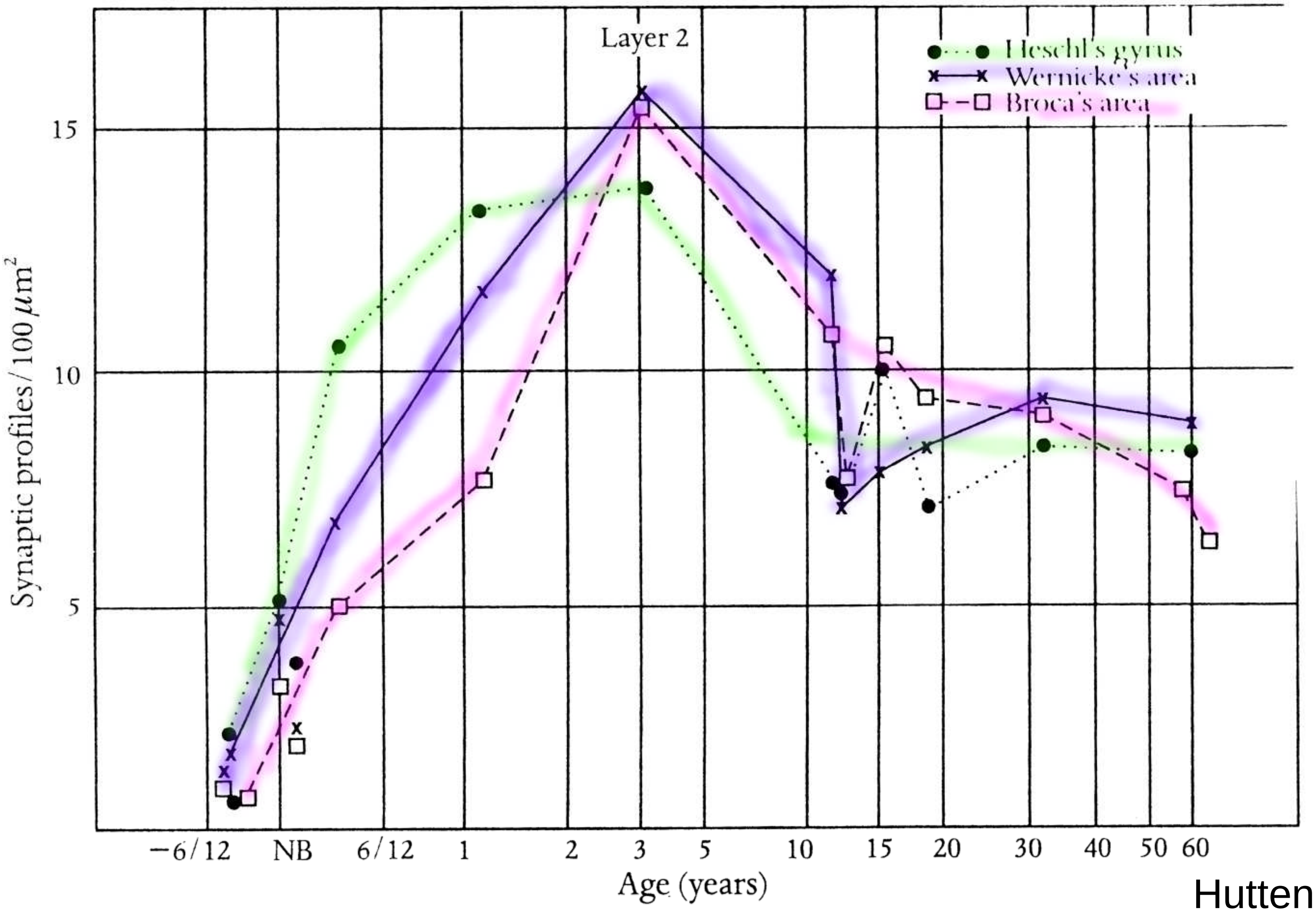
Global blood flow 50%-85% higher in children than adults Chiron et al 1992



Not due to new neurons nor glial cells

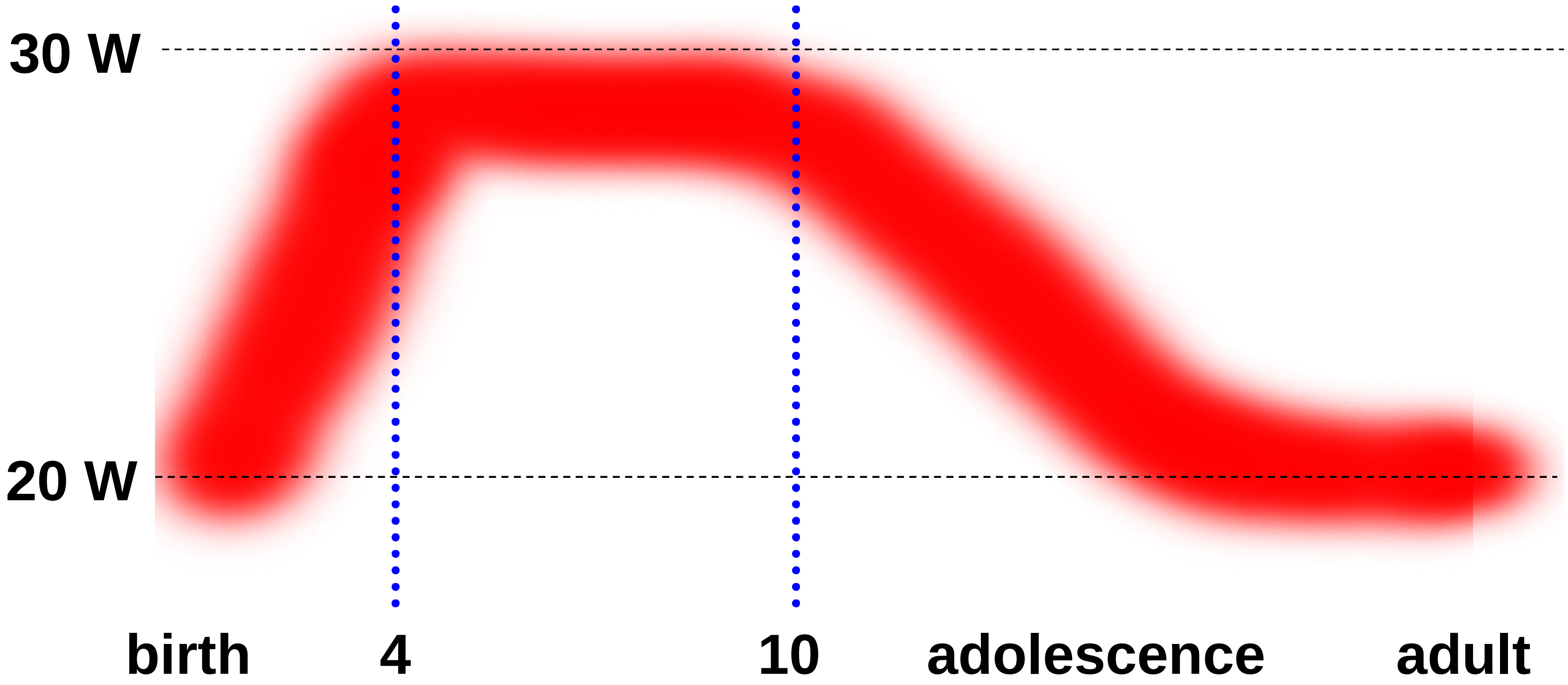


Exuberance of synapses – neuromaturation

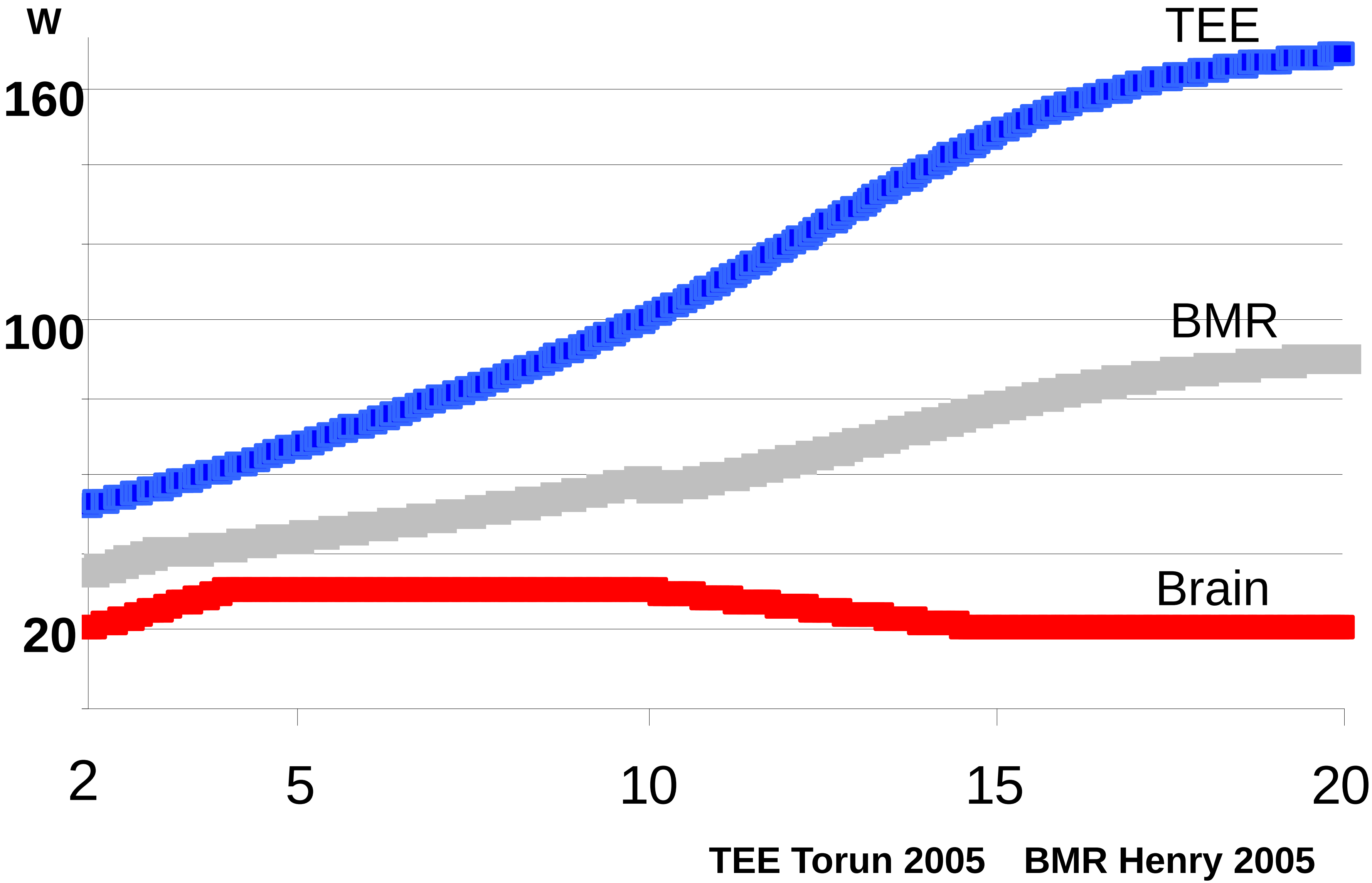


Huttenlocher 2002

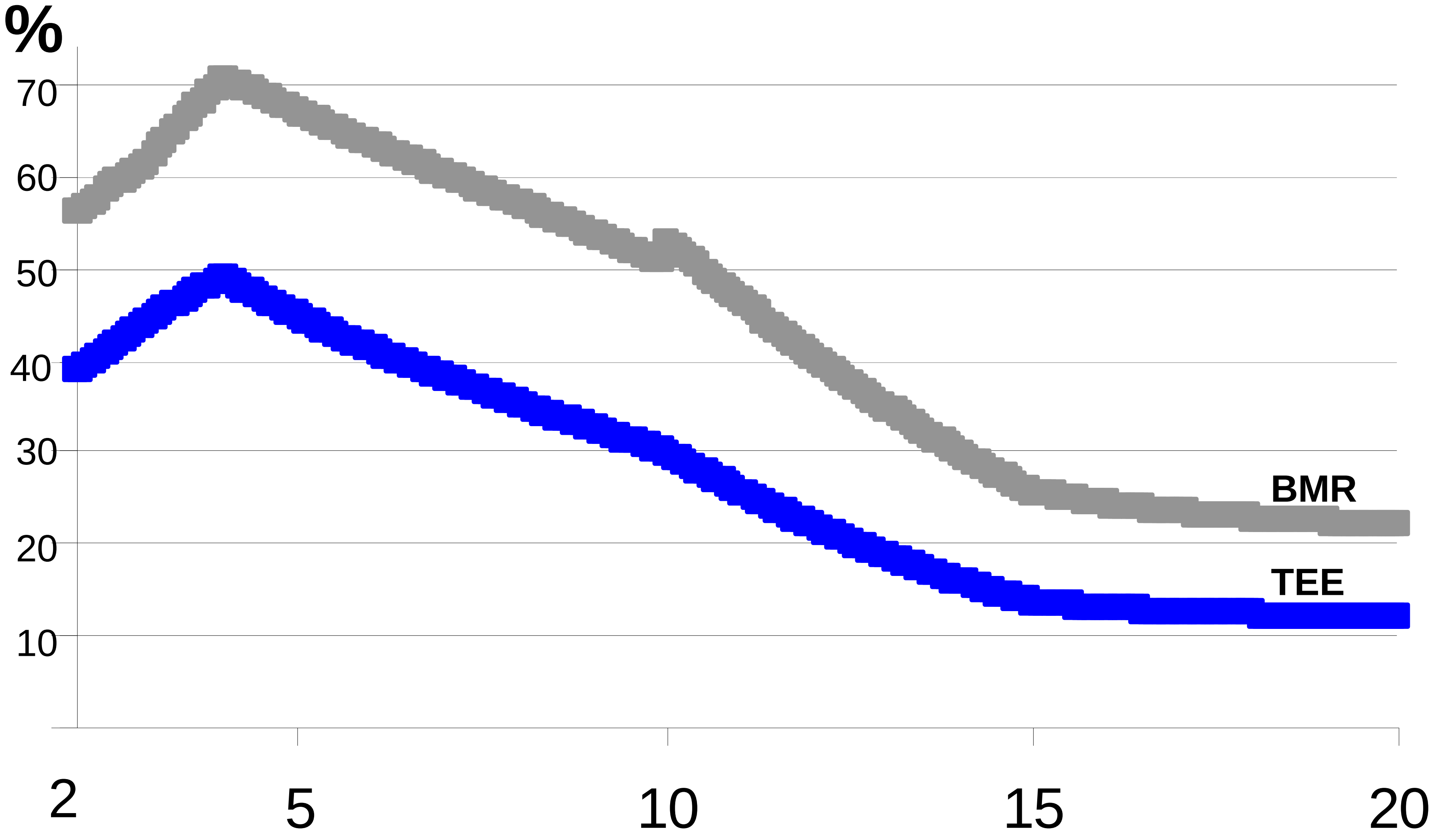
Total brain energy use



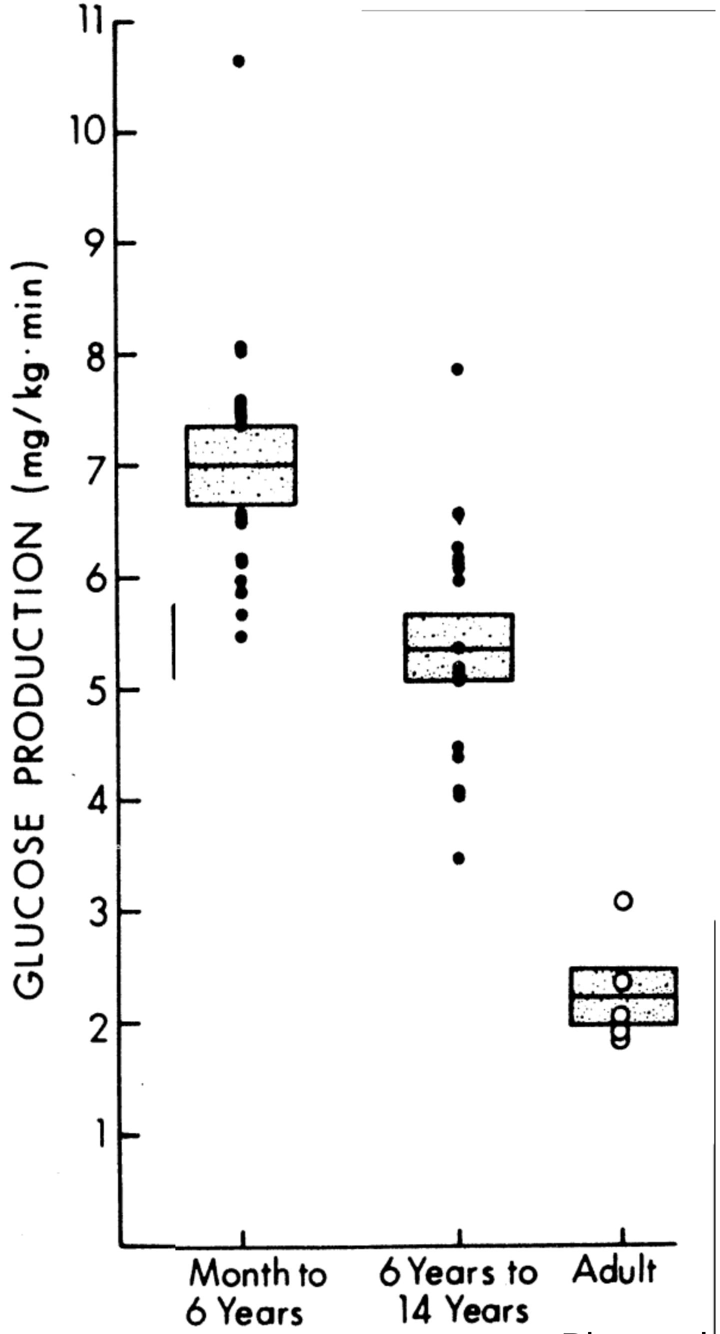
Total energy expenditure, Basal metabolic rate and brain in Watts as they change in development



Brain metabolism as a percentage of total energy expenditure and basal metabolic rate

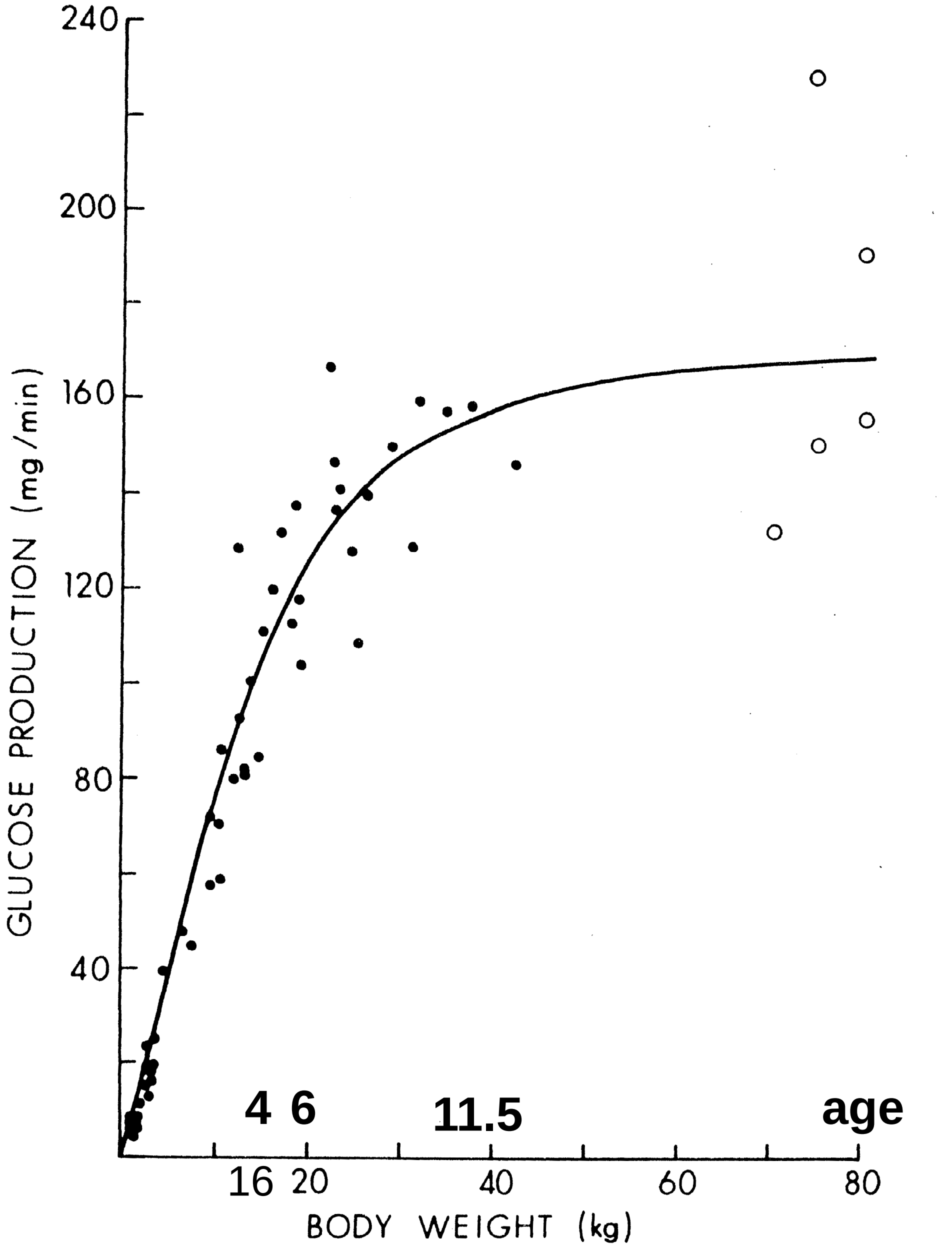


Children's livers make vast quantities of glucose



Bier et al 1977

Children's liver's glucose total production: half adult range by four



Bier et al 1977

Lability—plasma glucose shortage risk

15 kg child (3 yrs 6 m) has 3.4 g of circulating glucose

30 kg child (9 yrs 4 m) 6.7 g
80 kg adult 18 g

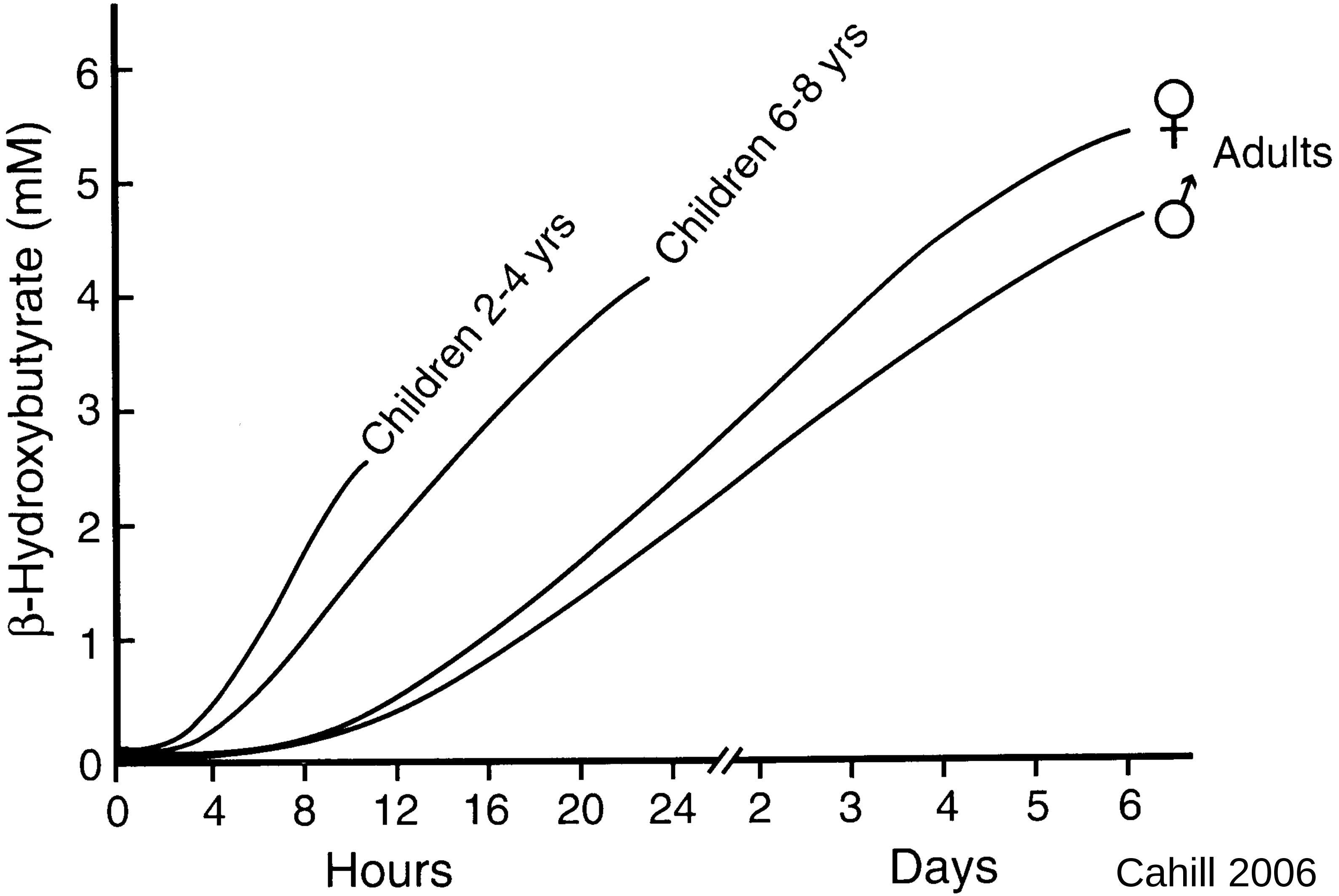
half life rate of plasma glucose turnover

15 kg child = 26 min

80 kg adult = 78 min

Haymond & Sunehag 1999

children are quick in fast to hypoglycemia (indexed here by production of β-hydroxybutyrate)

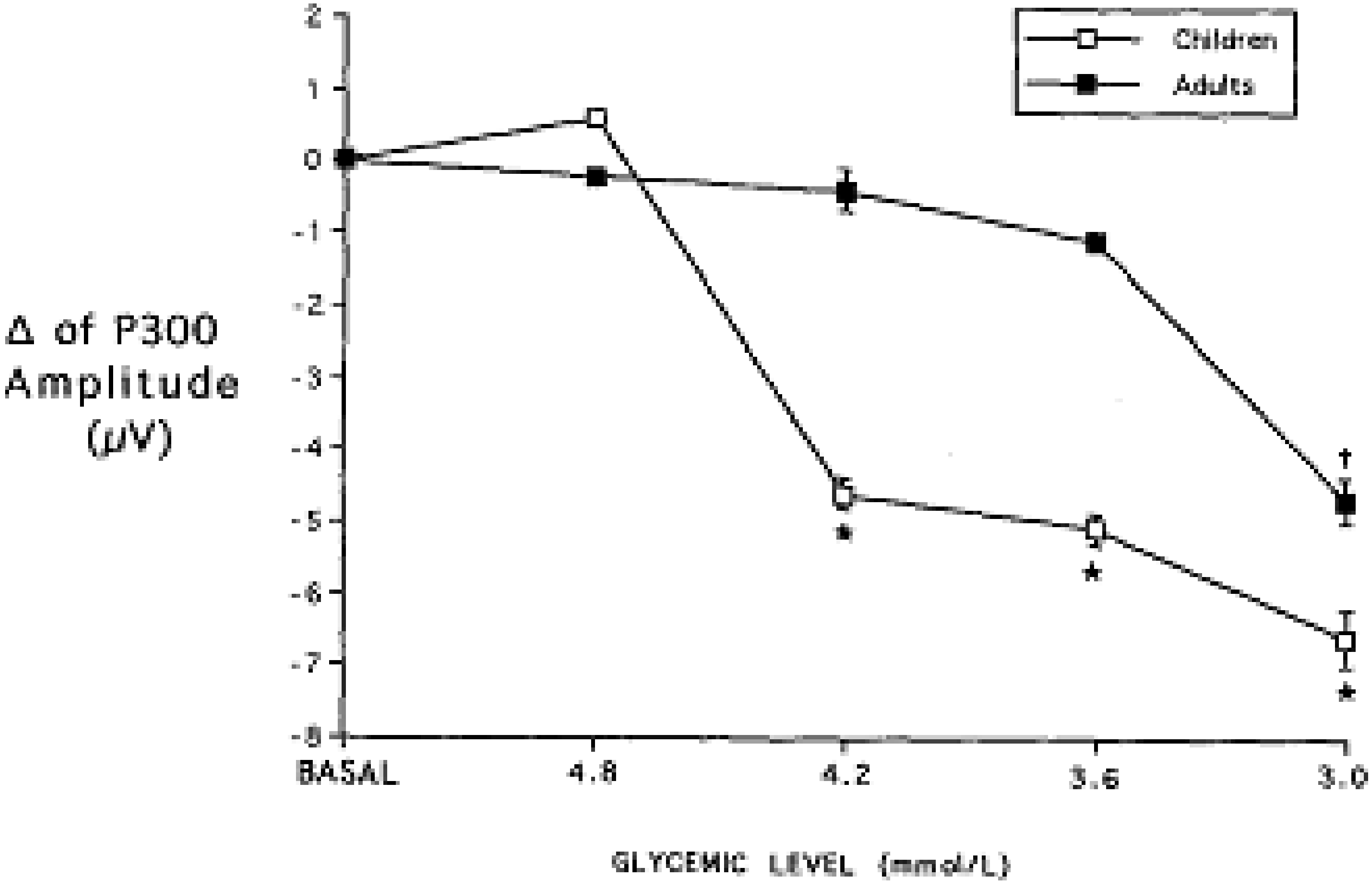


Cahill 2006

Lability— other evidence of plasma glucose risk

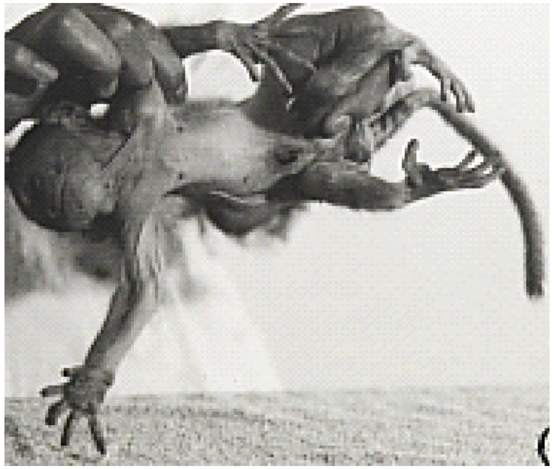
- Children during controlled insulin hypoglycemia –a two-fold greater peak of the counter-regulatory hormone epinephrine to plasma glucose depletion than adults and with a lower plasma glucose reduction Amiel et al 1987 Davis et al 1994 Jones et al 1995.

Children risk neuroglycopenia with lower falls in plasma glucose

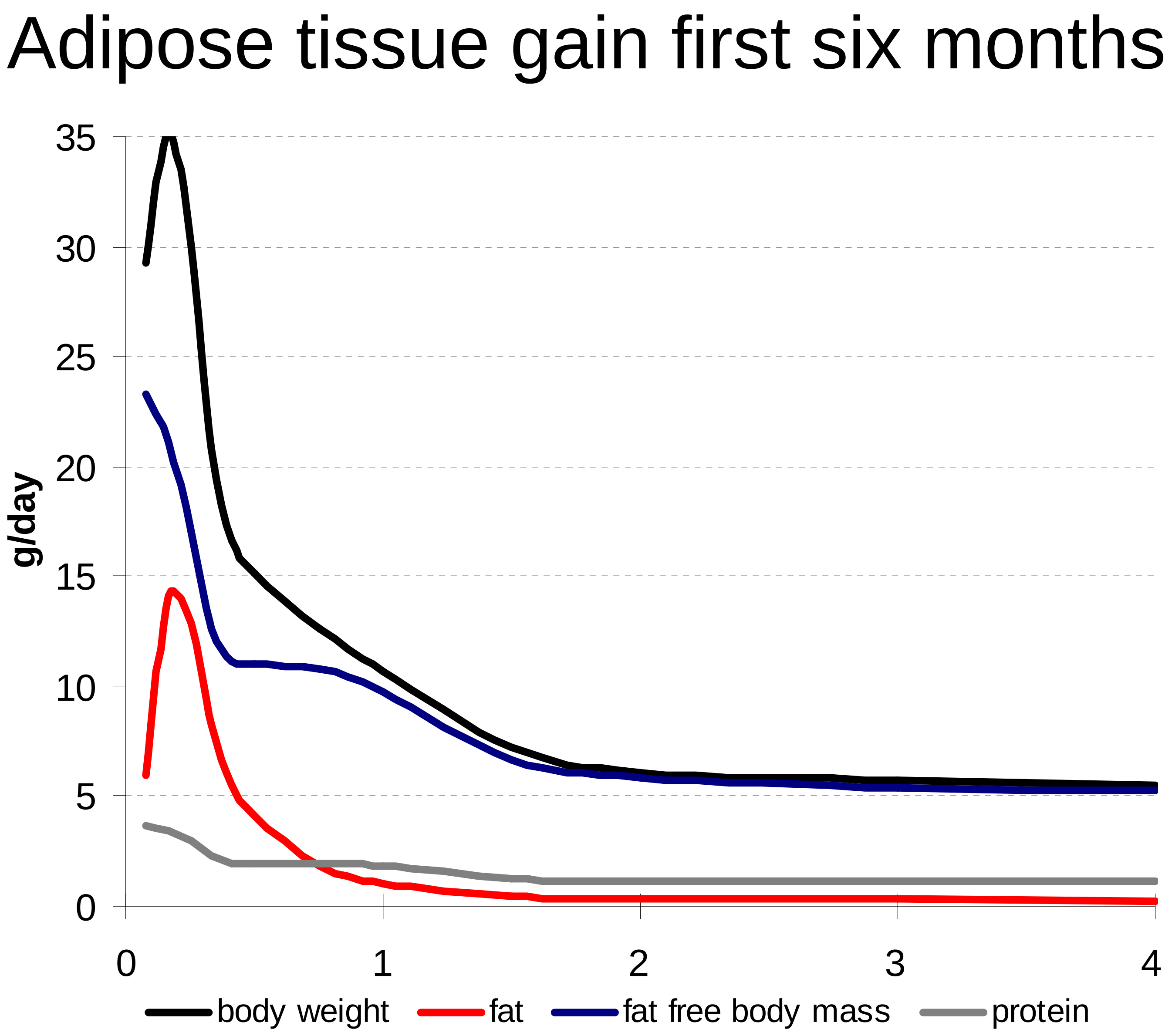


Jones et al 1985

Newborns adipose tissue



The supine position of postnatal human infants Takeshita et al 2009

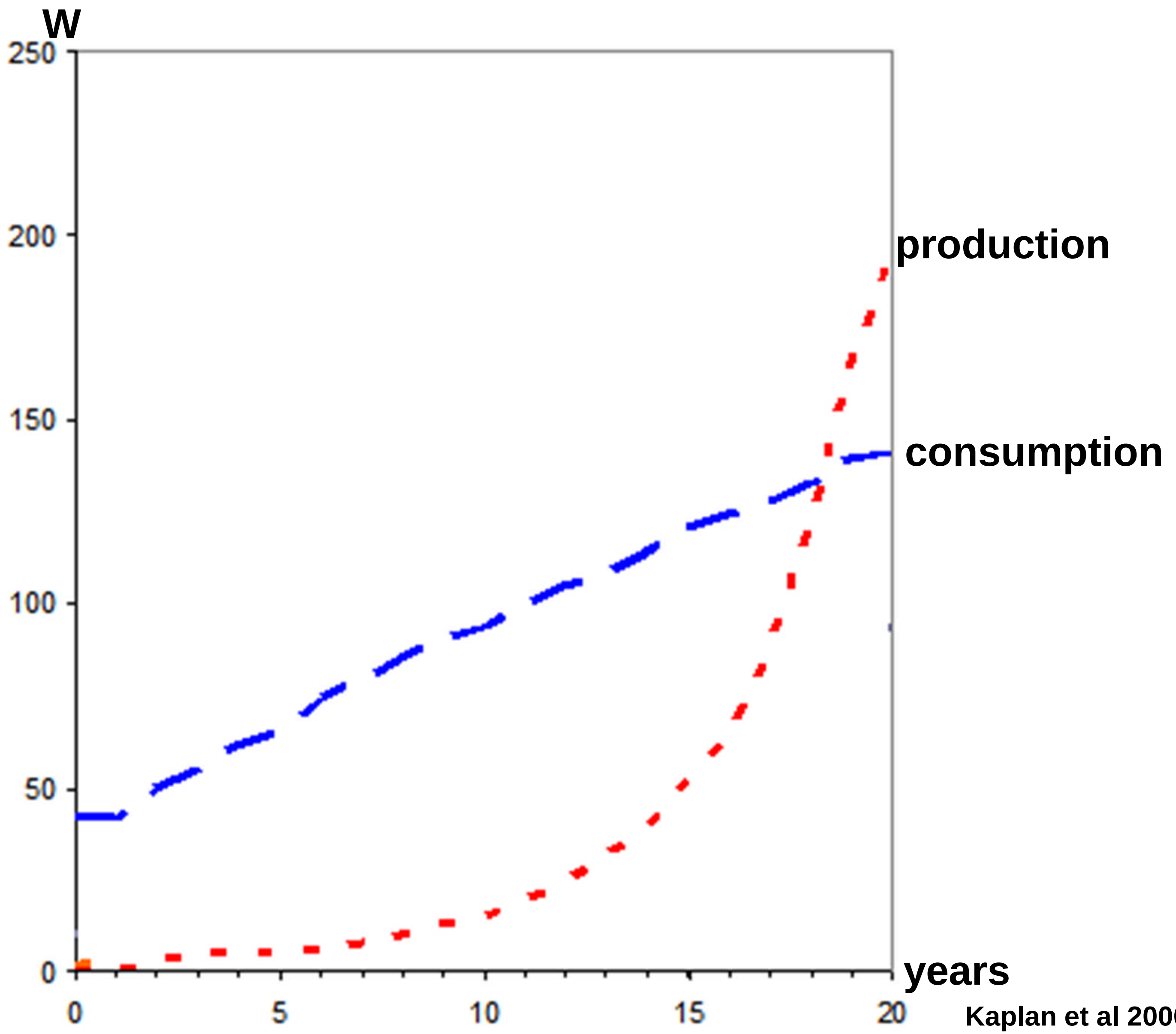

Adipose tissue gain first six months
g/day
35
30
25
20
15
10
5
0
0
1
2
3
4
body weight
fat
fat free body mass
protein

Weaning in humans is very early

	Age at weaning	Age of first molar emergence
Lar Gibbon	1.8	1.8
Siamang	2.2	2.3
Chimpanzee	5.0	3.1–4.1
Orangutan	7.0	3.5–4.6
Gorilla	3.2	3.2
Human	2.4	4.7–7.1

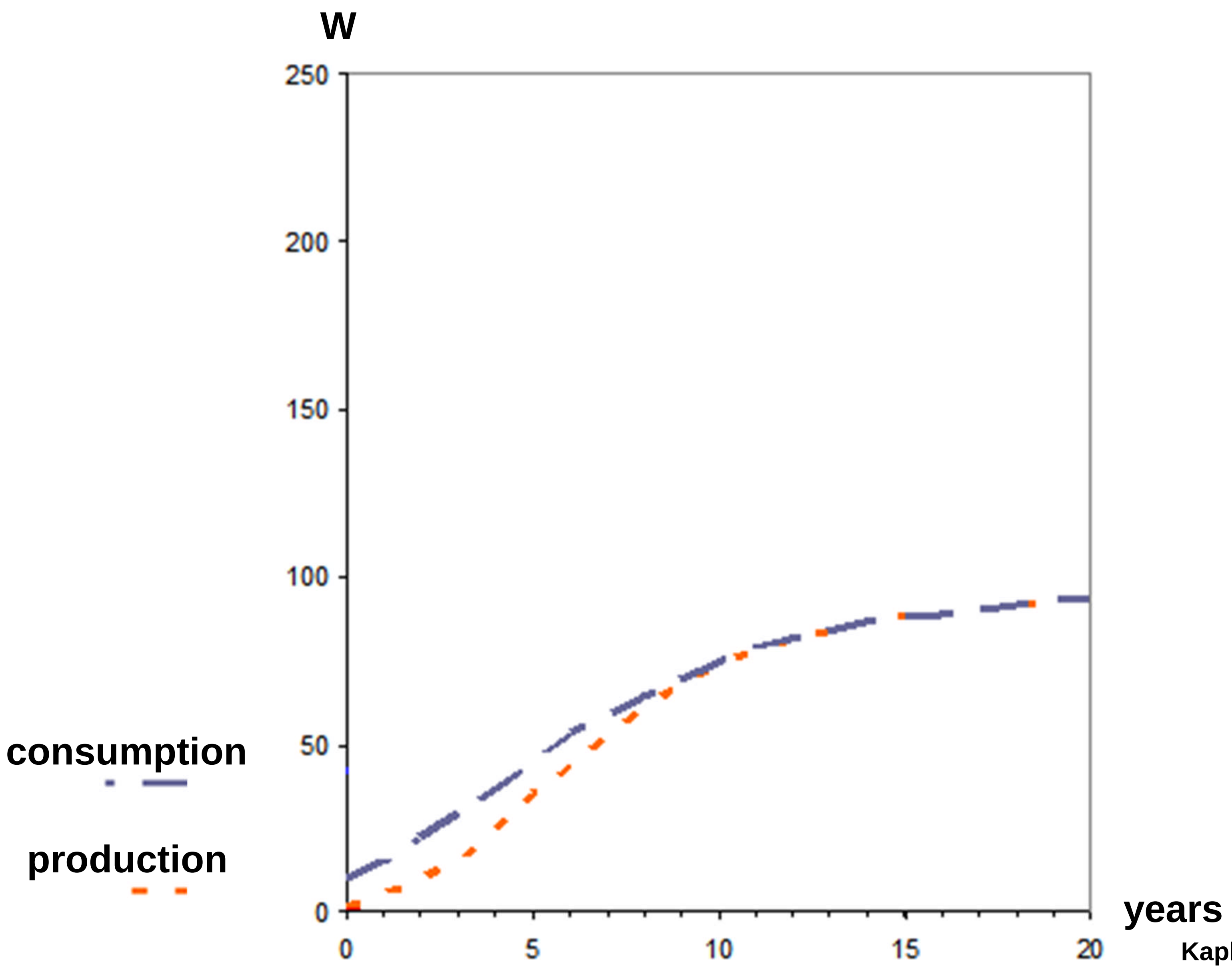
Humphrey 2010

Human hunter-gatherer's energy consumption and production



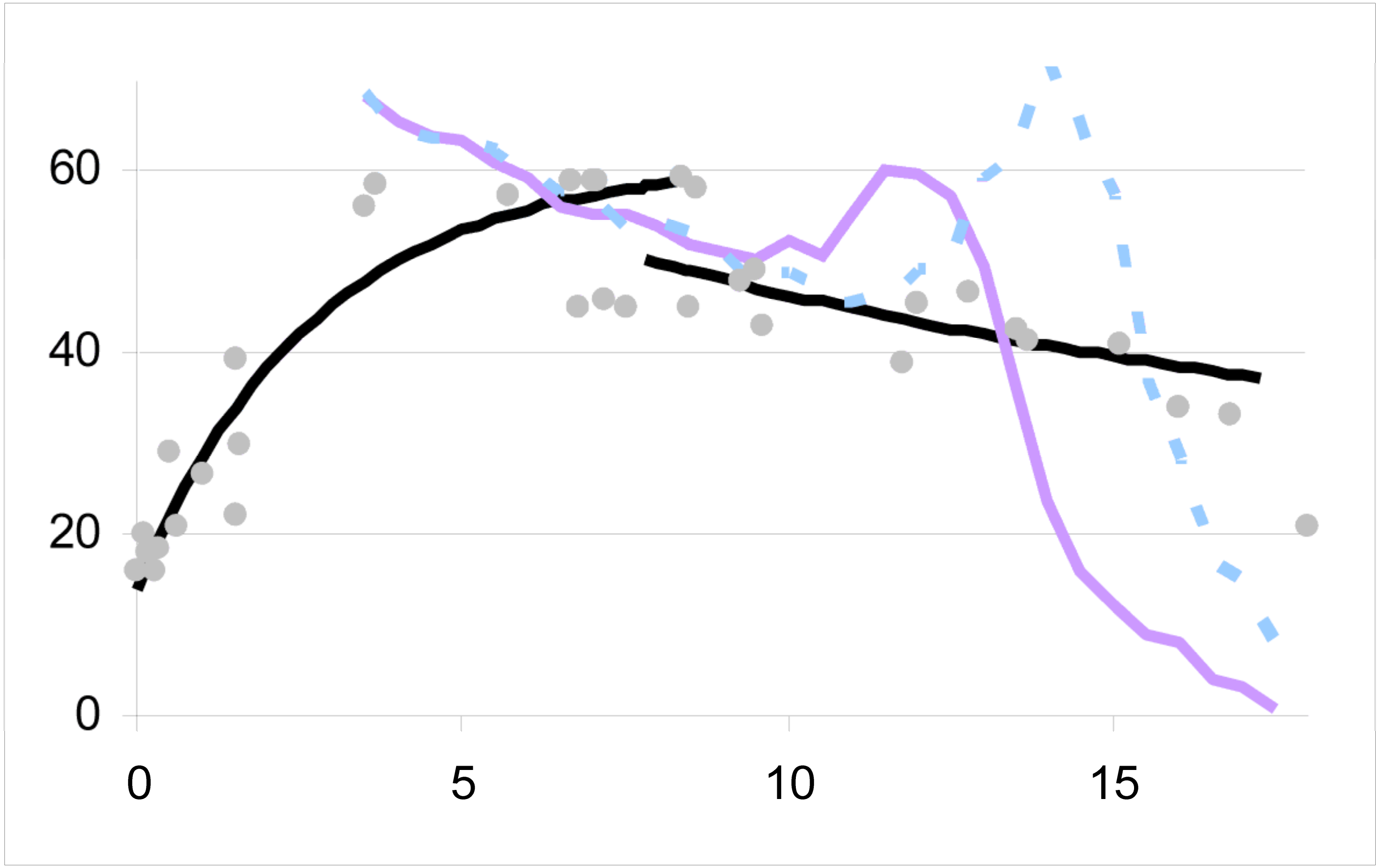
Kaplan et al 2000 fig 3

Chimpanzee's energy consumption and production

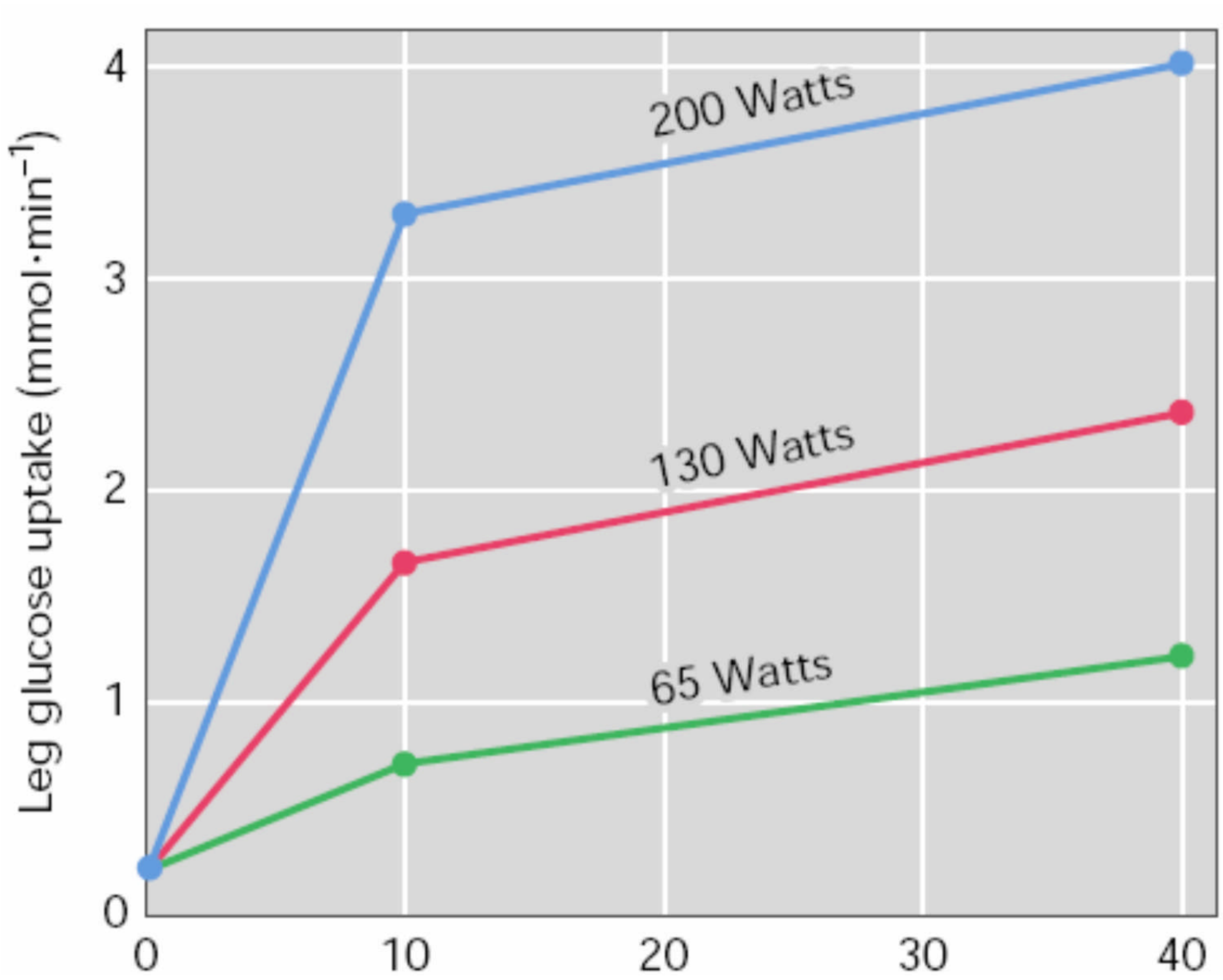


Kaplan et al 2000 fig 3

Human children postpone growth to adolescence after the peak of energy lability



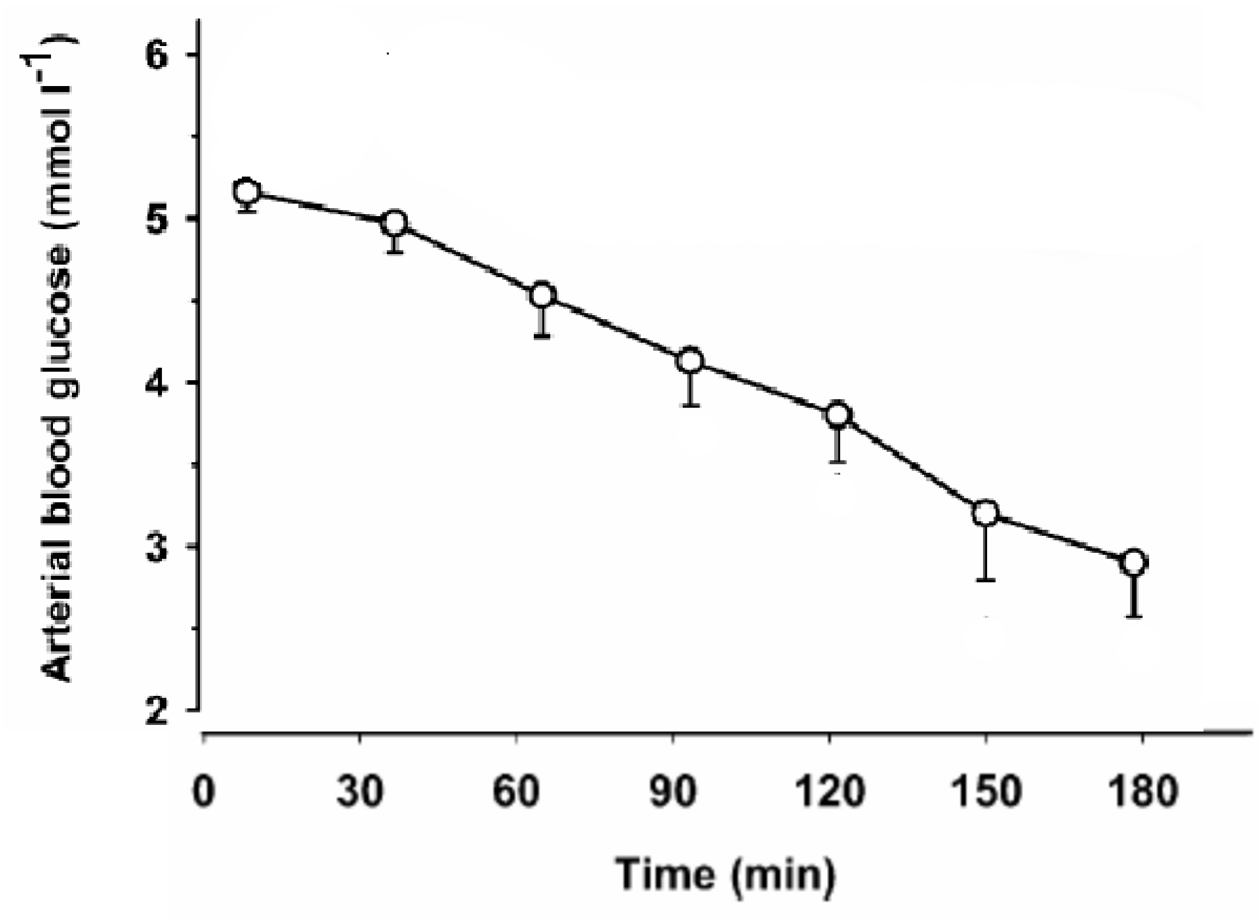
Skeletal muscle uptakes glucose



mins cycling on ergometer

Rose & Richter 2005

Exercise can produce hypoglycemia (in adults)

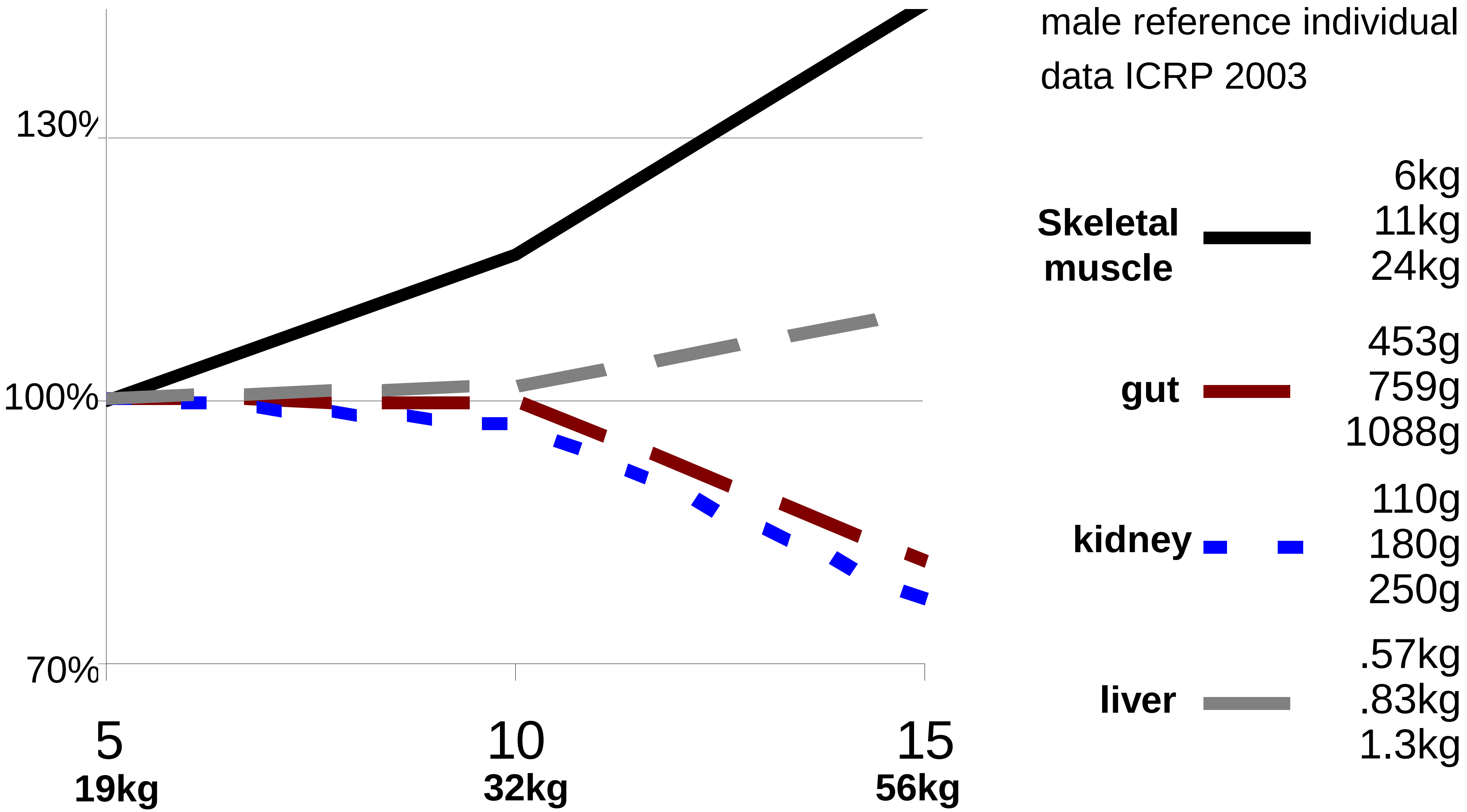


Nybo et al 2003 cycling

Body composition and growth

Children are not only small, they lack skeletal muscle

Skeletal muscle ↑ % body mass with age; other organs↓



Children do not exercise intensely

“Even though children [6 to 7] appear moderately active, they very seldom experience high intensity physical activity” Gilliam et al 1981

“Children [6 to 11] playing sport in a club do not necessarily show a greater energy expenditure and increased habitual physical activity. ..sports children have a lower spontaneous activity level. This is in contrast with adult athletes .. [who] do not compensate by having a more sedentary lifestyle.” Falgirette et al 1996

Children readily suffer exercise hypoglyemia

18 minutes of 60% VO2max exertion plasma glucose drops from 3.75-3.78 mmol l-1 to 3.1-3.4 mmol l-1. This drop does not occur in adults Delamarche et al 1994

“Even at rest, it would appear to be difficult for children to maintain blood glucose concentration at a steady level; an immaturity of their glucoregulatory system would seem to be likely, therefore causing a delay in an adequate response to any stimulus to hypoglycemia like prolonged exercise.” (Delamarche et al 1992 p. 71).

Children have muscle exercise metabolism that minimizes glucose competition

Show more oxidative metabolism during exercise than glycolytic (lactate producing but glucose substrate dependent) metabolism and this oxidative metabolism is more from free fatty acids rather than glucose. (Boisseau & Delamarche, 2000; Eriksson, Karlsson, & Saltin, 1971; Hebestreit, Meyer, Htay, Heigenhauser, & Bar-Or, 1996; Kaczor, Ziolkowski, Popinigis, & Tarnopolsky, 2005; Zanconato, Buchthal, Barstow, & Cooper, 1993).

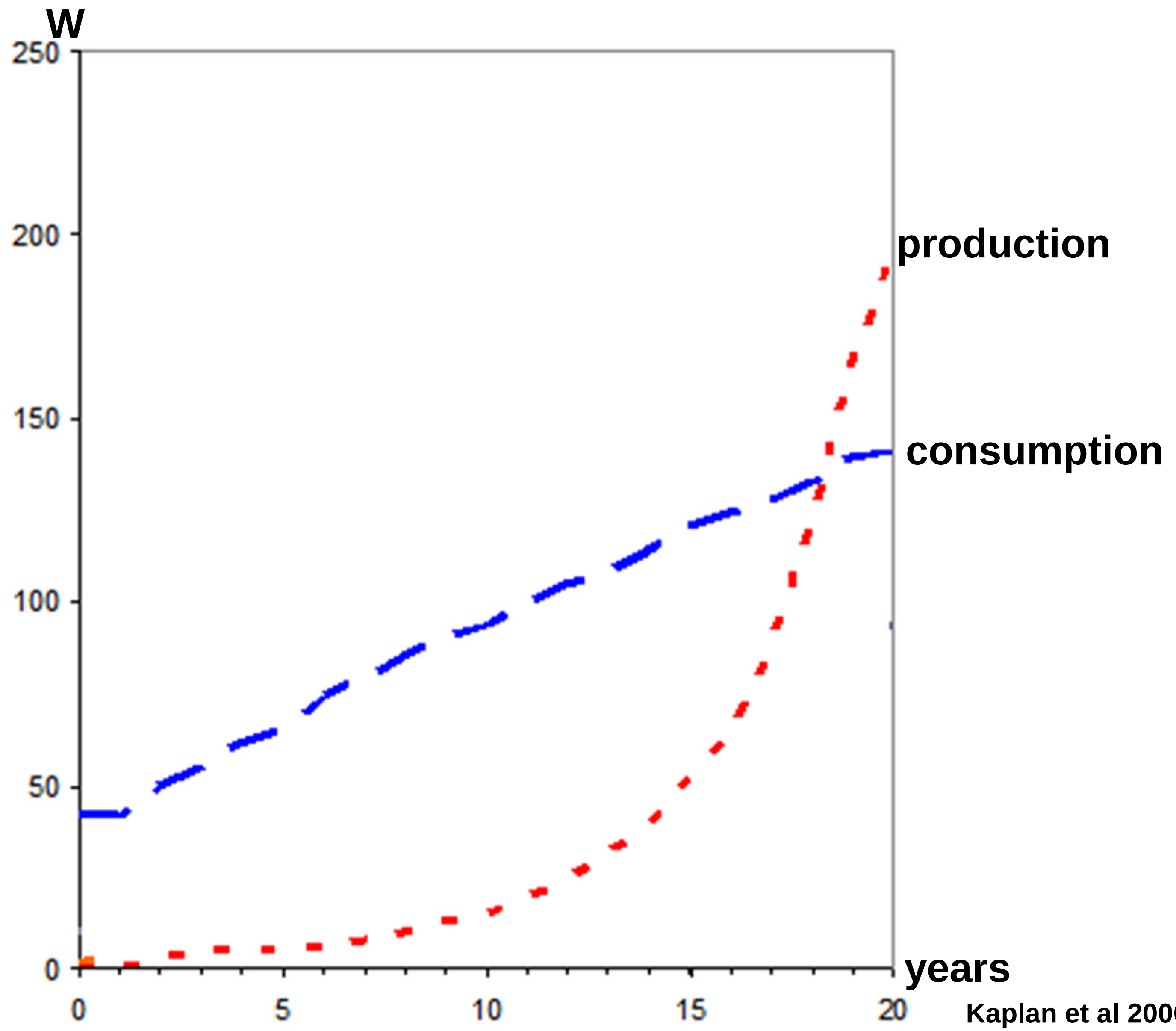
Fatty acids contribute 35.5% in a child vs. 19% in an adult of energy in the last half hour of an hour’s cycling exercise at 70% of Vo2peak (Timmons et al., 2003).

Muscle fibre optimized for less intense exertion in children

- Children might have a greater proportion of fibers from type I (slow-twitch oxidative and use fatty acids over glucose as fuel) to type II (fast-twitch oxidative-glycolytic that utilize glucose) in autopsy sampled vastus lateralis muscle (65% at 5 years-of-age to 50% at 20 years-of-age (Lexell, Sjostrom, Nordlund, & Taylor, 1992); 54% 6-10 years-of-age to 47%, 10-15 years-of-age, 42%, 15-20 years-of-age (Oertel, 1988)).

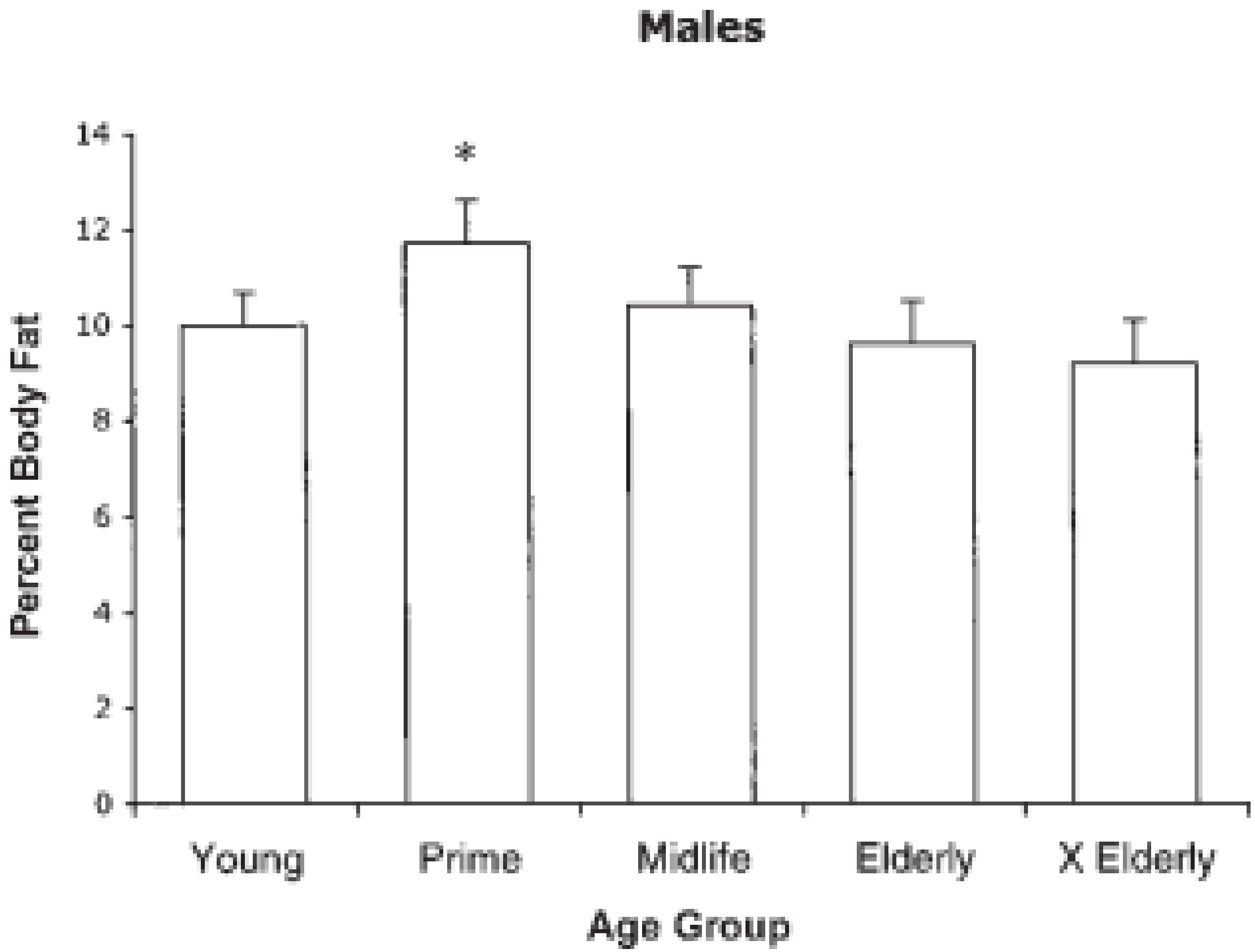
- However, contrary findings exist (Bell, MacDougall, Billeter, & Howald, 1980), and opinions differ.

Human hunter-gatherer's energy consumption and production



Kaplan et al 2000 fig 3

Nutritional Homogeneity



"Anthropometric Data Indicate Nutritional Homogeneity in Hadza Foragers of Tanzania"
Sherry & Marlowe 2007

Food pooling spreads risk of hunting unreliability

men acquire 68 % of the calories and almost 88 % of the protein; women acquire the remaining Kaplan et al. 2001

Ache hunters of moderate size animals return empty-handed on 40 % of hunting days but when successful several hundred thousand calories of meat Hill et al 1987

Hadza large-game hunting successful on less than 3% of hunting days Hawkes et al1991

hunters often experience longer runs of hunting failure owing to injury or illness on 21 % days

9 of the 12 best hunters at least one three-month period of hunting success of less than 10 per cent of their long-term average rate Hill Magdalena Hurtado 2009

Gossip and food pooling

In one hunter-gatherer band 56% of 308 conversations involved norm enforcement criticisms, of which 49% concerned sharing or obligations (Wiessner, 2005)

Of these 22% involved mocking, joking, or pantomime; 41%, outright complaint or criticism; 35%, harsh criticism; and 2% actual violence (Wiessner, 2005)

Ability to use reputation information is limited in nonhuman animals

The capacity to acquire and use reputation information to modify behavior is limited in nonhuman animals (Stevens and Hauser, 2004)

Particularly the ability "to quantify the costs and benefits, time the returns, delay gratification, assess reputation, compute the contingencies and punish cheater" (Hauser et al 2009, p. 3264)

"even in cases where some of the relevant psychological components are in place, what is missing are the interfaces between these components" (Hauser et al 2009 p. 3264)

The HEBE –Human essential bioenergetics ring