Cardiorespiratory fitness and activity explains the obesity-deprivation relationship in children

Original Article

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Running Head: Fitness Vs. physical activity

Abstract

This study examined the association between obesity and deprivation in English children and whether cardiorespiratory ~~physical~~ fitness or physical activity (PA) can explain this association. Obesity was assessed using IOTF criteria in 8,398 10–16 year olds. Social deprivation was measured using the Index of Multiple Deprivation (IMD) (subdivided into 3 groups; high, mid and low deprivation). Obesity was analysed using binary logistic regression with stature, age and sex incorporated as confounding variables. Children's fitness levels were assessed using predicted VO_2 max (20-metre shuttle run test) and PA was estimated using the PA Questionnaire for Adolescents or Children (PAQ). A strong association was found between obesity and deprivation. When fitness and PA were added to the logistic regression models, increasing levels in both were found to reduce the odds of obesity, although it was only by including fitness into the model that the association between obesity and deprivation disappeared. Including estimated PA into the model was found to be curvilinear. Initial increases in PA increase the odds of obesity. Only by increasing PA to exceed the 71st percentile (PAQ=3.22) did the odds of being obese start to decline. In order to reduce deprivation inequalities in children's weight-status, health practitioners should focus on increasing cardiorespiratory fitness via physical activity levels in areas of greater deprivation

Keywords: ~~Aerobic~~Cardiorespiratory fitness, physical activity, binary logistic regression.

Introduction

Health is not distributed equally across society and there is clear evidence of social and economic inequalities in many aspects of health including obesity (The Marmot Review Team, 2010). In adults, obesity prevalence is associated with measures of socio-economic position with higher levels of obesity found among more deprived groups (The Marmot Review Team, 2010). This association is ~~also~~ stronger in women than men (The Information Centre, 2010). This social gradient is also evident in children with data from the National Child Measurement Programme spanning the years 2006 to 2012 indicating that obesity prevalence for English children in reception year (ages 4-5) and Year 6 (ages 10-11) in the most deprived 10% of electoral wards is approximately double that of the least deprived 10% (Roberts et al., 2013).

Data documenting the association between physical activity and deprivation is more complicated, potentially due to the varied measures of deprivation/socio-economic status and physical activity that have been used in the literature (Roberts et al., 2013). Data from the Active People Survey has identified a social gradient whereby adults of high socio-economic status are more likely to participate in regular sport and physical activity than their low socio-economic status peers (Hillsdon, 2011). There is no simple explanation for the association between physical activity and deprivation with differences in the physical environment being cited as a key influence on physical activity behaviour (The Marmot Review Team, 2010). Individuals from more deprived areas are more likely to live in areas that do not support walking or cycling (Institute of Public Policy Research, 2002). High levels of traffic and fear of traffic have also been cited as more prevalent in the most deprived areas of the UK and also as a key factor in parents' decisions on whether children can play outside. The social environment also plays an important role in opportunities to be physically active and works in tandem with the physical environment. Data suggest that individuals living in the most deprived parts of the UK have less discretionary leisure time, outside of employment, to undertake physical activity (Public Health England, 2013). Education also plays a key role in uptake of physical activity (Bauman, et al.,2012) with a higher level of education being associated with increased levels of physical activity, and with lower levels of education being seen in the most deprived areas (Lawlor, et al., 2005).

The underlying mechanism explaining how deprivation might be associated with obesity is therefore complex due to the interrelated range of relations between social, economic and physical environments and individual factors that underlie the development of obesity (Kopelman, et al., 2007). In the context of children, a number of papers have examined a range of these social (Rutten, et al., 2013) and built environmental (Eyre, et al., 2015) correlates of physical activity and fatness. Recent research in 11 to 13 year old British children has also identified that children from deprived areas and girls were more likely to have low levels of ~~aerobic~~cardiorespiratory fitness and also that low fitness was associated with increased metabolic risk (Charlton et al., 2014). However, the potential impact of cardiorespiratory ~~physical~~ fitness on the association between deprivation, physical activity and obesity has not yet been explored in adults or children.

Regular physical activity improves cardiovascular fitness which reduces the risk of disease-related mortality even in overweight or obese individuals (Jakicic and Davies, 2011; McAuley, et al., 2011). Review studies have also confirmed the 'fat but fit' concept (Jakicic and Davies, 2011; McAuley, et al., 2011). whereby it is possible for an individual to be overweight/obese whilst also being physically fit because exercise affects lipid metabolism, increases HDL-Cholesterol and improves glucose and insulin metabolism (Trayhurn, 2005; Goldberg and Elliot, 1987).

Hence, the aims of this study were twofold. Firstly, we wished to investigate the association between obesity and greater deprivation (using the IMD) in English school children, both before and after controlling for the confounding effects of body size (stature), sex and age. Secondly, we wished to discover to what extent either cardiorespiratory physical fitness and/or physical activity can overcome this association in the same population.

Materials and Methods

Participants

This study is based on secondary data analysis of the East of England Healthy Heart Study. Comprehensive detail regarding the methods used are presented elsewhere (Voss and Sandercock, 2010). Following approval by the university of Essex ethical review committee, 8,398 (10.0–15.9 year olds) children were recruited from a structured convenience sample of 23 state schools. All data collection occurred between 2007 and 2009. Only state-run, comprehensive schools were sampled. Letters were sent to schools in the East of England region inviting them to participate in this study. Purposeful sampling was then used to select a representative mix of volunteer schools to take part in the study. The sample was selected to ensure that it had characteristics similar to the East of England in terms of rural (30%) or urban location (70%) and area-level deprivation. In England, 80% of the population live in urban areas, whereas the East has more rural areas. The East of England itself is also relatively affluent with a deprivation score of ~10% below the national average. Physical education (PE) is compulsory for all English school pupils until age 16. All pupils normally attending PE were potentially included in the study; exclusion criteria were the presence of known illness (such as underlying cardiomyopathy) and lack of parental or pupil consent. Schools provided consent for pupils to take part in data collection~~be tested~~ and we used an additional opt-out approach to parental consent. Finally, verbal consent was required from each participant ~~at a point of testing~~before being allowed to take part. This approach resulted in response rate of 98.2%.

Measures of Overweight and Obesity

Participants' body mass and stature were measured (to the nearest 0.1 kg and 0.1 cm, respectively) in T-shirts and shorts and without shoes. Body mass index (BMI) of each participant was calculated as kg/m^2 using the UK 1990 Growth Reference which adjusts for age, sex and skewness (Cole et al., 1990). We categorized BMI twice to determine the effect of our categorization. In the first analysis, BMI was categorized as underweight, normal weight, overweight and obese according to the International Obesity Task force (IOTF) criteria (Cole et al., 2000) which are less arbitrary criteria than the 85th and 95th cut-offs (Cole, et al., 1990) used by the UK's National Obesity Observatory (National Obesity Observatory, 2011). We grouped underweight and normal weight together, to create three groups based on BMI scores: normal and underweight, overweight, and obese.

Measures of Physical Activity

Each participant completed the Physical Activity Questionnaire for Adolescents (PAQ-A) or Children (PAQ-C). Participants of high school age (>11 years) completed the PAQ-A and primary schoolchildren (<11 years) completed the PAQ-C (Crocker, et al., 1997). This instrument has been previously validated, showing acceptable relationships with accelerometer derived scores for moderate (rho = .56) and vigorous (rho = .63) physical activity in a sample 11-13year olds (n = 210) (Janz, et al., 2008). This is a self-administered, 9-item, seven day recall of physical activity designed for adolescents of the ages taking part in the study which shows satisfactory reliability and validity (Kowalski, et al., 1997). The PAQ-A is scored on a 5 point Likert scale (1–5), with higher values indicating greater levels of physical activity. A sample item is: ‘In the last 7 days, what did you do most of the time at break?’ with participants being able to select a range of commonly used physical activities (e.g., tag, badminton, dance) or add other activities undertaken. Overall physical activity is provided by deriving the mean of all 9-items. PAQ-A/C were anglicised (recess became break; soccer became football) as described previously (Voss et al., 2013).

Measurement of Cardiorespiratory ~~Physical~~ Fitness

Cardiorespiratory Ffitness was assessed using the 20-metre shuttle run test (20mSRT), an incremental running test to maximal exertion (Leger, et al., 1988). Running speeds at final completed level were converted to predicted VO_2 max, which was used as a measure of fitness (Leger, et al., 1988).

Measures of Deprivation

We obtained an area-level measure of deprivation for each participant using their individual home postcode. The English Index of Multiple Deprivation 2007 is measured based on the small-area geographical units known as lower super output areas (LSOAs); each LSOA containing 1,000-3,000 inhabitants (Department for Communities and Local Government, 2007). An average population of only 1,500 allows identification of small pockets of deprivation within an area (Department for Communities and Local Government, 2007). There are 32,482 LSOAs in England and these are ranked from 1, the most deprived to 32,482, the least deprived based on multicomponent score ranging from 0.4 (least deprived) to 85.5 (most deprived). A lower score indicates low area-level deprivation, with a high score indicating higher deprivation. Within the present data, this resulted in 32,394 IMD units/ranks ranging from low (very deprived) to high (less deprived).

Statistical Methods

Initially, the association between obesity (defined using the IOTF criteria) and the IMD (divided into 3 groups; high, mid and low deprivation) was explored using Pearson's chi-squared tests of independence.

Due to the possible effects of confounding variables, binary logistic regression was used to explore the strength of the association between obesity and deprivation having controlled for the effects of age, gender and stature. Note that stature was included in the model because it is thought to be positively associated with adults but negatively associated with children (Bosy-Westphal et al. (2009)). Finally, estimated cardiovascular fitness and physical activity (PA) were introduced into the binary logistic regression model to explore to what extent fitness and PA might affect the association. Model selection (goodness-of-fit) was based on the change in deviance (-2*log-likelihood) (McCullagh and Nelder, 1989), known to have a chi-square distribution with degrees of freedom equal to the difference in the number of parameters used in competing models.

Following this, as additional post-hoc analysis, Receiver Operating Curve (ROC) analysis was completed separately by sex to assess whether predicted VO_2 max could discriminate between non obese and obese children. The predicted VO_2 max threshold or cut-point for each model was defined as the coordinate that had the closest value to 1 for the difference between the true positive (sensitivity) and the false positive (specificity) values. This procedure was adopted to optimise the sensitivity-specificity assocaition. The area under the curve (AUC) was employed as a measure of the global accuracy of the cut-off values. Significance level was set at $P<0.05$.

Results

There was strong evidence that children from areas of high-deprivation were more likely to be obese (girls=6.1% and boys=7.2%) compared with those who lived in the least deprived areas (girls=3.3% and boys=4.4%), see Table 1. These observations were supported by significant chi-square tests of independence for girls χ^2 (df=2) = 11.3 (P=0.004), for boys χ^2 (df=2) =11.8 (P=0.003) and boys and girls combined χ^2 (df=2) = 22.6 (P<0.001).

However, these results might be influenced by a number of other confounding variables including age and stature. For this reason we explored these other associations with obesity using binary logistic regression. The initial binary logistic regression confirmed the strong association between obesity and social deprivation for both boys and girls combined (Table 2a). When we repeated the analysis to incorporate sex, age and stature (height), the significantly higher odds/probability of obesity in the mid- and most deprived groups remained (Table 2b).

Not only were children from the most deprived areas more likely to be obese, they were also less fit and performed less physical activity. The mean VO_2max scores of children from high, middle and low areas of deprivation were 42.8, 43.5 and 44.5 $ml.kg^{-1},min^{-1}$ respectively (P<0.001). Similarly, mean PAQ scores of children from high, middle and low areas of deprivation were 2.79, 2.84, and 2.85 respectively (P=0.023). Note the overall mean and median PAQ score was 2.83 (SD=±0.7) and 2.80, respectively.

Consequently, we repeated the analysis reported in Table 2b, but to include estimated cardiovascular fitness (predicted VO_2max) and PA (estimated using the PAQ scores) as additional predictors in the binary logistic regression. Initially, these measures of fitness and PA were entered separately into the binary logistic regression model (Tables 2c and 2d respectively), but subsequently they were both entered simultaneously (Table 2e) to explore how they effected the association between obesity and deprivation.

When we added estimated cardiovascular fitness alone to the binary logistic regression model, the odds/probability of obesity in the mid- and most-deprived groups was no longer significant, i.e. no longer different from the least deprived reference group (Table 2c). As expected, the odds of being obese declined with increasing levels of cardiovascular fitness (estimated VO_2max) (OR=0.761; 95% CI 0.742 to 0.780). The change in deviance from model in Table 2b (=3473.0) to that in model Table 2c (=2531.7) was 941.3 (1 df) ($P<0.001$), highlighting the importance of estimated VO_2max in assessing the odds of being obese.

In contrast, when we added estimated PA alone (using the PAQ scores) to the binary logistic regression model, the odds/probability of obesity in the mid- and most-deprived groups remained significant (see Table 2d). Note that we found the association between the odds of being obese and the PAQ scores was now curvilinear and better explained using a quadratic model (by adding PAQ^2 to the model). Also the odds of being obese appears to rise initially (positive B=0.922, P>0.05) with lower PAQ scores and only begins to decline after 1.95 =0.922/(2*0.236) (quadratic maximum, estimated using elementary differential calculus). The change in deviance from model in Table 2b (=3473.0) to that in model Table 2d (=3066.0) was 407 (2 df) (P<0.001). This change in deviance suggests that estimated PA is still important, but considerably less so, than including estimated VO_2max when assessing the odds of being obese.

We repeated the binary logistic regression analysis by including both estimated cardiovascular fitness (predicted VO_2max) and PA (estimated using the PAQ scores) as predictors simultaneously. Note that we found the association between the odds of being obese and both age and PAQ scores was now curvilinear and better explained using a quadratic model (by adding both an Age^2 and PAQ^2 to the model). With these additional terms, the odds/probability of obesity in the mid- and most deprived groups was again no longer significant, i.e. no longer different from the least deprived reference group (see Table 2e). However with this revised model, the odds of being obese appears to rise more steeply with lower PAQ scores (B=1.733, P=0.004) and only begins to decline after 3.22 =1.733/(2*0.269) (quadratic maximum, estimated using elementary differential calculus). The change in deviance from model that included estimated VO_2max in Table 2c (=2531.7) to that in model Table 2e (=2256.2) was 275.5 (3 df) (P<0.001), confirming that PA in addition to fitness is important when assessing the odds of being obese.

The effect that the odds of being obese appears to rise with increasing but lower levels of PA (i.e. before the PAQ quadratic curve reaches its maximum), is counter intuitive. To help explain this anomaly, i.e., why the odds of being obese appears to rise with small increases in PA scores, we investigated the differences in PAQ scores by IOTF weight categories using fitness (predicted VO_2max) as a covariate. For the same level of fitness, obese and overweight children report significantly more activity that normal and underweight children (see Table 3)., suggesting that there is an element of over reporting of PA with obese and overweight children that might be responsible for the anomaly observed with the significant PAQ quadratic terms reported in Table 2e.

Given the importance of predicted VO_2max, as opposed to PA, in the results presented above, Post-Hoc ROC analysis was undertaken, for boys and girls, to determine the VO_2max cut-point that would best discriminate between children who were normal weight versus being obese. AUC values were .830 for boys and .772 for girls, with associated cut-points being 42.4 ml kg^{-1} min^{-1} (sensitivity of 69% and specificity of 82%).and 40.2 ml kg^{-1} min^{-1} (sensitivity of 61% and specificity of 80%) for boys and girls respectively.

Discussion

While the impact of deprivation on overweight and obesity has been previously established in adults, in children the evidence is less clear. This current study confirms the association between obesity and greater deprivation (using the IMD) in English school children, both before and after controlling for the confounding effects of body size (stature), sex and age. The current study is novel in identifying the way in which cardiorespiratory physical fitness and PA are both associated with a reduction in the odds of being obese in English school children, but only cardiorespiratory ~~physical~~ fitness, as opposed to PA, is able to explain the observed association between obesity and social deprivation.

Table 1 confirms a strong association between obesity and deprivation, with a higher percentage of obese children in the most deprived areas (girls=6.1% and boys=7.2%) compared with those who live in the least deprived areas (girls=3.3% and boys=4.4%). The significance of these relationships was confirmed using the Pearson's chi-squared tests of independence. Boys also have a greater percentage of obese (6.1%) compared with girls (4.7%). These results were also confirmed using the binary logistic regression (Table 2a). The odds of being obese were 50.7% and 78.2% higher with children from the mid- and most-deprived areas of deprivation respectively, compared with children with the reference least-deprived areas.

These differences remained after we introduced the possible confounding effects of sex, age and body stature, i.e., the odds of being obese were 51.0% and 80.7% higher with children from the mid- and most-deprived areas of deprivation respectively, compared with children from the least-deprived areas. Girls were less likely to be obese (OR=0.798; 95% CI 0.657 to 0.971) compared with boys, and the odds of being obese is lower with older children (OR=0.782; 95% CI 0.712 to 0.856), i.e. the odds of being obese is 21.9% (1.0-0.781) less with each additional year. Taller children are also more likely to be obese (OR=1.038; 95% CI 1.026 to 1.051), having adjusted for~~of~~ differences in age, sex etc.

However, as soon as the children's predicted VO_2 max and PA, estimated using the PAQ score (entered as a quadratic), were added separately to the binary logistic regression model, increases in both fitness and PA were associated with a reduction in the odds of being obese. However, these separate analyses revealed that only the inclusion of predicted VO_2 max as a measure of fitness was able to explain the associations between obesity and deprivation, with the differences in the areas of high, mid and low deprivation no longer being significant. This can be explained by the fact that children from more deprived locations are less fit (rather than less active) than children from less deprived areas. These findings suggest that if children from more deprived locations were as fit but not necessarily more active as the children from less deprived areas, the differences in obesity would also disappear.

In the final model when both fitness and PA were included in the model, the significant quadratic in age also suggest that the odds of being obese declines in older children but this curvilinear association appears to plateau at 17.7 years (estimated using elementary differential calculus) and the odds of being obese is likely to increase thereafter in young ~~older adolescents/~~adults.

The results in Table 2e did raise one initially inexplicable finding. When predicted VO_2 max was entered into the binary logistic regression model, as expected, the beta associated with VO_2 max resulted in negative slope parameters ($P<0.001$), suggesting that greater levels of fitness will reduce the odds of being obese. However, when the PAQ score was entered into the model as a quadratic, the odds of being obese appears to rise initially with lower PAQ scores and only begins to decline after a peak of 3.22 (quadratic maximum, estimated using elementary differential calculus). This value of 3.22 is greater than the mean (2.83±0.7) and median (2.8) PAQ score found in this study. Indeed, the 3.22 value was found to be in the 71st percentile in this population implying that the level of PA required to reduce obesity in this sample is well in excess of the mean and median PA undertaken by English children of this age group. This anomaly might be explained simply by the fact that, for the same level of fitness, overweight and obese children appear to report significantly higher levels of PA than normal and underweight children (see Table 3). The tendency to overestimate PA by certain individuals has been observed in previous studies that have used subjective measures of PA, such as the PAQ (Conway, et al., 2002; Jakicic, et al., 1998; Lightman, et al., 1992). There is evidence that obese individuals overestimate PA by 30% to 50% (Rauner, et al., 2013; Lightman, et al., 1992), whereas normal-weight participants overestimate by 8% to 30% (Conway, et al., 2002). A recent systematic review concluded that the potential inaccurate reporting of PA in subjective measures may be a major reason for the difficulty in establishing the interrelationship between BMI, fitness and PA (Rauner, et al., 2013). The current study appears to support these concerns and further questions the validity of the PAQ as a measure of physical activity.

It is of course important to note that although the measures of PA, obesity and fitness are valid and used due to their applicability in large scale epidemiological studies, the use of BMI as a proxy for body fatness and self-reported PA do have their limitations. Given the increasing availability of triaxial accelerometry to assess free living PA in epidemiological studies future research should consider adopting such objective measures to better quantify the ~~associaiotn~~association between PA, obesity and deprivation. Such technology is also able to provide details on when health enhancing PA takes place (e.g., in school Physical Education, after school at weekends) and would thus provide more precise direction to intervene for health benefit.

In summary, we were able to confirm a strong association between obesity and deprivation, with a greater percentage of children from more deprived locations categorised as obesewith children from more deprived locations have a greater percentage of obese children. The associations persisted even after all of the confounding variables of age, stature and gender were incorporated into the logistic regression model. We also established that children from more deprived locations were less physically fit and reported less PA. Indeed, as soon as levels of fitness and PA measures were included in the logistic regression models, new insights into the associations with obesity were obtained. The participant sample in the current study would likely contain individuals at different stages of sexual maturation, however, assessment of maturation was logistically not possible. Understanding if and how maturation might influence the results presented here would therefore be useful for future research.

Firstly, increasing levels of both fitness and PA were found to be associated with a reduction in the odds of being obese, although the inclusion of fitness, as opposed to PA, would appear to be the most effective of the two (confirmed by the greater change in deviance when including VO_2max alone=941.3 (1 df) compared with including PA alone=407 (2 df)). Indeed, it was only by including fitness into the logistic regression model that the association between obesity and deprivation disappeared, i.e. if all the children had the same levels of cardiorespiratory physical fitness, the differences in deprivation would no longer be significant.

The contribution that estimated PA made to the final logistic regression model was found to be curvilinear. Initial increases in PA would appear to be associated with an increase in the odds of being obese. It is only after increasing levels of PA (PAQ scores) to be in excess of the 71st percentile (PAQ=3.22) will the probability/odds of being obese start to decline. Likewise, ROC analysis identified cut-points of 42.4 and 40.2 ml kg^{-1} min^{-1} being associated with obesity for boys and girls. Clearly these findings have important implications for public health policy and health promotion and suggest there is no quick fix to reducing obesity in children. A long term strategy focused on enhancing children's ~~aerobic~~cardiorespiratory fitness will have obvious health benefits and, at the same time, may be an effective means to reduce fatness in such deprived populations.

Perspective

The findings presented here develop understanding in the areas of physical activity and public health. While prior research has identified that deprivation impacts on obesity prevalence (Kopelman, et al., 2007) and that a range of built and social variables (Eyre et al., 2015; Rutten et al., 2013) influence this association, the present study is one of the first to examine the relative contributions of physical activity and cardiorespiratory ~~physical~~ fitness in the association between childhood obesity and deprivation. The findings of the current paper suggest it is enhancing cardiorespiratory ~~physical~~ fitness, through physical activity, that may be a more effective focus than simply promoting any form of physical activity that would have the greatest benefit in reducing deprivation related inequalities in obesity in British children.

Conflict of Interest: None

References

Bosy-Westphal A, Plachta-Danielzik S, Dörhöfer RP, Müller MJ. (2009) Short stature and obesity: positive association in adults but inverse association in children and adolescents. British Journal of Nutrition, Aug;102(3):453-61. doi: 10.1017/S0007114508190304. Epub 2009 Mar 2.

Bauman, A.E., Reis, R.S., Sallis, J.F., Wells, J.C., Loos, R.J., Martin, B.W. (2012) Correlates of physical activity: why are some people physically active and others not? Lancet. 380:258–71.

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Charlton, R., Gravenor, M. B., Rees, A., Knox, G., Hill, R., Rahman, M. A., Jones, K., Christian, D., Baker, J. S., Stratton, G., Brophy, S. (2014) Factors associated with low fitness in adolescents – a mixed methods study. *BMC Public Health,* 14, 764.

Cole T. J., Freeman, J. V., Preece, M. A. (1990) Body mass index reference curves for the UK, 1990. *Archives of Diseases in Children,* 73, 25-9.

Cole, T. J., Bellizzi, M. C., Flegal, K. M., et al. (2000) Establishing a standard definition for child overweight and obesity worldwide: international survey. *BMJ*, 320, 1240-3.

Conway, J. M., Seale, J. L., Jacobes, D. R., Irwin, M. L., Ainsworth, B. E. (2002) Comparison of energy expenditure estimates from doubly labelled water, a physical activity questionnaire, and physical activity records. *American Journal of Clinical Nutrition,* 75, 519 –25.

Crocker, P. R., Bailey, D. A., Faulkner, R. A., et al. (1997) Measuring general levels of physical activity: preliminary evidence for the Physical Activity Questionnaire for Older Children. *Medicine and Science in Sports and Exercise,* 29, 1344-9.

Department for Communities and, Local Government. (2007) The English Indices of Deprivation 2007 London: Department for Communities and Local Government.

Eyre, E. L., Duncan, M. J., Birch, S. L., Cox, V., Blackett, M. (2015) Physical activity patterns of ethnic children from low socio-economic environments within the UK. *Journal of Sports Sciences,* 33, 232-242.

Goldberg, L., Elliot, D. L. (1987) The effect of exercise on lipid metabolism in men and women. *Sports Med*icine, 4, 307 – 21.

Hillsdon, M. (2011) Occupational social class, occupational physical activity, and leisure-time physical activity. *American Journal of Preventive Medicine,* 40, 494-495.

Institute of Public Policy Research (2002). Streets Ahead: safe and liveable streets for children. London: Central Books.

Jakicic, J. M., Davies, K. K. (2011) Obesity and physical activity. *Psychiatric Clinics of North America,* 34, 829 – 40.

Jakicic, J. M., Polley, B. A., Wing, R. R. (1998) Accuracy of self-reported exercise and the relationship with weight loss in overweight women. *Medicine and Science in Sports and Exercise,* 30, 634–8.

Janz, K. F., Lutuchy, E. M., Wenthe, P., et al. (2008) Measuring activity in children and adolescents using self-report: PAQ-C ,and PAQ-A. *Medicine and Science in Sports and Exercise,* 40, 767-72.

Kopelman, P., Jebb, S. A., Butland, B. (2007) Executive summary: Foresight Tackling Obesities: Future Choices' project. *Obesity Reviews* Suppl 1, vi-ix.

Kowalski, K., Crocker, P., Kowlaski, N. (1997) Convergent validity of the physical activity questionnaire for adolescents. *Pediatric Exercise Science,* 9, 342–352.

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Lawlor, D. A., Batty, G. D., Morton, S. M., Clark, H., Macintyre, S., Leon, D.A. (2005) Childhood socioeconomic position, educational attainment, and adult cardiovascular risk factors: the Aberdeen children of the 1950s cohort study. *American Journal of Public Health*. 95:1245–51.

Leger, L. A., Mercier, D., Gadoury, C., Lambert, J. (1988) The multistage 20 metre shuttle run test for aerobic fitness. *Journal of Sports Sci*ences, 6, 93–101.

Lightman, S. W., Pirsarska, K., Berman, E. R., et al. (1992) Discrepancy between self-reported and actual caloric intake and exercise in obese subjects. *New England Journal of Medicine,* 327, 1893– 8.

McAuley, P. A., Blair, S. N. (2011) Obesity Paradoxes. *Journal of Sports Sci*ences, 29, 773 – 82.

McCullagh, P., Nelder, J. (1989) *Generalized Linear Models.* London: Chapman & Hall/CRC.

National Obesity Observatory. (2011) National child measurement programme. London: National Obesity Observatory.

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Public Health England (2013) Social and economic inequalities in diet and physical activity. London: Public Health England.

Rauner, A., Mess, F., Woll, A. (2013) The relationship between physical activity, physical fitness and overweight in adolescents: A systematic review of studies published in or after 2000. *BMC Pediatrics,* 13, 19-2431-13-19.

Roberts, K., Cavill, N., Hancock, C., Rutter, H. (2013) Social and economic inequalities in diet and physical activity. London, Public Health England.

Rutten, C., Boen, F., Seghers, J. (2013) The relation between environmental factors and pedometer-determined physical activity in children: The mediating role of autonomous motivation. *Pediaric Exercise Sci*ence, 25, 273-287.

The Information Centre. (2010) Statistics on Obesity, Physical Activity and Diet: England. Leeds: The Information Centre.

The Marmot Review Team. (2010) Fair Society, Healthy Lives: Strategic Review of the Health Inequalities in England post-2010: The Marmot Review. London.

Trayhurn, P. (2005) The development of obesity in animals: the role of genetic susceptibility. *Clinical Endocrinology and Metabolism,* 13, 451 – 474.

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Voss, C., Ogunleye, A. A., Sandercock, G. R. H. (2013) Physical Activity Questionnaire for Children and Adolescents: English norms and cut-points. *Pediatrics International,* 55, 498-507.

Voss, C., Sandercock, G. R. H. (2010) Aerobic fitness and mode of travel to school in English schoolchildren. *Medicine and Science in Sports and Exercise,* 42, 281–287.

Table 1. The number of obese boys and girls (%) by high, middle and low areas of social deprivation (based in IMD ranks).

		not obese		obese	
		n	%	n	%
Girls	most deprived	1201	93.9	78	6.1
	middle deprived	1225	95.3	60	4.7
	least deprived	1306	96.7	45	3.3
	Total	3732	95.3	183	4.7
boys	most deprived	1385	92.8	108	7.2
	middle deprived	1406	93.4	100	6.6
	least deprived	1419	95.6	65	4.4
	Total	4210	93.9	273	6.1
combined	most deprived	2586	93.3	186	6.7
	middle deprived	2631	94.3	160	5.7
	least deprived	2725	96.1	110	3.9
	Total	7942	94.6	456	5.4

Table 2a. The binary logistic regression (logit) model exploring the probability (Odds Ratio=Exp(B)) of obesity by social deprivation groups (IMD ranks divided into thirds).

	B	SE	Sig.	Odds Ratio Exp(B)	95% CI.for Exp(B) Lower	Upper
IMD (least deprived)				1.0		
IMD (mid deprived)	.410	.127	.001	1.507	1.175	1.932
IMD (most deprived)	.578	.123	<.001	1.782	1.399	2.269
Constant	-3.210	.097	<.001	.040		

Reference group=least deprived third (IMD ranks).

Chi-square (2df)=23.4: Deviance(-2 log-likelihood)=3520.3

Table 2b. The binary logistic regression (logit) model exploring the probability (Odds Ratio=Exp(B)) of obesity by social deprivation groups incorporating sex, age and stature.

	B	SE	Sig.	Odds Ratio Exp(B)	95% CI for Exp(B) Lower	Upper
IMD (least deprived)				1.0		
IMD (mid deprived)	.412	.127	.001	1.510	1.177	1.938
IMD (most deprived)	.591	.124	<.001	1.807	1.417	2.303
Sex(girls)	-.225	.100	.024	.798	.657	.971
Age	-.247	.047	<.001	.781	.712	.856
Stature	.037	.006	<.001	1.038	1.026	1.051
Constant	-5.792	.698	<.001	.003		

Reference group=boys from the least deprived third (IMD ranks).

Chi-square (5df)=70.7: Deviance(-2 log-likelihood)=3473.0

Table 2c. The binary logistic regression (logit) model exploring the probability (Odds Ratio=Exp(B)) of obesity by social deprivation groups, sex, age, stature and estimated VO_2max.

	B	SE	Sig.	Odds Ratio Exp(B)	95% CIfor Exp(B) Lower	Upper
IMD(least deprived)				1.0		
IMD(mid deprived)	.223	.141	.115	1.250	.947	1.649
IMD(most deprived)	.144	.141	.308	1.155	.876	1.523
Sex(girls)	-1.062	.115	<.001	.346	.276	.433
Age	-.518	.053	<.001	.596	.536	.661
Stature	.043	.007	<.001	1.044	1.030	1.059
PredictVO2	-.274	.013	<.001	.761	.742	.780

Constant	8.403	1.056	<.001	4459.302		

Reference group=boys from the least deprived third (IMD ranks).

Chi-square (6df)=679.3: Deviance(-2 log-likelihood)=2531.7

Table 2d. The binary logistic regression (logit) model exploring the probability (Odds Ratio=Exp(B)) of obesity by social deprivation groups, sex, age, stature and estimated PA and PA^2.

	B	SE	Sig.	Odds Ratio Exp(B)	95% CIfor Exp(B) Lower	Upper
IMD(least deprived)				1.0		
IMD(mid deprived)	.435	.135	.001	1.545	1.185	2.014
IMD(most deprived)	.594	.133	. <.001	1.812	1.396	2.353
Sex(girls)	-.297	.107	.006	.743	.602	.917
Age	-.309	.051	<.001	.734	.665	.811
Stature	.040	.006	<.001	1.041	1.028	1.054
PAQ	.922	.532	.083	2.514	.887	7.131
PAQ^2	-.236	.096	.014	.790	.655	.953
Constant	-6.017	1.079	. <.001	.002		

Reference group=boys from the least deprived third (IMD ranks).

Chi-square (7df)=100.2: Deviance(-2 log-likelihood)=3066.0

Table 2e. The binary logistic regression (logit) model exploring the probability (Odds Ratio=Exp(B)) of obesity by social deprivation groups, sex, age, stature and estimated VO_2max and PA.

	B	SE	Sig.	Odds Ratio Exp(B)	95% CIfor Exp(B) Lower	Upper
IMD(least deprived)				1.0		
IMD(mid deprived)	.252	.150	.094	1.286	.958	1.726

IMD(most deprived)	.183	.151	.224	1.201	.894	1.614
Sex(girls)	-.979	.122	. <.001	.376	.296	.477
Age	-2.055	.617	.001	.128	.038	.429
Age^2	.058	.023	.013	1.060	1.012	1.109
Stature	.051	.007	<.001	1.052	1.037	1.067
PredictVO2	-.281	.014	<.001	.755	.735	.777
PAQ	1.733	.603	.004	5.659	1.736	18.449
PAQ^2	-.269	.107	.012	.764	.619	.943
Constant	14.915	4.085	<.001	3002604.7		

Reference group=boys from the least deprived third (IMD ranks).

Chi-square (9df)=618.16: Deviance(-2 log-likelihood)=2256.2

Table 3. Differences in reported physical activity (using PAQ-A or PAQ-C) by IOTF weight status category having controlled for differences in children's fitness (predicted VO_2max).

Dependent variable PAQ-A or PAQ-C			95% CI	
IOTF Weight status category	Mean	SE	Lower	Upper
(-1) Underweight	2.727[a]	.029	2.670	2.784
(0) Normal	2.829[a]	.009	2.812	2.846
(1) Overweight	2.902[a]	.016	2.871	2.933
(2) Obese	2.980[a]	.031	2.920	3.040

a. Covariates appearing in the model are evaluated at Predicted VO_2max = 43.429283.