Curr Obes Rep (2013) 2:261–266
DOI 10.1007/s13679-013-0060-0

ERGONOMY (N TEASDALE, SECTION EDITOR)

Physical Activity and Development and Obesity

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Published online: 8 June 2013

Abstract Regular physical activity is consistent with better health including body composition status. More commonly, studies of physical activity and health have focused on the adult years when poor health as a consequence of inappropriate lifestyle behaviors, becomes more evident. In recent years, greater attention has been paid to developmental aspects of health and disease. This includes the notion that early life experiences or exposures to nutrition and movement and subsequent physical activity and exercise behaviors are related to phenotypic changes including predisposition to overweight and obesity at younger ages. The current obesogenic environment is characterized by the coexistence of overnutrition and low levels of physical activity, a situation that has been referred to as an evolutionary mismatch. Overweight and obesity are commonplace at all stages of the lifespan, including during the reproductive years with the prevalence of maternal obesity and gestational diabetes mellitus increasing rapidly along with obesity and diabetes in their offspring. There is an urgent need for effective strategies to break this cycle, ideally by optimizing physical activity and healthy eating in adolescents and young mothers to increase the opportunity of healthy growth and development, including healthy body composition, in infants and young children.

Keywords Obesity · Exercise · Developmental · Nutrition · Evolutionary mismatch · Body composition · Obesogenic · Diabetes · Metabolic · Physical activity

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Introduction

Regular physical activity is consistent with better health during the growing years and beyond including a healthy body composition status [1–4]. Typically, considerations of physical activity and health have focused on the adult years when poor health as a consequence of inappropriate lifestyle behaviors, becomes more evident. In recent years, greater attention has been paid to developmental aspects of health and disease. This includes the notion that early life experiences or exposures to movement and subsequent physical activity and exercise behaviors are related to phenotypic changes including predisposition to overweight and obesity at younger ages. In short, physical activity is a central platform of a healthy lifestyle and along with sound nutrition and positive childhood experiences has an important influence on lifelong behaviour and health [5].

Overnutrition and low levels of physical activity characterize our increasingly obesogenic environment, a situation Gluckman and Beedle [6••] referred to as an evolutionary mismatch. This scenario is commonplace at all stages of the lifespan, including during the reproductive years. Maternal obesity and gestational diabetes mellitus are increasingly common along with obesity and diabetes in their offspring [7]. There is an urgent need for effective strategies to maximize physical activity and healthy eating in adolescents and young mothers to increase the opportunity of healthy growth and development, including optimal body composition, in infants and young children.

This paper provides an overview of important and current issues associated with physical activity and development and obesity with a specific focus on critical stages and windows of opportunity to maximize the many benefits to be derived from healthy eating and activity behaviors.

Nutrition and Physical Activity Transition – Implications for Healthy Development

The global burden of obesity, diabetes and other non-communicable diseases (NCDs) is rising rapidly in both the developed and developing world [8, 9••] and is consistent with both nutrition [10, 11•] and physical activity transitions. Popkin [12] popularized the term nutrition transition but actually referred to shifts in both diet and physical activity. Much later, Katzmarzyk and Mason [13] coined the term physical activity transition to reference the effects of declining physical activity levels on health and life expectancy consistent with economic advancement. They postulated that lower levels of physical activity in today's society will likely attenuate the expected gains in life expectancy associated with the epidemiological transition (including nutrition transition).

The increasing prevalence of NCDs is particularly problematic in populations in the developing world including Asia where nutrition and activity transitions are rapid and pronounced [14, 15]. The constellation of chronic diseases is dominated by type 2 diabetes and cardiovascular disease and the major risk factors for both are obesity, poor diet and physical inactivity. Developing countries are also confronted with arguably the most important global health issue underpinning chronic disease, the so-called double burden of malnutrition where under- and overnutrition coexist, often in the same family. The most vulnerable population groups are pregnant and lactating women and their young infants as there is a relationship between the quality of growth of the fetus and infant and later development of chronic diseases. In the industrialized world and an increasing proportion of low- and middle-income countries, a rapidly increasing sub-set of the population is obese pregnant women. Overlaying maternal health issues associated with obesity and related conditions are the subsequent effects on the fetus and newborn. There is strong evidence that children born to obese mothers may experience suboptimal conditions *in utero* and have an increased likelihood of becoming obese [16, 17]. Adverse biological consequences of obesity and related conditions are also often exacerbated by a heavy psychosocial and economic burden [5].

Mismatch, Physical Activity, Development, and Obesity

Gluckman and Beedle [6••] refer to the concept of mismatch between an individual and his/her environment to explain the risk of development of diseases including obesity and diabetes. In simple terms, mismatch with respect to obesity refers to the differential between humans' evolutionary range of nutritional density and workload (habitual physical activity and exercise) and that of the modern obesogenic environment. The outcome includes a metabolic overload and greater likelihood of obesity and metabolic disease. Paradoxically, levels of physical inactivity and sedentary behaviors are so prominent that we now see an 'ergonomic mismatch' with low functional capacity in the overweight and obese despite greater opportunities for leisure-time physical activity participation in today's society.

We hypothesize that another way of expressing such a mismatch is that 'metabolic fitness' (and health more broadly) is compromised by a lack of exposure to a wide range of movement and activity experiences during the formative years of growth and development. It could be argued that inappropriate patterning for many individuals, particularly those more predisposed to poor metabolic health, is not restricted to a single period but is influenced by the health status and lifestyle practices of one's parents and both prenatal and postnatal environments. It is very interesting to speculate how eating and activity behaviors of mother (and father), infant and young child impact short, medium and longer-term metabolic health and the obese phenotype.

It is similarly interesting to consider the obesogenic factors in the current environment which were not commonplace in the past and the impact of such factors on physical activity participation, motor skill development and consequent health outcomes of the young generation. There are certainly many examples of increased controls or limitations on the activity practices of infants and young children today which were not seen in the past. Gluckman and Beedle [6••] refer to greater control in the rearing of infants and prepubertal children and cite the greater proportion of women in the workforce, concerns regarding child safety and the emphasis on formal education from a younger age as potential reasons. The so-called 'maladaptive responses', including heightened risk of overweight and obesity in an increasing number of infants and young children, require urgent redress, ideally by being proactive at the most opportune time(s) during the so-called 'windows' of opportunity.

'Windows' of Opportunity

The term, 'window of opportunity' has traditionally been used in relation to early life, particularly infancy (the first two years of life), and the importance of providing the young child with adequate nutrition to optimize growth and development and health status. Recently, the 'window of opportunity' with respect to nutritional adequacy has been widened to encompass the prenatal period and the '1,000 day window,' from conception to the child's second birthday. Collectively, the medium- and

longer-term consequences of both intrauterine under- and over-nutrition include stunting, wasting, underweight and micronutrient deficiency plus predisposition to later chronic disease [22–24]. Adequate nutrition during the '1,000 day window' is therefore critical to all aspects of growth and development.

We contend that the term 'window of opportunity' should also reference physical activity exposures during early, mid- and late-childhood. The importance of opportunities to explore one's body and physical surrounds from birth is consistent with optimal growth and development and nutritional adequacy. Sensorimotor experiences underpin the development of fundamental movement patterns so important to successful ergonomics and later involvement in meaningful physical activity. If sensorimotor experiences and opportunities to move freely are limited during the formative years, individuals may be significantly disadvantaged from both body composition and movement perspectives. In short, as excessive weight gain in the early postnatal period has been linked to increased risk of obesity in adulthood [18, 19], it is imperative that nutrition and activity are optimized at this time. Unfortunately, obesity in early life is also consistent with an increased risk of co-morbid health conditions. For example, individuals who are obese in the preschool years are more likely to be obese in later childhood and present with a range of obesity-related co-morbidities [20, 21].

Given the extent of the global obesity problem it may be just as important to reference additional developmental phases or critical periods where significant morphologic changes are commonplace and where physical activity opportunities may be compromised. Additional 'windows of opportunity' including the transition from childhood to adolescence across the pubertal barrier, may also be critical in the context of reducing the risk of obesity development and further declines in physical activity participation.

One might argue that an earlier and overarching contributor to risk of obesity in youngsters is maternal health status, including body composition which is impacted by the health and lifestyle practices of adolescent girls. Adolescent health issues, including obesity, have arguably received less attention than during the preceding childhood or later adult years. Now more than ever before there is an urgent need to invest in strategies to improve the eating and activity behaviours of adolescent girls in order that they maximise not only their personal health status but that of later offspring [24]. Here we focus specifically on the opportunities presented by a more physically active lifestyle during adolescence, pre-pregnancy and pregnancy as forerunners to optimizing eating and activity behaviours during the early years.

Physical Activity during Adolescence, Pre-Pregnancy and Pregnancy

The impact of the combination of reduced levels of physical activity and risk of increased fatness may be magnified at critical stages or windows including during adolescence, pre-pregnancy and pregnancy. Maternal obesity and excessive gestational weight gain are associated with poor health outcomes for mother and infant [4, 7, 25]. In addition, gestational weight gain is an independent risk factor for obesity in the child [26] and high and low birth weights (linked to maternal obesity) are also associated with higher maternal and infant complications and the development of childhood obesity. Further, rapid weight gain during infancy significantly increases the risk of later obesity [27, 28]. Engagement in healthy eating and activity behaviours during pregnancy (or ideally pre-pregnancy) may be one of important approaches to attenuate excessive weight gain as well as improve health outcomes for mother and optimize growth and development of the fetus and infant [4].

Research suggests that risk for childhood obesity is not limited to the nature of gestation but exists before pregnancy as a function of maternal weight and epigenetic influences from the previous generation [29, 30]. Accordingly, the vicious cycle sees adolescent girls who are high-risk being more likely to bear high-risk offspring who subsequently are more likely to become high-risk individuals during the growing years [31••].

A major opportunity to maximize the pre-pregnancy health status of women is for adolescent girls to adopt healthy eating and activity behaviours and move into the childbearing years with an optimal body composition. Hanson et al. [9••] refer to the promotion of 'health literacy' in adolescents including nutrition, physical activity, family planning, breastfeeding and infant feeding practices. We should add to this, the demystifying of physical activity during pregnancy. Traditionally, the major focus on healthy growth and development of the fetus has related to adequacy of nutritional intake (primarily to minimize the chance of fetal undernutrition). Less is understood of the role of physical activity (and exercise), including in combination with an ideal energy intake, on downstream infant and child growth and development [4, 32••].

In the knowledge that a higher pre-pregnancy weight and gestational weight gain up to 36 weeks gestation are related to increased adiposity and related risks in offspring [33], Hanson et al. [9••] argue that interventions to target weight loss during pregnancy may be too late to have the greatest effects on the health status of the offspring and his/her later risk of NCDs. Accordingly, earlier interventions targeting adolescent girls are warranted. Nader et al. [31••] contend that interventions are necessary before, during, and after pregnancy, and for very young children, along with systems approaches for sustainable prevention of childhood obesity and its consequences [34].

Both pregnancy and early life are critical windows and promising times for the incorporation of appropriate interventions to reduce rapid weight gain. If successful, interventions

to prevent preconception obesity, subsequent excessive weight gain during pregnancy and postpartum weight retention represent important opportunities to break the cycle and reduce obesity prevalence in adult women [35].

Early Life Opportunities to Prevent Obesity

How important are early life influences, including maternal and paternal health and lifestyle (including physical activity and exercise), on obesity and related co-morbidities? Similarly, what is the impact of maternal obesity on prenatal and infant development and subsequent response to challenges such as those presented by the current obesogenic environment? As indicated above and supported by the literature risk reduction for NCDs should commence in adolescence and young adult women both before conception and during pregnancy [9••].

During the prenatal period, alterations in the development of physiological processes may be related to increased susceptibility to disease later in life [36]. It is interesting to speculate on the adaptive responses of the fetus to the maternal milieu and the influence on the longer term health and well-being of the child. What is the impact for example, of a particular diet or food supplement or dietary deficiency on the developing fetus? Similarly, what is the effect of a physically active pregnancy or a pregnancy characterized by engagement in particular types of physical activity and exercise [32••]? Maternal exercise may provide numerous benefits for the developing fetus, including positive adaptive responses that translate into later cardiovascular health benefits [37]. Given that a significant proportion of the maternal population is inactive [38], this population may benefit the most from a healthy pregnancy encompassing regular physical activity [32••] such as simple walking to provide an aerobic fitness benefit [39]. The strong association between aerobic fitness and all-cause-mortality in adults is well documented [2] therefore reducing inactive behaviours and increasing active behaviours must be a high priority during the gestational period and beyond [32••].

Physical Activity and Motor Development

As mentioned above, physical activity participation during the formative years is critical for normal motor development, including development of fundamental movement skills. A strong foundation or platform of motor skills underpins subsequent participation in sport and physical activity in later years [3, 8, 40, 41]. However, exposure to an increasingly 'toxic' obesogenic environment means that many young people are not sufficiently active to maximize motor skill development. For too many children, more active behaviours have been replaced by sedentary behaviours including television and screen-based games [8]. Fisher et al. [40] assessed the relationships between objectively measured habitual physical activity and fundamental movement skills in a representative sample of preschool children and reported that total physical activity ($r=0.10$, $P<0.05$) and percent time spent in moderate to vigorous physical activity (MVPA) ($r=0.18$, $P<0.001$) were significantly correlated with total movement skills score. Similarly, Jones et al. [41] in a cluster randomized controlled trial of preschool children reported a significantly higher movement skill proficiency in the intervention vs. control group after being provided structured physical activity opportunities. A decrease in habitual physical activity levels, along with poor eating behaviours, has a major impact on undesirable weight gain. This scenario may be compounded by pain, discomfort and poor movement economy with a consequent lack of engagement in activity [8]. In summary, early childhood is a critical period for the establishment of both eating and activity behaviours [42].

During infancy, early experiences of physical activity include reaching, grasping, turning, rolling, crawling and subsequently walking. Developmental milestones are typically achieved in a stepwise fashion consistent with increasing maturation of the neuromuscular system and movement experience. Motor skill development in infants and young children governed by growth, maturation and experience, provides an important foundation for the refinement of fundamental movement patterns which underpin an individual's physical repertoire for engagement in physical activity and sport [43].

The persistence of health-related habits from childhood into the adult years has been referred to as 'tracking.' Despite the lack of strong evidence of the tracking of eating and activity behaviours established in the formative years, logic suggests that the creation of health habits during the growing years will be advantageous. Rowland [44] contends that the lack of evidence for tracking of such behaviours may relate to the lack of quality longitudinal studies and accurate measures of habitual physical activity plus the failure to address the following key question. If one intervenes to increase activity levels in children, will the augmented activity persist across the adult years?

It is also reasonable to suggest that early exposure to, and subsequent engagement in enjoyable physical activity, may have a significant impact on the 'activity trajectory' of youngsters. This includes the likelihood of remaining physically active during later developmental phases and reducing the well-documented precipitous decline in physical activity commonly seen in the transition from childhood to adolescence [45]. The implications for a reduction in NCDs related to inactivity are significant [3].

It is particularly unfortunate that the apparently natural desire of many young children to be active through play and structured physical activity, and the likelihood of maximizing motor skill development, is stymied by a host of contributing

factors. The result is that too many children display consistently low levels of physical activity and high levels of sedentary behaviour [5, 8], as is the case in adolescence and adulthood. From a health perspective, recent research findings quash the widely held societal belief that very young children are healthy and that health problems related to poor body composition status do not begin during the early years of growth and development.

It is also interesting to note our preoccupation with activity guidelines as a means of quantifying minimum requirements of physical activity for health, including in young people. In the past such guidelines were superfluous as most youngsters, in fact people of all ages, were habitually more active. As obesity rates have escalated in younger and younger age groups consistent with reduced activity levels and increased sedentary activities, we are now addressing physical activity guidelines for the pre-school child. As a guide, the young child should engage daily in approximately 60 minutes of structured play with adult supervision and a further 60 minutes of free play [24, 46•]. As mentioned previously, the early childhood years represent the optimal time to develop fundamental movement skills consistent with an individual's developmental stage. Lake [24] references the importance of nutrition and physical activity being constants rather than using them as a reward for good behaviour or withholding as a form of punishment.

Conclusion

There are numerous opportunities for the better utilization of physical activity to positively impact growth and development including during key windows or defined time points. An increase in habitual physical activity combined with more desirable eating behaviours is likely to translate into healthier alternatives to the overweight and obese phenotypes. Best bets for obesity prevention and healthy growth and development include: an optimal pre-pregnancy weight (across the adolescent years), avoiding excessive gestational weight gain, an early return to a healthy postpartum weight, promotion of breastfeeding, monitoring of infant growth and development including weight gain, promoting healthy feeding practices, limiting screen time and other sedentary activities and the promotion of healthy nutrition and physical activity.

Compliance with Ethics Guidelines

Conflict of Interest Andrew P. Hills declares that he has no conflict of interest.

Steven J. Street is an honorary research fellow at the Mater Medical Research Institute.

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Najat Mokhtar declares that she has no conflict of interest.

Nuala M. Byrne declares that she has no conflict of interest

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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- •• Of major importance

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