REVIEW ARTICLE

A Brief Review of the Physical activity, Stress, and Metabolic Syndrome Relationship in Youth: Consideration of Socioeconomic Position as a Chronic Stressor

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Abstract

Childhood obesity and physical inactivity continue to be critical public health concerns. The global magnitude of these issues warrants consideration of the practical details of the relationships between these variables, as well as the compounding effects of the multiple antecedents that contribute to these issues. The influence of psychosocial stress on health is well-acknowledged, although operationalized in a variety of ways across the pediatric literature. Further, socioeconomic position is frequently considered as an independent determinant of health outcomes, making it difficult to appreciate the ubiquity and pervasiveness of the construct. This review aims to briefly review the current understanding of physical activity, psychosocial stress, and metabolic health in youth, as well as the growing body of literature which considers the relationships between these variables. Of particular merit in this review is the consideration of socioeconomic position as a chronic stressor and the confounding influence it can have on physical activity levels.

Keywords: Obesity, Metabolic Syndrome X, Psychosocial Stress, Socioeconomic status

1. Introduction

Pediatric obesity and other related metabolic health conditions continue to be major public health concerns. The interrelated roles of several putative contributors have received increased attention the literature. This review first explains the rudimental concepts of pediatric obesity, metabolic syndrome, physical activity, fitness, and the current understanding of the relationships of these of these variables in youth. The role of stress in the metabolic health of children and adolescents is also examined with a keen focus on the growing body of evidence suggesting physical activity acts as a moderator on this relationship. Fur-

thermore, this review considers the distinct influence of socioeconomic position by considering it as a source of chronic stress as well as a direct barrier to the moderating potential of physical activity. Mindful rumination on social inequities and the social gradient of health is critical for imparting meaningful changes on public health.

2. Pediatric Obesity and Metabolic Syndrome.

The Centers for Disease Control define obesity in children and adolescents as a Body Mass Index (BMI) equal to or greater than the 95th percentile[1] and extreme obesity as equal to or greater than 120% of that value.[2] The most recent estimates of obesity among U.S. children and adolescents (aged 2-19 years) are approximately 17%.[3] Childhood obesity is associated with a number of physiological maladies including early maturation, orthopedic issues, sleep apnea, polycystic ovary disease,[4] and cardiovascular disease (CVD) risk factors, such as insulin resistance, hypertension, and dyslipidemia during childhood.[5-9] The clustering of these risk factors, commonly referred to as the metabolic syndrome, lacks explicit pediatric classification criteria, some authors have adapted adult criteria and estimated prevalence among adolescents (ages 12-19 years) to approximate 4.2-9.2%.[10-12] Metabolic syndrome in adolescence affects more males than females (6.1% vs. 2.1%, respectively)[11] and varies by ethnicity.[12]

Metabolic syndrome diagnosis was designed to complement the classic Framingham risk score used to estimate short-term risk (10-year) in adults which tends to underestimate the importance of obesity in CVD risk.[13] Obesity is considered to be the proximal causal factor in development of metabolic syndrome.[13,14] Likewise, some researchers suggest that impaired insulin function,[15] sometimes described in combination with metabolic sensitivity,[16] is also a key precipitate of metabolic syndrome diagnosis. These attributes often overlap and are well established as contributors in the development of the two other components of the syndrome; atherogenic dyslipidemia and hypertension.[13-15,17]

In addition to negative physiological outcomes, Dietz[4] notes adverse psychosocial consequences as the most prevalent morbidity associated with obesity. Childhood obesity is associated with increased emotional distress[18] and one mechanism for this is observed through teasing and/or bullying. Obese children are more likely to be teased and/or bullied compared to their normal weight peers.[19] Likewise, childhood obesity is also associated with a decrease in their quality of life (QOL) during this time period.[20] Schwimmer et al.[20] showed a significantly lower QOL in obese children and adolescents compared to normal-weight children. Furthermore, the QOL in obese subjects was comparable to that of children and adolescents who had been diagnosed with cancer.

Childhood obesity tends to persist into adulthood.[21-23] The child-adult relationship is modest and stronger when the initial assessment is done at an older age (r = 0.46-0.91 and 0.60-0.78 for adolescent boys and girls, respectively).[21] The degree of obesity also influences the persistence into adulthood in that children or adolescents at higher BMI percentile are more likely to be obese as adults.[22-25]

The literature very clearly demonstrates that childhood obesity increases risk for other components of the metabolic syndrome

later in life (i.e., hypertension,[26-29] dyslipidemia,[27-29] and insulin resistance[30,31]), poor vascular health,[32,33] and CVD and all-cause mortality.[31,34] Likewise, childhood obesity also increases the risk for metabolic syndrome as an adult.[35-37] Because metabolic syndrome is a progressive condition and typically does not clinically manifest until later in life, some authors have created composite risk scores in order to examine to what extent the clustering of characteristic associated with metabolic syndrome track into adulthood. Available literature consistently reports moderate tracking of clustered risk factors.[7,38-41] An analysis of the Princeton Lipid Research Follow-up Study suggested that metabolic syndrome diagnosis during childhood increases the risk for adult diagnosis by 6.2 times.[42] Children with metabolic syndrome were 14.6 times more likely to develop CVD compared to healthy children.[42] The same group also examined the sensitivity of pediatric metabolic syndrome which showed that examination of individual components are less sensitive for predicting adult metabolic syndrome compared to examination of all five components.[43] Different combinations of risk factors may better predict risk specific to the degree of adult obesity, as was suggested by follow-up of the Bogalusa Heart Study.[44] Among normal weight adults, abnormal metabolic risk profiles were associated with higher low density lipoprotein cholesterol and insulin levels during childhood. Contrastingly, abnormal metabolic risk profiles in obese adults were associated with higher mean arterial pressure and glucose levels during childhood.[44] Risk factors during childhood persist through adolescence and predict risk in adulthood. Further, aggregated risk tends to track stronger into adulthood than individual risk factors.[45]

3. Physical Activity and Fitness in Youth

Physical activity is defined as any bodily movement produced by skeletal muscles that results in an increase in energy expenditure above resting rate.[46] This broad definition allows the researcher a considerable amount of latitude in the description and categorization of physical activity. Physical activity can be weight-bearing, non-weight-bearing, occupational, leisure-time, continuous, intermittent, organized or non-organized, and commonly categorized by the frequency, intensity, duration, and type of the activity when considering its influence on health. The wide lens with which physical activity is considered makes accurate assessment of a research variable problematic. Several techniques (e.g. surveys and questionnaires, pedometers, accelerometers) are commonly used to assess physical activity; however, a detailed account of each of these methods is beyond the scope of this review (see *Medicine and Science in Sports and Exercise, (29) 6S)*. Several excellent reviews are available that examine the relative precision and practicality of assessment tools that are available for children.[47-49] Likewise, an entire issue of the journal *Research Quarterly for Exercise and Sport, (vol. 71, issue 2)* has been devoted to the reliability and validity of various assessment tools in a number of subpopulations.

Current recommendations for children and adolescents require school-aged youth to participate in at least sixty minutes of physical activity daily.[50] It is recommended that the majority of that sixty minutes be spent participating in activities that are of moderate-to-vigorous intensity and aerobic. Furthermore, the recommendations suggest that at least three of the days should be at a vigorous intensity. Muscle- and bone-

strengthening activities should also be incorporated as part of the sixty minutes of activity at least three days each week.[50] Recent estimates suggest only 27.1% of high school-aged youth meet the recommendation of sixty minutes of physical activity per day.[51]

Welk, Corbin, and Dale[52] note that the assessment techniques must be sensitive enough to capture the short, intermittent bouts of activity characteristic of the physical activity behaviors of children, which is a difficult task even when using a more objective measure (e.g., accelerometer). Accelerometers detect and quantify motion in units of 'counts' by determining the amount of disruption of a signal within the monitor during a specified interval of time, or epoch. Counts are summarized for each epoch (e.g., counts/minute), which can obscure short bouts of vigorous activity that are alternated with bouts of rest.[52] MET-specific cut-points are often applied to the counts in each interval of time to determine the amount of time spent in various intensities. MET values are not well established in children,[53] and when those cut-points are then used to identify participation in adequate levels of physical activity (i.e., $\geq$60 minutes MVPA/day) the error of the estimate can be exacerbated further.

While physical activity refers to a behavior, physical fitness refers to a set of physiological attributes relating to the ability to do physical activity.[54] Health-related fitness consists of body composition, aerobic fitness, flexibility, muscular endurance, and strength.[54] Aerobic fitness receives considerable attention in the literature compared to other components because of the well-established connection with health outcomes in adult literature.[55] However, this relationship between physical activity and aerobic fitness is much less clear in children and adolescents, and was examined thoroughly following the 1993 International Consensus Conference on Physical Activity Guidelines for Adolescents in a review by Morrow and Freedson.[56] Briefly, the apparently high levels and modest trainability of aerobic fitness in children and adolescents[57] are noteworthy contributors to the modest relationship typically observed between physical activity and aerobic fitness in this age group. Likewise, aerobic fitness remains relatively stable through adolescence, particularly in boys, regardless of physical activity participation.[58] Payne and Morrow[59] suggest the trainability of aerobic fitness in prepubertal children and adolescents is very modest (~5%), but may be greater in sedentary pubertal children and adolescents.[60] Morrow and Freedson concluded that the modest association between physical activity is conceivably explained by the high levels of aerobic fitness combined with the inherent error associated with physical activity assessment in youth and probable lack of a true association.[56]

4. Physical activity, fitness, and metabolic syndrome

Given the lack of consensus regarding the cut-points of individual risk factors for metabolic syndrome classification in youth, studying the relationships between physical activity, aerobic fitness, and metabolic syndrome in this age group is challenging and often examined as individual risk factors.[61-64] As previously mentioned, some researchers use composite scores to represent clustered metabolic syndrome risk.[65-67] The continuous variable created allows for examination of associations between the severity of the metabolic syndrome with other

variables such as physical activity or fitness.

The European Youth Heart Study (EYHS) has shown an inverse, graded relationship between quintiles of objectively measured physical activity and clustered metabolic risk.[68] Additional analysis of the Danish arm of the study, found that this inverse relationship was maintained even after adjusting for aerobic fitness.[66] Ekelund examined the various sub-components of physical activity (i.e., time spent in low, moderate, vigorous and total physical activity) in this group and observed a stronger association for total physical activity compared to moderate-to-vigorous.[69] Similarly, when examining quartiles of aerobic fitness in the EYHS, the least fit were significantly more likely to have clustered risk factor profiles compared to the most fit (OR= 15.8 and 10.4 for boys and girls, respectively).[70] This inverse relationship held when fitness was examined as a continuous variable[71] and regardless of fatness.[69] Examination of objectively measured physical activity and aerobic fitness as independent influences is limited, but generally suggest that both variables are inversely associated with clustered risk factors in youth[72] and that fitness partially mediates the relationship between physical activity and clustered risk.[73]

5. Psychosocial Stress and Health in Youth

Stress broadly refers to challenges to homeostasis evoking adaptive responses when it exceeds the homeostatic threshold.[74] McEwen's concept of allostatic load[75] considers the result of repeated cycles adaptive responses to conceptualize the totality stress and consider health implications. If we consider normal allostasis as consisting of an appropriately sized stress response of the sympathetic adrenomedualry (SAM) and hypothalamic-pituitary-adrenal (HPA) axes, immediately followed by a rapid deactivation and return to baseline, McEwen suggests at least four other circumstances exist which could add further challenge the allostatic load of an individual: (a) excessively frequent repeated activations, (b) failure to habituate, (c) slow recovery and return to baseline, and (d) failure to respond.[75] This more nuanced approach is more apt when investigating the relationships between stress and health outcomes.

Björntorp[76,77] suggests that obesity and insulin resistance are exacerbated and partially driven by increased stress activation. Further, the abdominal adiposity clearly linked with metabolic syndrome, appears to be exaggerated in chronic conditions of excessive stress activation.[76,78] Excessive stress loads have consistently been associated with the development of obesity, metabolic syndrome, and CVD in adults,[79-84] and is receiving attention in children and adolescents.[85-87] Given the methodological constraints in the assessment of stress,[80] investigations in children and adolescents have operationalized stress in a variety of ways (e.g., low self-esteem, maternal depression, neglect, anxiety, depression, etc.) and have generally agreed on a positive correlation with higher BMI and poor health.[86] The ubiquitous nature and varied methodology used to examine stress is further complicated when considering subgroups of the population. Differences in sources of stress are difficult to capture without using multiple indicators.[87] This broad perspective is critical as we consider opportunities for interventions among the various social indicators of health.

6. Socioeconomic Position as a Stressor

Socioeconomic position (SEP) is a well acknowledged contributor to health disparities between population subgroups.[88,89] SEP is another catch-all term used to represent the latent variable created as a result of the combined influence of various social and economic factors (e.g., education, social class and status, income, occupation, etc.).[90] Despite having a different theoretical perspective, the term "socioeconomic status" is often used to represent the same construct. For the purpose of this paper SEP is used as it more aptly represents how, within the structure of a society, one's footing is influenced by a myriad of factors.[89-91]

Baum et al., suggests that lower SEP may exert the bulk of its influence on health through chronic stress, both in terms of more frequent exposures to stressors and less access to effective coping resources.[92] Lower SEP tends to limit residential options, which can lead to greater concentrations of low SEP people living in disadvantaged neighborhoods.[93] This higher concentration can exacerbate the burdens of high population density, noise, and pollution on allostatic load. Disadvantaged neighborhoods tend to have higher crime rates and less access to resources such as adequate healthcare or places to purchase produce, further contributing to the cumulative burden represented by allostatic load.[92] Baum et al. also notes the greater proportion of ethnic and racial minorities who comprise the lower SEP classification, as they are likely to experience the chronic stress of racism and discrimination, which further contributes to allostatic load.[92] Additionally, the influence of SEP on health outcomes may be mediated by unhealthy or inadequate coping behaviors such as substance use/abuse (e.g., tobacco, alcohol, etc.), higher consumption of more palatable, less nutrient dense food, and lower adherence and/or utilization of preventive and medicamentous healthcare.[92] The influence of SEP extends to other health-related variable including physical activity. Examination of the role SEP may have on physical activity levels is especially intriguing given the potential role physical activity may serve in buffering the effects of stress on health.

7. Physical activity, stress, and health

The notion that physical activity may aid in attenuation of the deleterious effect of stress on health stems from Sothmann's cross-stressor adaptation hypothesis. This line of injury questions if the adaptations to one kind of stressor (i.e., exercise) are applicable when subjected to other sources of stress.[94] The beneficial adaptations of exercise training on other exercise stressors is generally accepted.[95] However, the evidence of exercise training adaptations translating to non-exercise stressors is unclear. Separate systematic queries have quantitatively examined the available evidence and suggested only a modest influence of aerobic fitness and exercise on psychological stressors in adults.[96-98] Given the diverse methodology used to quantify stress in the studies examined, this area of inquiry can still be considered methodologically neophytic. Implications of these findings are difficult to interpret, but may indicate some benefit of exercise training benefits that extend beyond CVD risk factor improvements in adults.[80]

This line of inquiry has received even less attention in youth, and stress researchers infer from work which examines relationships between habitual physical activity or

exercise bouts and stress-related variables. For example, Brown and Siegel's[99] earlier work showed that increased exercise frequency tended to blunt or lessen the relationship between stress and disease. Similarly, Strauss et al.[100] observed lower self-esteem in adolescents who were less active. Habitual physical activity has been shown to be inversely associated with anxiety and depression, and positively associated with self-esteem in children.[101] Likewise, the secular decline in physical activity appears to be inversely associated with depressive symptoms over a two-year period.[102] These studies along with others[103-106] provide a preliminary evidentiary standard for confidence in a true inverse relationship between stress and physical activity in youth.

The bivariate relationships between physical activity, stress, and health have prompted some investigators to question is the physical activity could have some beneficial influence on the relationship between stress and health. Only a handful of studies[107-113] have examined the moderating potential of physical activity and/or fitness on the stress-health relationship, but tend to agree that greater levels of habitual physical activity and aerobic fitness may play at least a modest buffering role on the unfavorable stress-health relationship.

The focus on habitual physical activity and aerobic fitness is a particularly noteworthy aspect of these investigations. Regular physical activity and aerobic fitness have consistently been linked with improved risk for several chronic conditions. Generally, aerobic fitness levels are tied to higher physical activity levels, though this relationship is somewhat muddled in youth.[56] Perhaps regular bouts of aerobic provide an opportunity for physiological "toughening" of the stress response system as suggested by Dienstbier.[114] Further, habitual exercise may also provide a means of developing healthy coping strategies and a propensity toward resiliency in youth. The term resiliency refers to the mental toughness that results from the experience of stress and utilization of effective coping strategies and is characteristic of those who persevere regardless of adversity.[115] Physical activity and exercise are associated with greater mental toughness in youth.[116-118] Furthermore, greater mental toughness is associated with greater resiliency to psychological stressors in youth.[119]

Aerobic physical activity may provide benefits that directly influence the risk factors associated with poor metabolic health, as well as provide a mechanism of developing effective coping strategies and resiliency. Understanding this relationship is important for all age groups, but particularly so in children and adolescents where attitudes and behavioral patterns are being developed. Early interventions that focus on developing a lifelong appreciation of physical activity and provide opportunities to develop mental toughness and resiliency, could translate into meaningful health outcomes in adulthood.

8. Socioeconomic Position and Physical Activity Levels

As discussed earlier, SEP is a well acknowledged determinant of health. The relationship between SEP and healthy behaviors, namely physical activity, warrants further attention as SEP has the propensity to influence several determinants of physical activity. Stalsberg and Pedersen[120] wrote an excellent systematic review which examines the influence of SEP on physical activity levels specifically in children and

adolescents and reported a general consistency in the literature regarding the relationship between lower SEP and lower levels of physical activity. The authors highlighted the direct financial implications of lower SEP on youth participation in activities requiring specialized equipment or participation fees. Stalsberg and Pedersen[120] also discuss the relevancy of clustered, lower SEP among neighborhoods and fewer public recreational areas, greater distances in between these neighborhoods and recreational facilities, as well as the influence of perceived safety in these neighborhoods all contributing to lower levels of physical activity. An examination of the National Longitudinal Study of Adolescent Health used Geographic Information Systems (GIS) technology to link access to physical activity facilities to individual respondents and results were in accordance with the trends in the literature.[121] Furthermore, the GIS methodology used in this study was able to illustrate the inequity among physical activity facilities that were expected to be more equitably available in lower SEP neighborhoods (e.g., public parks, schools, youth organizations, etc.) which highlights the importance of a more strategically built environment when addressing physical activity in this demographic.[121] In addition to proximity, the affordability of these recreational facilities also determines their use in lower SEP neighborhoods. Some preliminary quasi-experimental evidence from the United Kingdom suggests that the removal of usage fees combined with increased outreach and program marketing efforts in impoverished neighborhoods may lead to increased physical activity at the population level.[122] Differences in physical activity levels by SEP are principally determined by early adolescence,[123] which underscores the need for effective interventions early in life.

9. Conclusion

Significant mitigation of childhood obesity and related metabolic health conditions requires the consideration of multiple interrelated antecedents. Effectively addressing these conditions at the population level also requires consideration of the role of social equity; a construct that is too frequently dismissed as "too vague and ill-defined, too freighted with political baggage" and a distraction from a more scientifically pure investigation of exposure and outcome.[124] This review provided a brief overview of the relationship between psychosocial stress and health in youth and our general understanding of the role that physical activity can play in moderating that relationship. Further, this review considered the role of low SEP as a persistent source of stress throughout the life course that can affect the frequency and magnitude of stress activation, as well as the availability and utilization of healthy coping resources. In a recent essay, Marmot discussed the importance of psychosocial influences on social determinants of health and health equity.[124] He affirmed the significance of education and experiences during childhood in proving context for choices made throughout life, including the development of habitual behaviors that influence health (e.g., smoking, diet, drug use, etc.). Further, Marmot emphasized the cruciality of consideration of the influence of psychosocial stress on physical disease and noted that mental illness is a salient repercussion of social inequity.[124] These considerations are particularly meaningful when taken together with the results of a recent meta-analysis on coping, emotion regulation, and psychopathology in childhood and adolescence, which suggested that youth who employ engaged emotion regulatory and adaptive coping strategies

tend to exhibit fewer symptoms of psychopathology and greater resilience.[125] These engaged coping strategies are characterized by a response to stressors through actively trying to change the situation or emotional responses to it, or adapt to the stressor via acceptance, distraction, cognitive restructuring, and positive thinking.[126] Participation in physical activity and exercise as a means of coping with a stressor are prime examples of these engaged coping strategies, which can also have a direct and meaningful influence on metabolic health. Furthermore, developing and learning how to employ these strategies during childhood and adolescence may significantly impact the social gradient of health on the greater population level as well as health in general throughout the life of an individual.

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