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Nonexercise activity thermogenesis – liberating the life-force

■ J. A. Levine

From the Endocrine Research Unit, Mayo Clinic, Rochester, MN, USA

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Obesity occurs when energy intake exceeds energy expenditure over a protracted period of time. The energy expenditure associated with everyday activity is called NEAT (Nonexercise activity thermogenesis). NEAT varies between two people of similar size by 2000 kcal day^{-1} because of people's different occupations and leisure-time activities. Data support the central hypothesis that NEAT is pivotal in the regulation of human energy expenditure and body weight regulation and that NEAT is important for understanding the cause and effective treatment for obesity.

Keywords: energy expenditure, NEAT, obesity, physical activity.

Introduction

By the law of conservation of energy, body fat increases when energy intake is consistently greater than energy expenditure. Excess body fat and obesity are the result of sustained positive energy balance. The pandemic of obesity has spread from the US to Europe and is now emerging in middle and even low income countries [1]. In the United States for example, since the 1970s the weight of the average person has increased by ~12 kg and importantly this trend effects all ages, races and socio-economic groups [2]. Because of the health [2, 3] and economic costs of obesity [4] the urgency to understand why humans are gaining weight has intensified.

It is accepted that nutritional quality is often poor [5]. However, there is controversy as to whether increased energy intake has accompanied the obesity epidemic. For example in Britain obesity rates have doubled since the 1980s yet energy intake appears to have decreased [6]. The NHANES surveys in the United States are difficult to interpret because the method used to examine energy intake changed between surveys [7, 8]. In the absence of firm data that link increased dietary intake to obesity [9], the role of energy expenditure in human energy balance has come under greater scrutiny.

Classically, there are three components of human daily energy expenditure (Fig. 1a). The components of human energy expenditure are basal metabolic rate, the thermic effect of food and activity thermogenesis. Basal metabolic rate is the energy required for core body functions and is measured at complete rest without food [10, 11]. It accounts for about 60% of daily energy expenditure in a sedentary person. Nearly all of its variability (~80% of the variance) is accounted for by body size – or more precisely lean body mass – the bigger a person, the greater their basal metabolic rate [12]. The thermic effect of food is the energy expended in response to a meal and is that associated with digestion, absorption and fuel storage [12, 13]. The thermic effect of food accounts for about 10% of daily energy needs and does not vary greatly between people. The remaining component, activity thermo-

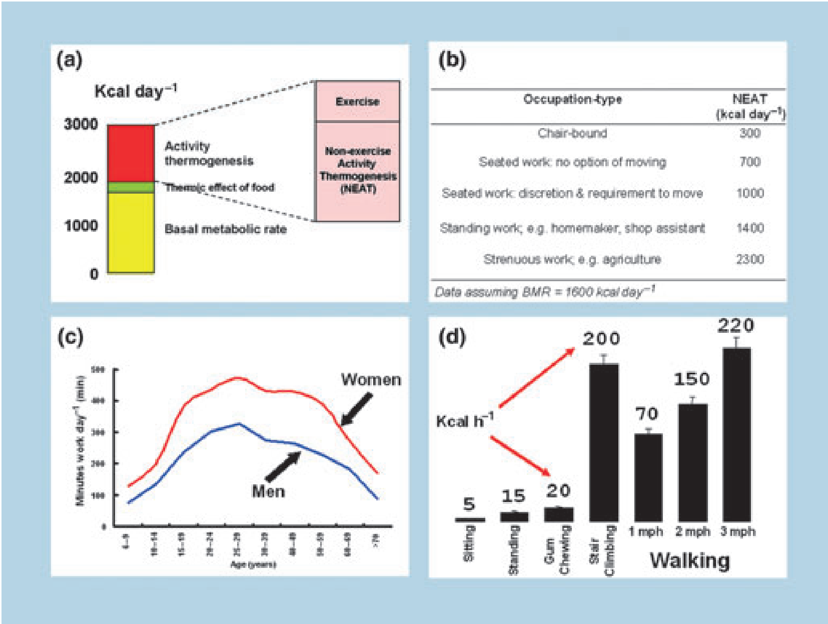

Fig. 1 (a) Components of total daily energy expenditure (TDEE) in a free-living sedentary adult. (b) The effect of occupational intensity on energy expenditure (data from [14]). (c) Work burdens for women and men from the Ivory Coast versus age (from [16, 20]). (d) Energy expenditure above resting for a variety of activities (data from [23]).

genesis can be subdivided into exercise and nonexercise activity thermogenesis (NEAT).

This paper focuses on NEAT. Five themes will be addressed:

1 NEAT varies by 2000 kcal day^{-1}.
2 NEAT is important in human fat gain and obesity.
3 NEAT is underpinned by a profound and subtle biology.
4 NEAT is central in the genesis of the obesity epidemic.
5 NEAT-enhanced living is achievable.

NEAT varies by 2000 kcal day^{-1}

Daily energy expenditure varies substantially [14]. In fact highly active people expend three times more energy per day than inactive people [14] and this marked variability in daily energy expenditure is even greater when data from nonindustrialized countries are considered [15, 16]. Overall, for two adults of similar size, daily energy expenditure varies by as much as 2000 cal day^{-1}. As noted above, basal metabolic rate is largely accounted for by body size and the thermic effect of food is a small. Thus, activity thermogenesis must vary by approximately 2000 cal day^{-1}.

If activity thermogenesis varies by 2000 cal day^{-1}, is it because of exercise or is it because of NEAT? Exercise is defined as 'bodily exertion for the sake of developing and maintaining physical fitness' for example sport or, visiting the gym [17]. The vast majority of world-dwellers do not participate in exercise, as so defined and for them, exercise activity thermogenesis is zero. Importantly too, the vast majority of 'exercisers' participate in exercise for less than 2 h week^{-1} and for them, exercise accounts for an average energy expenditure of less than 100 kcal day^{-1}. On an aside, exercise is associated with massive health benefit including diminished diabetes, heart disease and maybe cancer and is associated with prolongation of life-span [18] and the converse appears to be true for inactivity [19]. One wonders whether exercise is a modern surrogate for the hunter-gatherer or agriculturist life style. If so, high NEAT might confer massive health benefit and longer life. Overall, for the vast majority of people, NEAT must explain why an active person can expend 2000 cal day^{-1} more than an inactive person of the same size.

Nonexercise activity thermogenesis is the energy expenditure of all physical activities other than volitional sporting-like exercise. NEAT includes all those activities that render us vibrant, unique and independent beings such as dancing, going to work or school, shoveling snow, playing the guitar, swimming or walking in the modern Mall. NEAT is expended every day and can most easily be classified as NEAT associated with occupation and NEAT associated with leisure.

Occupation is a key determinant of NEAT. For someone of average age, sex and weight, occupational NEAT varies as shown in Fig. 1b. If an average person were to go and work in agriculture, their NEAT could theoretically increase by 1500 kcal day^{-1} [16].

Understanding the role of occupation on NEAT is far from straightforward, however, because occupation-related NEAT is over-laid simultaneously, by societal and biological drives. In Fig. 1c the occupational NEAT of more than 5000 dwellers from Agricultural Regions of the Ivory Coast is shown. Each individual was followed for 7 days by a trained enumerator and all their daily tasks were recorded using one of 200 numeric codes. First, the societal effect of sex on work burdens can be seen; women work more than men. In these societies, the societal construct is that women conduct all (>95%) of domestic tasks and about a third of agricultural tasks. Men work exclusively in agriculture and have greater leisure time than women [16]. Second, these data demonstrate the interaction of ageing on work participation, noting that this population is unfettered by retirement policy. As ageing occurs, occupational-NEAT declines (Fig. 1c) [20]. Across all species that have been studied, nonexercise activity levels decline with ageing [21]. These data thereby depict the interplay of both society and biology. Other studies [14] and these suggest that occupation is the major predictor of NEAT; active work can expend 1500 kcal day^{-1} more than a sedentary job [15, 16].

Variability in leisure [22] also accounts for substantial variability in NEAT. The energy expended in several activities is shown in Fig. 1d [23]. Consider that an office worker returns home from work by car at 5 pm. From then until bedtime at 11 pm the primary activity is to operate the television remote control in a semi-recumbent position. For these 6 h, the average energy expenditure above resting would approximate 8% and the NEAT will thus approximate 30 kcal for the evening [$0.08*1500^{BMR}*(6/24)$ h]. Now imagine he/she becomes aware of the unpainted bedroom, the weeds growing in the yard, and the possibility of cycling from work. The person then decides to undertake these tasks. The increase in energy expenditure would be equivalent to walking approximately 1–2 mph for the same period of leisure-time (5–11 PM). NEAT then increases to 750–1125 kcal for the evening [2 or $3*1500^{BMR}*(6/24)$ h]. Thus, for this hypothetical office worker, the variance in leisure-time NEAT has the potential of impacting energy expenditure by up to 1000 kcal day^{-1}.

Therefore, nonexercise activity varies by as much as, 2000 kcal day^{-1}. This is because some occupations are far more energy expending than others and, because leisure activities range from almost complete rest to those that are highly energized. Since NEAT varies by 2000 cal day^{-1}, could NEAT be important in weight gain?

NEAT in weight gain and obesity.

In humans, the manipulation of energy balance is associated with changes in NEAT. In one study [24], 12 pairs of twins were overfed by 1000 kcal day^{-1}. There was fourfold variation in weight gain, which by definition must have reflected substantial variance in energy expenditure. As the changes in energy expenditure were not accounted for by changes in basal metabolic rate, indirectly changes is NEAT were implicated. Interestingly, twinness accounted for a substantial minority of the inter-individual variance in weight gain suggesting that NEAT is both under environmental and biological/genetic influences. When positive energy balance is imposed through overfeeding, NEAT increases [25, 26]. Moreover, the change in NEAT is predictive of fat gain [27]. Those who with overfeeding increase their NEAT the most, gain the least fat (Fig. 2a). Those who with overfeeding do not increase their NEAT, gain the most fat. Therefore NEAT is fundamentally important in human fat gain.

If people, who fail to increase NEAT with overfeeding gain excess body fat, could there be a NEAT defect in obesity? To examine this question, we integrated micro-sensors into undergarments (Fig. 2b). These sensors allowed body postures and movements, especially walking, to be quantified every half second for 10 days. The data (Fig. 2c) demonstrated that obese subjects were seated for 2½ h day^{-1} more that lean subjects. The lean sedentary volunteers stood & walked for more than 2 h day^{-1} longer than obese subjects. Importantly the lean subjects lived in a similar environment and had similar jobs compared to the obese subjects. Because all the components of energy expenditure were measured it could be calculated that if the obese subjects were to adopt the same NEAT-o-type as the lean subjects, they might expend an additional 350 cal day^{-1}. Thus NEAT and specifically walking are of substantial energetic importance in obesity. Lean individuals exploit opportunities to walk, where the obese find opportunities to sit.

It might seem obvious that because people with obesity are heavier, they sit more than lean people. However, these differences do not reflect greater body weight alone. When lean subjects gained weight through overfeeding their tendency to be stand/ambulate persisted (Fig. 2d). When obese subjects became lighter, their tendency to sit did not change (Fig. 2b).

Thus, obesity is associated with a NEAT-defect that predisposes obese people to sit [28]. Lean people have an innate tendency to stand and walk. Overall, it is likely that there is a numerically substantial

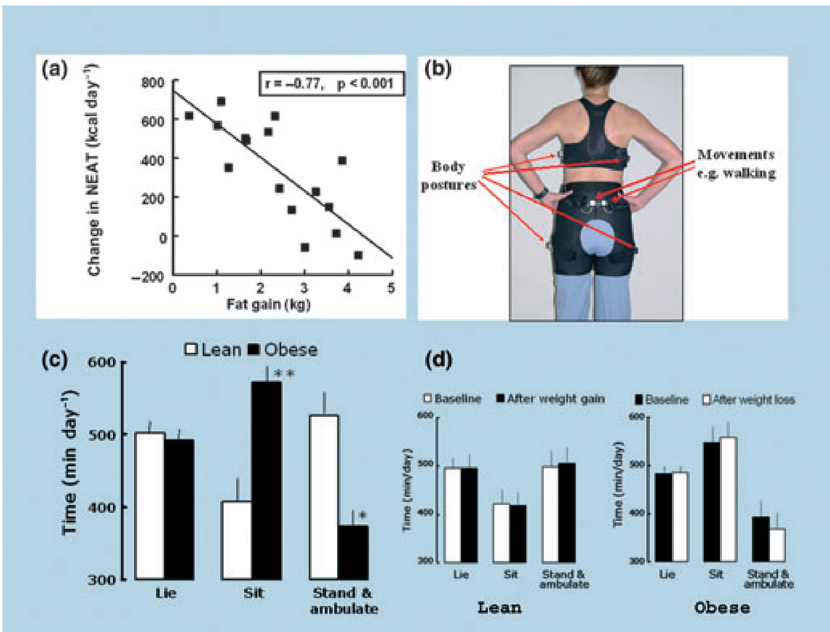

Fig. 2 (a) Fat gain versus changes in NEAT with 8 weeks of overfeeding by 1000 kcal day^{-1} in 16 lean, sedentary volunteers [27]. (b) Posture and activity sensing undergarments [69]. (c) Time allocation for components of NEAT in 10 sedentary lean and 10 obese individuals during weight maintenance feeding [69]. (d) Time allocation for components of NEAT in lean subjects before and after weight gain and obese subjects before and after weight loss [69].

NEAT defect in obesity. This may reflect a hitherto ill-defined biology whereby those with obesity have a greater likelihood to respond to sedentary cues to sit.

NEAT biology

The world around us is an apparent mingling of human frenetic activity. If NEAT is driven by biology, then our world may actually be a carefully orchestrated concerto of movement. Perhaps living is not a product of our work and home environment, but rather the echo of DRUM BEAT to move? Hypothalamic nuclei and the associated neurotransmitters have long been associated with the integration of body weight regulation. However, other, more primal, areas of the brain influence body movement and NEAT. For example, master motor cells [29] may exist in primitive areas of the brain such as the medulla [30–33]. Rather like the pounding of drums, these master control cells may initiate a pulsating stream signals to the body to move; these signals become integrated upstream for a variety of functions such as locomotion [34, 35], mastication [36] or copulation [37, 38] which in turn are processed to precipitate different behaviours such as hunting, eating and reproduction. Some of these signals stream to the hypothalamus where the integration of energy expenditure, NEAT and energy intake occur [39].

Orexin is an example of a putative hypothalamic mediator of NEAT. Orexin is one of the body's neurological signals for wakefulness which is when most NEAT occurs. Several lines of evidence suggest that orexin may be an important modulator of NEAT. First, the orexin-deficient dog has narcolepsy, and the orexin knockout mouse not only has disordered sleep, but is also obese [40, 41]. Second, orexin increases NEAT in a dose-dependent fashion when injected within the paraventricular nucleus of the hypothalamus which is a pivotal 'central terminus' for driving movement [42]. Third, when an orexin antagonist is injected within the paraventricular nucleus, spontaneous movement and NEAT decrease and rats sit still [42]. Fourth, orexin has site-specific effects on energy balance depending upon where it is injected; as mentioned above when orexin is injected in the paraventricular nucleus, NEAT increases but when orexin is injected in the lateral hypothalamus, feeding increases [43]. Finally, obese people have low levels of orexin [44]. Thus, orexin is an example a central mediator of energy balance that differentially affects energy expenditure and energy intake depending upon its site of action.

Orexin is also interesting in the central mediation of obesity, at least in animals. The orexin responsiveness of the obese brain appears dulled in comparison with the lean brain [45, 46]. When orexin is injected in the paraventricular nucleus of rats inbred for obesity, its effectiveness is dulled compared to animals inbred for leanness [45, 46]. The dulled response to orexin in the obese brain is retained as the animals gain weight. The friskiness of lean animals in response to orexin is retained when they are exposed to a high fat diet [45]. Thus, the obese brain may be resistant to NEAT stimuli.

It is certain that orexin is not the only mediator of NEAT because other neurotransmitters such as neuromedin U [47] and gastrointestinal peptides such as gherelin [48] and oleoylethanolamide [49] also stimulate NEAT. There is likely to be a network of central mediators of NEAT that integrate the pulses to move with the networks & neurotransmitters responsible for body weight regulation [50].

Overall, leanness may be a state whereby the signals that stimulate NEAT are plentiful & potent even in the presence of caloric excess; these animals could be termed, NEAT ACTIVATORS. Conversely, obesity may be a state of central NEAT resistance, whereby signals ripple through the nervous system to stimulate NEAT, but in obesity the response to these signals is dulled; these animals are NEAT CONSERVERS whereby they dissipate minimal energy through NEAT and become obese.

This information collectively suggests that there is a profound and subtle biology that is driving NEAT. The NEAT drum beat may pulse through each of us; when the drum beat is muffled, obesity occurs.

NEAT in the evolution of obesity

If we now collapse the human data with that from the animal studies, an apparent paradox emerges. On one hand there is a substantial NEAT defect in human obesity, which may be underpinned by a profound and subtle biology. An inference would be that NEAT is genetically driven [51] as twin data suggest [52, 53] and this conjecture is supported by the broad recognition that obesity is, to a substantial degree, genetically determined [54]. The paradox is that if NEAT is genetically influenced, how could obesity have affected a billion people over a mere century during which time our genes have not changed? To be more precise, the spontaneous DNA mutation rate [55] cannot explain the magnitude of the change in the human phenotype over this period of time. How can the relative genetic stability of *homo sapiens* be reconciled with the rapid and dramatic emergence of the obesity phenotype?

In order to understand this apparent contradiction, it is necessary to broaden the lens through which we look at obesity. A million years ago early humans emerged from the forests of Africa as knuckle walkers [56]. The fossil evidence is abundant that since then an evolving *homo sapiens* stood more erect and walked across the earth to populate it [57]. The earth-wide migration of humans enabled them to find nutrition and shelter and the species was perpetuated in the presence of adequate fuel and safety. This time course is consistent with the calculated, spontaneous mutation rate in DNA that explains the selective forces that explain our phenotype [55]. Thus, a fundamental feature of *homo sapiens* is the time-driven design to walk.

If walking, which is the predominant component of NEAT, served as an evolutionary selective force, a bimodal response in early *homo sapiens* to famine with respect to NEAT could be imagined. One response to famine would be for humans to search for food beyond their pre-existing physical boundaries whereby NEAT increases; this person would be a NEAT ACTIVATOR. An alternate response to famine in early humans might be to conserve fuel and stop moving so that NEAT decreases and body fat stores are NOT depleted; this person is a NEAT CONSERVER.

NEAT ACTIVATORS may therefore be people who are genetically programmed to be more responsive to NEAT-prompting cues, have high NEAT and are ‘lean-walkers’. These individuals have central networks that are reminiscent of the NEAT ACTIVATOR rats which are active and lean. In contrast NEAT CONSERVERS may be people who are genetically programmed to have blunted central responses to NEAT signals and may thereby be prone to sit, have low NEAT and develop obesity. The central biology in these individuals may mimic the obesity-prone rats described above. Although, this is only a theoretical model, it illustrates the appropriate time course to consider genetic influences on the human obesity phenotype.

If we bear this time course in mind and review the last 150 years, a fundamental change has occurred in the *modus operandi* of humans with respect to NEAT. 150 years ago, 90% of the world’s population lived in agricultural regions [58]. Much like our distant ancestors, they walked to work, had active work and walked home at the end of the day. Water carriage, food preparation and clothes washing were intensively manual [16] and socialization was ambulatory [59]. This living-style was akin to the biological design of humans namely, to walk all day long.

Over the last 150 years there was been an unprecedented shift in the human demographic. Half the world’s population moved to cities [58]. Interestingly early industrialization and urbanization were viewed as promoting ‘laziness’ according to the commentators of the time [60, 61]. With factory-based work becoming common-place, nonambulatory mass transit and chair-based working emerged and with mechanization, ‘physical tool use’ became ‘machine operation’ [61]. This trend towards day-long chair-addiction rapidly accelerated over the last 20 years with the emergence of micro-electronic technologies. In developed countries, half the worlds’ population now works predominately behind a computer [62] whereas 20 years ago, this was less than 1%. In 2004, more than two thirds of homes in the United States contain at least one computer whereas 20 years ago this number was zero [63]. There are innumerable sedentary activities in 2007, that 20 years ago were energy expending activities; examples include, banking, shopping, going to the library and video-soccer. All of these activities can now be conducted in front of a computer screen whilst seated whereas 20 years ago this was not so. In so doing, a modern person sits during their drive to work, sits all day at work, sits to drive home and sits in the evening watching television, surfing the internet or playing video games. In a mere 150 years, *homo sapiens* has become addicted to the chair.

In this context, we can understand the emergence of global obesity in a mere 150 years. Changes in post-war nutritional policy and advances in agricultural technology and food science [64] eliminated starvation for the majority of people in the developed world. Plentiful food became available at low cost [5]. In the absence of starvation and with the emergence of industrialization, people took to their chairs and in so doing the energy cost of living, NEAT, decreased by approximately 1500 kcal day^{-1} [65]. As a result there was population-wide positive energy balance. People maintained their energy intake at constant levels in the face of declining energy expenditure through NEAT [7, 8] and so energy excess became abundant and obesity resulted.

In the same way a bimodal response to starvation was imagined, a bimodal response to energy excess can be hypothesized too. NEAT Activators have genetic programming for high NEAT. As the environment imposed pressures over 150 years to decrease day-long activity, NEAT Activators found approaches to dissipate NEAT; for example they walked to work, naturally paced around the office between assignments and undertook home decorating projects; individuals with the greatest NEAT-drives attended gyms and exercised. NEAT activators may also have mechanisms to be energetically inefficient for example through myocyte uncoupling [66, 67] whereby more energy is dissipated per mile of walking (corrected for weight). Regardless of the precise mechanism, NEAT Activators retained their high NEAT-drive despite a flood of opportunities to sit.

The NEAT Conservers, on the other hand, are genetically programmed not to waste energy through movement or NEAT. NEAT Conservers over the last 150 years found their predilection to minimize NEAT fulfilled; they became able to sit at work, sit whilst in locomotion and sit during leisure. With the emergence of chair-based living, NEAT conservers ‘naturally’ (genetically) sat and thereby conserved 1500 kcal day^{-1} [65] whilst their energy intake was unchanged. It is not a surprise that they became obese.

The concepts of NEAT Activators and NEAT conservers are provided to illustrate how genetic variance implicates NEAT in obesity. It is important to appreciate that the variability with which people respond to cues to be active or inactive, and have high or low NEAT, is likely to be affected by multiple genes at multiple loci. There is most likely to be a genetic continuum across which people expend NEAT; at one extreme may be the marathon runner and at the other extreme may be the person who works, plays and eats from their arm-chair; most of us are in-between these extremes. Nonetheless, it is likely that obesity emerged hand-in-hand with the chair-based environment in those who had the genetic predisposition to exhibit low NEAT and weight gain. To reverse obesity we need to find ways of getting people out of their chairs.

NEAT-enhanced living

There are two approaches to getting people out of their chairs and reversing the energetic defect in obesity. The first approach is to persuade individuals to stand when they once sat namely, ‘individualized approaches’. The second approach to get people out of their chairs is to remove the chair and this is termed, ‘environmental re-engineering’. It could be argued that a person’s body weight is solely their own responsibility and so individualized approaches need to be the sole tenet of obesity treatment. An alternate argument is that obesity (from a NEAT perspective) is a population-wide problem that emerged as a result of environmental pressures to sit and so environmental re-design is necessary to seduce people back onto their feet. As there is no evidence as to which approach is correct, both personalized approaches and environmental reengineering need to be considered to diminish obesity.

Regardless as to which approach is taken to increase NEAT, the first question is, what is the goal for increasing NEAT? It is of note that the amount of 'exercise' associated with weight loss approximates 2000 kcal week^{-1} [68] which interestingly matches the NEAT deficit in obesity which is ~2½ h of walking integrated throughout the day and approximates 2000–2500 kcal week^{-1} [69]. Thus although, 'small steps' [70] are laudable as a starting point with respect to personalized approaches for weight loss, greater personal changes are likely to be needed [71] if the maximum health & weight loss benefits associated with increasing NEAT are to be realized.

A key problem in integrating an additional 2–3 h of walking/standing time throughout the day is that people's occupations and personal lives prohibit this degree of change. Thus both individualized approaches and environmental re-engineering are needed to help individuals reach their NEAT goals.

Personalized approaches for promoting NEAT

There are different approaches one can employ to help individuals get up from their chairs. Approaches to modify individuals' behaviours with respect to increasing NEAT have been described [72] that focus on behavioural economic theory [73, 74]. Behavioural economic theory is a framework for conceptualizing how people make behavioural choices based upon their perceived relative value [75]. As applied to NEAT, behavioural economic theory is concerned with how people choose between numerous activity/inactivity options. There are four key elements. First, it is important to provide individuals with free-choice [75]. Forcing an individual to choose a specific NEAT-promoting activity (e.g. 'you must walk further to work from your car') is likely to have the opposite to the intended effect. If a given activity is self-selected, it is likely to be more reinforcing and thereafter self-selected more often. Second, the delay between selecting the NEAT-promoting behaviour and the outcome (e.g. reward) needs to be minimized [75]. Many sedentary behaviours that people enjoy have immediately reinforcing consequences, while the health benefits of standing/ambulating may take longer to accrue. Thus, it is important to select NEAT-promoting behaviours that are pleasing (e.g. walk whilst listening to music, dancing video games or walk-and-talk with a friend). Third, behavioural 'cost' determines which activity/inactivity alternatives are selected [75]. If a person has to work hard to participate in a given activity they are less likely to do it (e.g. drive 40 min to the gym). People are more likely to choose NEAT-promoting activities that are more accessible such as an office-based activity program that does not require changing location or clothes. Fourth, for a person to choose a NEAT-promoting activity it needs to be more attractive ('valued') than available alternatives [75]. A person's behaviour will change by providing them with a competing behaviour that is more highly valued; for example, a person may prefer to surf the internet whilst seated rather than visit a gym. If, however, walking with a friend was an option she would choose that instead of internet-surfing.

These behavioural components have been synthesized into a simplified approach termed, STRIPE [72]. STRIPE is an acronym which represents;

S = select a NEAT-activity that is enjoyed and start it,

T = targeted, specific individual goals must be defined,

R = rewards need to be identified for reaching the defined goals,

I = identify barriers & remove them,

P = plan NEAT-activity sessions,

E = evaluate adherence & efficacy.

Overall, the STRIPE approach is safe and well grounded in conceptual evidence for increasing NEAT. Whether this approach will help individuals become more active and/or lose weight is unknown.

NEAT is also a potential target for pharmaceutical agents with respect to either increasing the amounts of activities people undertake (e.g. caffeine increases activity at least in animals [76]) or increasing the energy expenditure of activity (e.g. thyroxine or sympathomimetics increases the energy cost of activity [77–79]). Other therapeutic modalities such as gene therapy, for example targeted at muscle uncoupling [80] could also be considered as a means of increasing NEAT.

Regardless of how personalized changes in NEAT are achieved a major hurdle has been that measurement tools are often inaccurate for detecting free-living physical activity. For example, commercially available pedometers or uniaxial (one axis of measurement) accelerometer devices are often used to monitor walking programs despite being too inaccurate to provide reliable data [81–84]. Thus an individual could receive falsely reassuring information that they are compliant with their walking goal whereas in fact they are not. Also, a person who is achieving their walking goals may get discouraged by a pedometer readout that suggests they are not being compliant. An important challenge in promoting NEAT and understanding its role in health and disease is to make available tools that accurately and precisely measure free-living physical activity. This deficiency is likely to be rectified by instruments that include micro electro mechanical system (MEMS) that enable physical activity to be measured accurately and precisely in small, portable electronic devices. MEMS technologies (accelerometers and gyroscopes) are likely to enable research-grade measurements to be gathered in free-living people. Furthermore, such measurement tools could readily be integrated into pre-existing electronic units such as portable music players and cell phones. The wide-spread availability of measurement tools to measure NEAT and its components will enable the most cost-effective means of increasing a person's NEAT and improving health to be determined.

Environmental re-engineering for promoting NEAT

There is logic to the argument that the environment enticed NEAT-Conservers into their chairs and so environmental re-engineering is needed to seduce people back onto their feet. The problem with this argument is that it crosses traditional professional boundaries. For example, redesigning an office space for promoting NEAT requires the combined efforts of architects, interior designers, engineers, power & heating specialists, textile & clothing designers, ergonomic experts, physiologists, behavioural psychologists and scientists. Such endeavours are costly and the standards that define success are ill-defined.

There are five reasons to examine environmental re-engineering to promote NEAT despite the substantial investment in effort and cost. First, over the last century environmental cues have been so overwhelming that ambulatory individuals have been seduced to sit [85]. Therefore, we need to redesign the environment itself to reverse this effect; without so-doing, the battle to reverse obesity is unlikely to succeed. Second, the NEAT-deficit in obesity represents 2½ h of standing & ambulating per day. For a person to increase their standing/ambulating time to this degree, their environment will need to be activity-enticing or at least NEAT-permissive; it is therefore logical to scrutinize the environment *per se*. Third, the fiscal cost of excess body weight and obesity is sufficiently great that effective measures to prevent and treat obesity are likely to be cost-effective for adults and children. In the United States alone, obesity-related medical expenditures in 2003 approximated $75 billion and currently exceed $100 billion per year [86]. Thus, it is tenable to contemplate environmental engineering as a fiscal investment. Fourth, obesity rates in children are estimated to reach 50% in the United States by the end of the decade [87, 88] and childhood obesity in increasing throughout middle and high income countries [89, 90]. Generation-spanning interventions, such as environmental re-engineering are therefore appropriate for the time-span of the problem. Finally, the health impact of overweight and obesity is overwhelming both for individuals and societies. In the United States poor diet and physical inactivity are associated with 400 000 deaths per year [91] and obesity is emerging as a major health problem throughout middle- and even low-income countries [1]. Hence from a public health perspective, environmental re-engineering is likely to impact a sufficient proportion of the population to make it worthwhile.

At present there is not body of knowledge that best defines how to re-engineer environments to promote NEAT. Thus, we can only speculate as to what NEAT-enhanced environments might resemble.

In adults, as computer-based occupations are prevalent in industrialized and emerging economies and are projected to account for an even greater segment of the workforce, a NEAT-enhancing office environment could be developed. We developed a 5500 ft^2 office space whereby the mode of operation was predominantly to walk whilst working (Fig. 3). The concept is based around vertical treadmill-linked desks. Here people walk at about 1 mile per hour and perform all their normal work based computer tasks. Office workers interact with computers in an environment that allows walking, should the employee choose. An employee can choose to remain seated throughout the workday too. We found that obese and lean individuals tolerate this mode of working well. The reason that this is so energetically potent can be discerned by reviewing existing data (Fig. 1d). When a person walks at 1 mph, they double their energy expenditure so that a 70 kg person would expend an extra 100 kcal h^{-1} Thus, even if a person 'walked-and-worked' for half of every work day, they would expend an additional 400 kcal day^{-1} and exceed the NEAT-deficit in obesity. Negative energy balance of this magnitude would be associated with >30 pounds of weight-loss per year. Such dramatic environmental re-engineering interestingly is less expensive that the traditional cubicle office configuration (5$ ft^{-2} vs. $7–10 ft^{-2}) or ~$1500 per worker station versus ~$2000 per worker cubicle. We redesigned the traditional business suit to become equally functional in the board room as well as on a treadmill (Fig. 3). It is important that not all of this refurbishment is expensive; for example, carpet tape can be used to delineate a walking track (Fig. 3) and inexpensive 'walking meeting in progress stickers' can be used to transform sitting meetings to standing meetings. Also, such changes are likely to promote other NEAT-promoting activities in the workplace which include holding meetings & phone-conferencing while walking, celebrating birthdays with 'tune-for-day' rather than cake and having stretch bands and yoga stretching as a group-dynamic to start each work day. Studies are urgently needed to assess the cost-effectiveness and whether productivity improves with such interventions as subjective reports suggest.

If occupation is the principal determinant of NEAT in adults and represents an efficient means of promoting NEAT in a population, we should also examine the school as a NEAT-promoting environment for children. Childhood obesity is at its highest level globally and for the first time obesity-associated metabolic complications are becoming commonplace in children [87, 92]. Here we would envisage redesigning the school environment. Several concepts could be explored; mentored walk to school programs have been successfully trialled, school buses could park 1 mile from the school, the classroom could be engineered to be filled with treadmill desks, students could use portable data storage tools to listen to a lesson-associated Shakespeare Sonnet whilst walking in the school corridor, classes could be held using advanced communications where a teacher interacts with her students as the student shoots basketball hoops, hockey pucks or walks on a track, video linking could be aligned with tablet-format personal computers so that the 'black board' becomes portable and dynamic. Along these lines, we redesigned a 50, 000 ft^2 school environment with corporate partners. This school environment promoted physical activity by its nature. It was built around a village square motif (Fig. 4). The classroom was a plastic hockey arena (Fig. 4). Also, there were basketball hoops, trampolines, activity promoting video games and miniature golf. What we found was that children's physical activity levels increased by 50% above the values obtained in the traditional classroom. Contrary to our concerns, educational achievement improved and students, teachers and parents responded positively to the NEAT-promoting school. On a smaller scale, we were able to evaluate the energetic implications of converting sedentary activities to active ones for children and found that energy expenditure can be increased

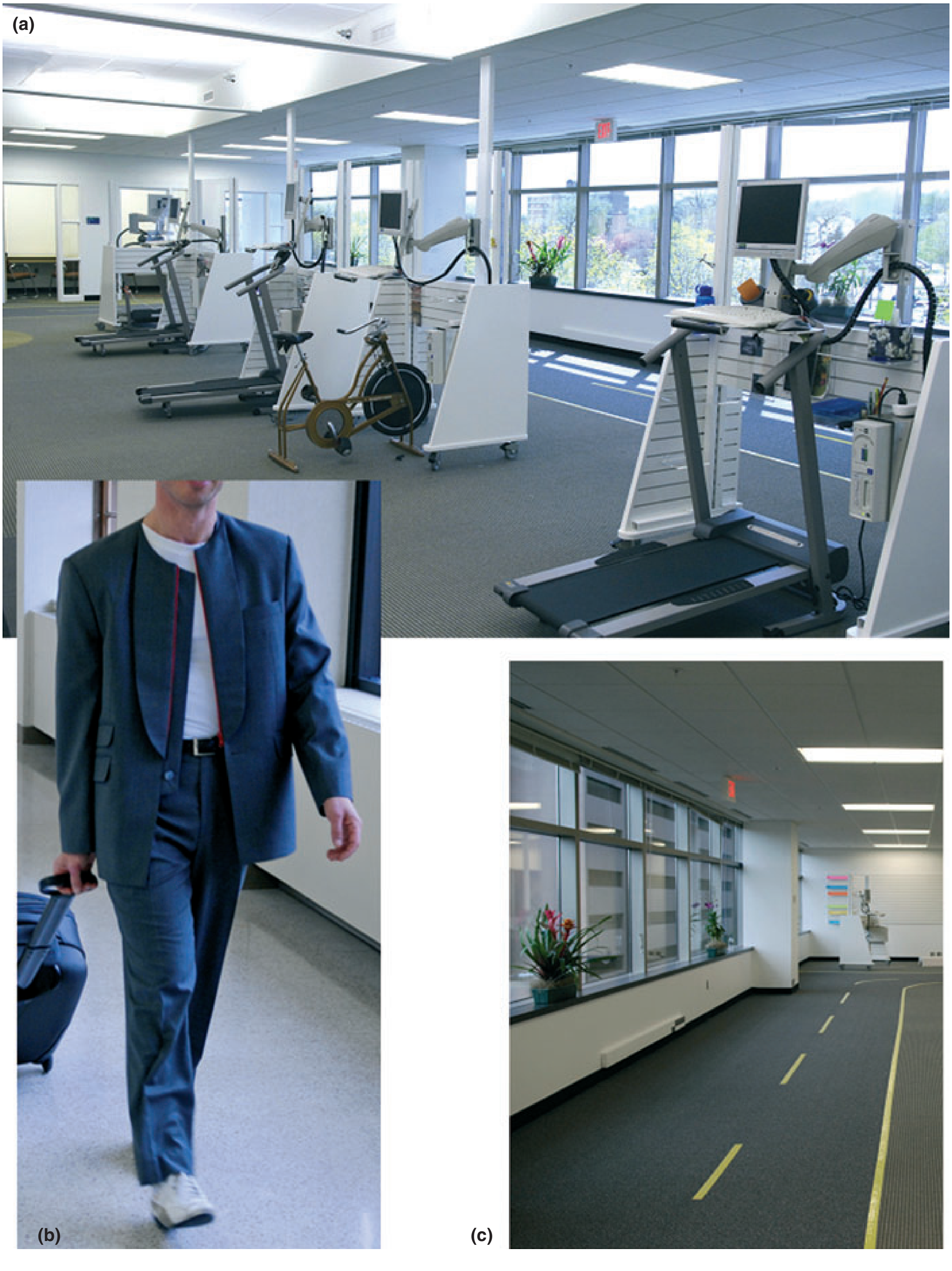

Fig. 3 (a) NEAT-promoting office environment showing vertical desks linked to a treadmill or stationary bicycle. (b) Business attire for promoting NEAT-enhanced working (J. Levine and G. Armani). (c) Walking track demarcated using carpet tape.

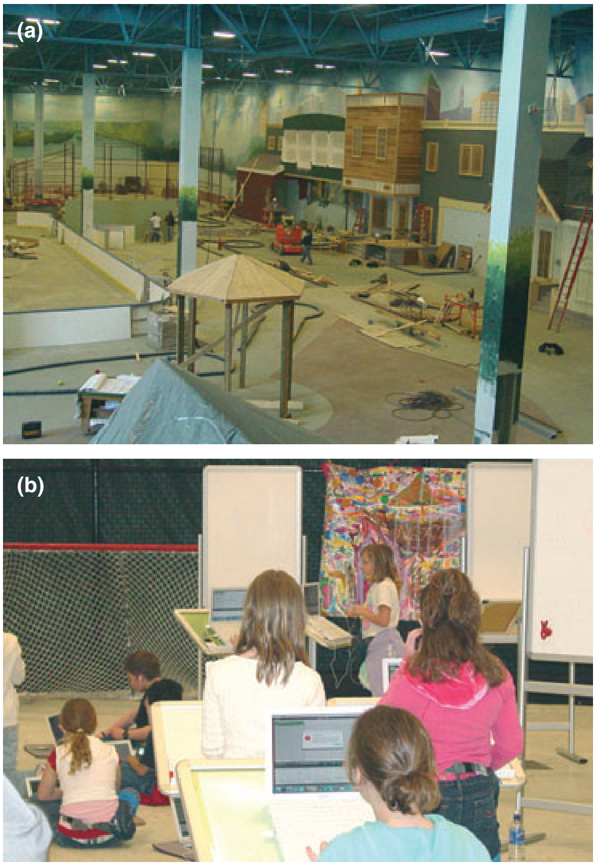

Fig. 4 NEAT-promoting school environment. (a) The school was built on a warehouse platform around a village square motif. (b) Classroom fashioned as a hockey arena (plastic flooring).

substantially in children [93]. Such approaches as these necessitate broad-based collaboration and extensive validation that includes measures of attentiveness and school grades. However, the Damocles sword that hangs over our weight-expanding youth merits such endeavour.

The leisure-time environment is also subject to redesign including tools that promote activity in the home such as an alarm clock that starts the bedroom treadmill, feature-enhanced video gaming that promotes movement while gaming and televisions that can only switch-on when the interlaced treadmill is in use. Perhaps movie theatres and airports will have walk-and-watch and walk-and-wait platforms. The opportunities are wide ranging but also include the office environment described above because a greater proportion of the workforce is projected to work from home [94]. When children perform their normal leisure activities such as television watching or video gaming in an active mode, energy expenditure can increase by 100 cal h^{-1} above the sitting-equivalent [95]. The effects are sufficiently large to potentially alter a child's energy balance and body weight.

It might be viewed as far-fetched and expensive to design environments to promote NEAT-living. However, technological capability exists that makes this is immediately possible. For example in February 2005, 7500 orange-coloured fabric panels were temporarily hung over 23 miles of pathways in Central Park in New York [96]. This two-week intervention precipitated four million people to walk through these gates in Central Park and generated an estimated $254 million in economic activity. Similarly, in 335 BC Aristotle founded the Lyceum, which was the center of learning that became known as the Peripatetic School because Aristotle and his students would learn whilst walking. From these walks came the foundations of science, logic, ethics, politics and metaphysics. Overall, the fiscal and heath consequences of obesity may render it cost- and health-effective to re-examine sedentary living as the norm. We suggest resources be allocated to examine the real-life feasibility of environmental re-engineering to promote NEAT. NEAT-living does not necessitate social revolution but rather the re-application of pre-existing technologies and concepts to render active-living normative.

Conclusion

In conclusion, NEAT is varies by up to 2000 kcal day^{-1} between people of similar size in part because of the substantial variation in the amount of activity that they perform. Obesity is associated with low NEAT; obese individuals stand and ambulate for 2½ h day^{-1} less than lean sedentary controls. As walking even at slow velocities is highly exothermic, the NEAT-deficit in obesity is likely to be energetically important. It is evident that both biological and, overwhelming environmental influences facilitated a seated life style. Because of the enormity of the problem of obesity in society and because of the magnitude of the NEAT-deficit, we suggest designing and evaluating both, personal behavioural approaches and re-engineered environments to promote active life and health.

Conflicts of interest

None.

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Correspondence: Dr J. A. Levine, Professor of Medicine, Richard Emslander Professor of Nutrition & Metabolism, Endocrine Research Unit, Mayo Clinic, Rochester, MN 5590, USA.
(fax: 507 255 4828; e-mail: levine.james@mayo.edu).