Addictive Behaviors, Vol. 14, pp. 581–588, 1989
Printed in the USA.

0306-4603/89 $3.00 + .00

BRIEF REPORT

EXERCISE SUPPRESSES HERITABILITY ESTIMATES FOR OBESITY IN MEXICAN-AMERICAN FAMILIES

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Abstract — In multivariate analysis, suppressor variables attenuate the true relationship between predictor and outcome variables. Although suppressor variable relationships were described more than 45 years ago, few examples have been reported in the health care literature. We studied the correspondence between body mass in 111 Mexican-American families. Estimates of exercise suppressed the correlation between body mass for some dyads within these families. We concluded that the suppressor variable relationship may cause underestimates of heritability in multivariate studies.

INTRODUCTION

Suppressor variables

Both genetic and environmental theories have been advanced to explain why obesity aggregates within families (Garrow, Blaza, Warwick, & Ashwell, 1980; Stunkard et al., 1986). Most studies have failed to demonstrate that obese people are addicted to a high calorie diet (Kromhout, 1983). However, new evidence suggests that energy expenditure may explain weight gain (Ravussin et al., 1988; Roberts, Savage, Coward, Chew, & Lucas, 1988).

Obesity has been found to be associated with a number of chronic medical disorders including high blood pressure and Non-Insulin Dependent Diabetes Mellitus (Connor, Connor, Henry, Sexton, & Keenon, 1984; Stamler, Stamler, & Pullman, 1967; Stern, 1988). In an earlier paper (Patterson, Sallis, Kaplan, & Nader, in press) we investigated the aggregation of obesity, as measured by body mass index, in Anglo and Mexican-American families. We also investigated how the correlations between family members were affected by adjustments for caloric intake and expenditure. In that paper, we used dietary kilocalories divided by subjects' weight and kilocalories expended per kilogram of body weight as covariates. Our results suggested that environmental factors are more important in modulating similarities of obesity for fathers and their children when compared to mothers and their children in both Anglo and Mexican-American families. However, adjustments for environmental factors produced increments rather than the expected decrements over the zero order relationships in some Mexican-American family dyads. This finding challenges the notion that habits explain the family aggregation of body mass. The purpose of this paper is to explore the unexpected effects of these adjustments in more detail.

In multiple regression research, the ideal situation is one in which predictor variables are highly correlated with the criterion but unrelated to one another. In practice, it is most common to find one or more valid predictors that are highly correlated with one another. Typically, adjusting for a covariate reduces the observed association between a predictor and

Supported by Grant R18 HL 30872 and Grant K04 HL 00809 from the National Heart Lung and Blood Institute.
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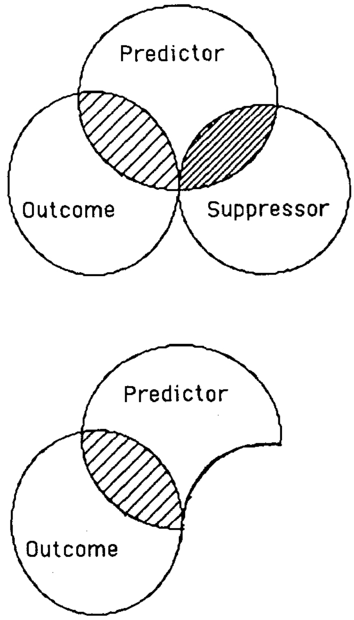

Fig. 1. Suppressor relationship shown in Venn diagram with suppressor included (top) and removed (bottom).

an outcome variable. If a covariate reduces the strength of a relationship, it is assumed that the covariate accounts for at least some of the observed correlation.

Many years ago, Horst (1941) described covariates that had the opposite impact upon observed relationships. These were called "suppressor variables." Suppressor variables are covariates that have essentially no correlation with the outcome but a high correlation with other predictors. Because of their unique quantitative relationships, suppressor variables have exactly the opposite properties as conventional predictors in multivariate analysis. The top section of Fig. 1 is a Venn diagram illustrating the suppressor variable phenomenon for three variables that we have labelled predictor, outcome, and suppressor. The investigator is interested in the relationship between the predictor and the outcome with adjustment for the suppressor. As the figure shows, the predictor overlaps with both the suppressor and the criterion. The suppressor variable is unrelated to the outcome but overlaps substantially with the predictor. The bottom half of Fig.1 shows the relationship between the predictor and the outcome with the suppressor removed. As the figure illustrates, a higher proportion of total area of the predictor now overlaps with the outcome. This occurs because a portion of the predictor was removed with the suppressor. As a result, the proportion of the predictor that overlaps with the outcome is increased. Yet, the independence of the outcome and the suppressor left the area of the outcome unchanged.

Although suppressor variables have been described in textbooks for over 45 years, there are still relatively few empirical examples of suppressor relationships. In this paper, we report on the suppressor relationship of exercise in the estimate of the association between body mass in fathers and their children.

METHOD

Subjects

The data reported here were gathered as part of a cardiovascular risk reduction program

Table 1. Means and standard deviations for all measures by family status for Mexican-Americans

		Weight (Kg)	BMI (kg/m^2)	Age	Total caloric intake	KKD (Kcals/Kg/day)
Father (N = 42)	$\bar{X}$	82.72	28.68	37.86	2604.88	41.14
	SD	12.00	4.18	6.85	1070.81	8.92
Mother (N = 101)	$\bar{X}$	67.33	27.51	35.44	1718.22	36.50
	SD	14.35	5.35	6.04	856.96	3.23
Younger child (N = 107)	$\bar{X}$	42.82	20.23	11.62	2028.02	37.19
	SD	11.81	3.89	.87	821.37	3.95
Older child (N = 63)	$\bar{X}$	45.18	20.03	12.48	2203.76	37.84
	SD	15.55	3.03	2.21	914.24	3.97

known as the San Diego Family Health Project (Nader et al., 1986). Anglo and Mexican-American families of fifth and sixth grade children were recruited from elementary schools in the San Diego Unified School District. This report uses data from the Mexican-American sample. Census tract data were used to identify schools with large numbers of Mexican-American families of lower to middle socioeconomic status (SES). One hundred eleven Mexican-American families (42 fathers, 103 mothers, 65 male offspring, 78 female offspring) participated in this aspect of the study. The Mexican-American group included many immigrants along with native born participants. Initial contact was made through a neighborhood survey. The survey asked about a variety of demographic variables, dietary practices, and exercise habits. Later, respondents were classified as not interested, interested but did not volunteer, and volunteer participant. There were very few differences between volunteers and members of the same community who decided not to participate (Atkins et al., 1987). These Mexican-American families showed the greatest variation in body mass and are the focus of the analyses reported here.

Table 1 shows the mean age along with the mean and standard deviations for weight, body mass index, total number of calories consumed, and kilocalories of energy expenditure, adjusted for body weight (KKD) expended during exercise. The Hollingshead (1965) two factor Index of Social Position indicated that the Mexican-American families were of lower social status ($\bar{X}$ = 3.73). The first child is the fifth or sixth grader, while the second child is an older sibling. The evaluation protocol targeted only two children per family because of limited resources and the availability of families with more than two children.

Individuals were excluded from participation in the study if there was some indication of high blood pressure, pre-existing cardiovascular disease, or some chronic illness that would prohibit an individual from participating in the exercise/diet program promoted in the intervention (Nader et al., 1986).

Procedures

Subjects were measured following a 12-hour fast between the hours of 7:00 and 11:30 a.m. Weight was measured without shoes or heavy objects in pockets. Height was obtained using a secured height anthropometer. The *quetelet* index (Kg/m^2) was used as a measure of obesity.

Collection of nutritional intake data was accomplished using a 24-hour dietary recall interview. The 24-hour dietary interview was conducted using standardized techniques and food models. Nutrition assessors were trained using Nutrition Coding Center procedures plus modifications to improve accuracy of children's reports (Frank, Berenson, Schilling, &

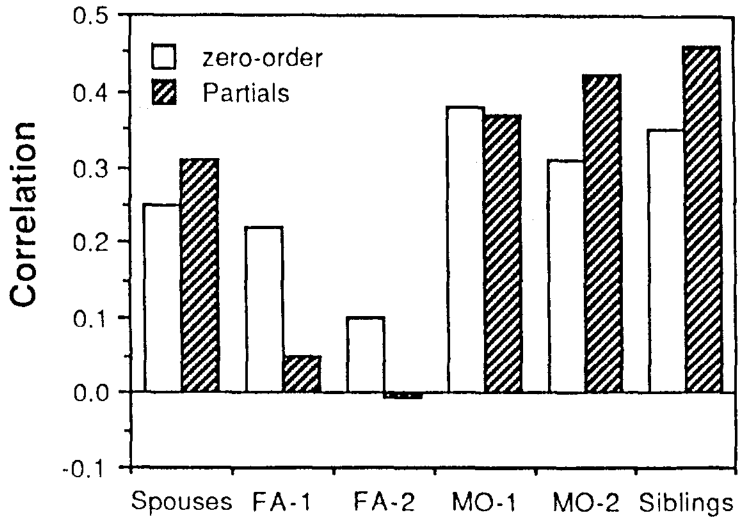

Fig. 2. Intra-family correlations of body mass in Mexican-American families. With and without adjustment. FA-1 is father with younger child. FA-2 is father with older child. MO-1 is mother with younger child. MO-2 is mother with older child.

Moore, 1977). Results were coded and analyzed for 27 nutrients at the Nutrition Coding Center at the University of Minnesota (Dennis, Ernst, Hjortland, Tillotson, & Grambsch, 1980). For this study, we used number of dietary kilocalories per kilogram of body weight per day for statistical adjustments.

The number of kilocalories expended during exercise was calculated from the 7-day Physical Activity Recall (PAR), a standardized interview. Reliability and validity of the PAR have been discussed in a number of publications (Blair, 1984; Sallis et al., 1985). Interviewers determined which portion of each of the previous 7 days subjects engaged in moderate, hard, and very hard intensity activities. Kilocalories per kilogram of body weight per day (KKD) were calculated following the procedures of Blair (1984).

RESULTS

Figure 2 shows the correlations between obesity levels (quetelet index) for spouses, parents with children, and siblings. The correlations are shown as zero order relationships and with adjustment for dietary intake and exercise (KKD). As the figure demonstrates, there is significant family aggregation for three of six dyads ($p < .05$). Aggregation was significant for mothers and first child, mothers and second child, and for siblings. However, the aggregation is enhanced with adjustment for covariates for spouses, siblings, and mothers and second child. For spouses, the zero order correlation was nonsignificant ($r = .25$, $t_{41} = 1.63$, $p =$ NS). With adjustment, the aggregation became statistically significant ($r = .33$, $t_{40} = 2.21$, $p < .05$). The aggregation value for mothers and second child was statistically significant ($r = .31$, $p < .001$) but became stronger with the adjustment ($r = .42$, $p < .001$). Similarly, the aggregation value for siblings ($r = .36$, $p < .002$) became more significant with adjustment ($r = .46$, $p < .001$). The changes in correlation coefficients were not statistically significant. Further analysis demonstrated that the enhancement resulted after adjustment for the exercise covariate but not after adjustment for the dietary covariates. These enhancements are exactly the opposite of what would be expected in ordinary multivariate analysis. If covariates explain the relationship between body masses, we would

Table 2. Summary of components of suppressor effect

Reference person (1)	Other member of dyad (2)	Body mass 1–2	Exercise 1–2	Body mass (1) exercise (2)	Body mass (2) exercise (2)
Mother*	Father N	.25	.16	.00	.23
Mother*	2nd Child	.31	.36	−.02	.23
1st child*	2nd Child	.25	.35	.03	.23
Father	1st Child	.22	.24	−.11	.10
Father	2nd Child	.10	.55	.25	.23
Mother	1st Child	.38	.39	−.02	.09

*Shows suppressor pattern.

expect the addition of these variables to attenuate the observed relationships. In contrast, the data suggest that these relationships are enhanced.

The empirical data, then, suggest that there is a suppressor variable relationship for some dyads. In order to evaluate whether or not this is a true suppressor relationship, we studied the zero order correlations between quetelet scores and exercise for various family dyads. These correlations are shown in Table 2. A suppressor variable is defined as having a significant relationship with the predictor but no relationship to the criterion. Table 2 lists a reference person and other member for each dyad in the first two columns. The aggregation of body mass for the dyad is given in the third column and the aggregation of exercise is given in the fourth column. The fifth column shows the correlation between the body mass of the reference person with the other member's exercise, while the final column gives the body mass-exercise correlation for the second member of the dyad. The data for the first three dyads in Table 2 show the suppressor effect. Notice that in each of these cases the body mass for the reference person is uncorrelated with the exercise for the other member of the dyad. However, the body mass and exercise variables for the second member of the dyad are correlated. In contrast, consider the three cases shown in the bottom half of Table 2 for which the suppressor effect was not observed. In each of these cases, the correlations listed in the last two columns of the table are approximately the same strength. The definition of a suppressor variable suggests that the suppressor is uncorrelated with the outcome but correlated with the predictor. In these examples, exercise of the second person might serve as the suppressor while body mass of this person would serve as the predictor. Body mass of the other member of the dyad might be analogous to the outcome.

Figure 3 gives an example of the suppressor relationship observed for spouses. Here, exercise of the father is correlated with body mass for the father. Further, body mass for the father is uncorrelated (aggregated) with body mass for the mother. However, exercise for the father is correlated with body mass for the mother. Thus, the example fits the typical suppressor variable pattern.

Contrast this with the situation shown in Fig. 4. Here, body mass for the father and exercise for the father are correlated. However, in addition, exercise for the father is correlated with body mass for the second child. Thus, removing the effect of father's exercise diminishes the correlation between father's body mass and body mass of the second child. Figure 4 is not drawn to exactly represent the correlations in order to illustrate the point.

DISCUSSION

Although suppressor variable relationships have been theoretically noted in the literature for nearly 45 years, there are relatively few documented empirical examples. In this paper,

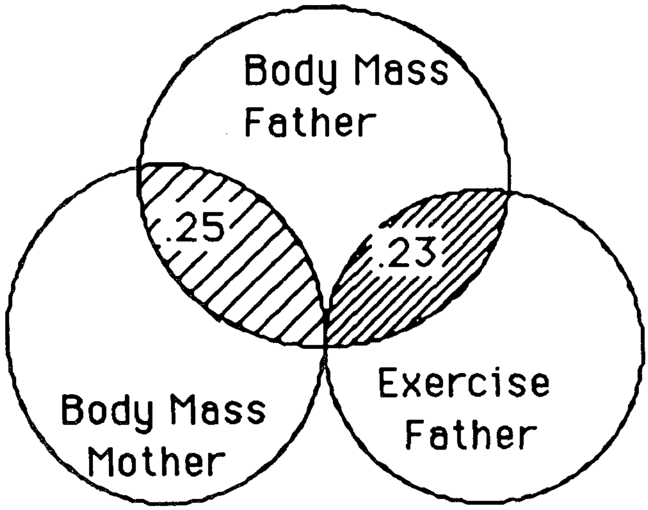

Fig. 3. Example of suppressor relationship for spouses.

we present evidence that exercise suppresses estimates of family aggregation in body mass in some cases. What do these relationships mean?

There is considerable controversy about the heritability of body mass. Although most investigators concede that body mass is determined by both environmental and genetic factors, it has been difficult to separate these competing influences. The traditional approach has emphasized the role of environmental determinants of obesity (e.g., Brownell & Stunkard, 1980). However, Stunkard et al. (1986) have recently argued forcefully for the heritability of body mass. Adjustment for health habits has a paradoxical effect in some cases. We might expect that body mass aggregates because family members have common

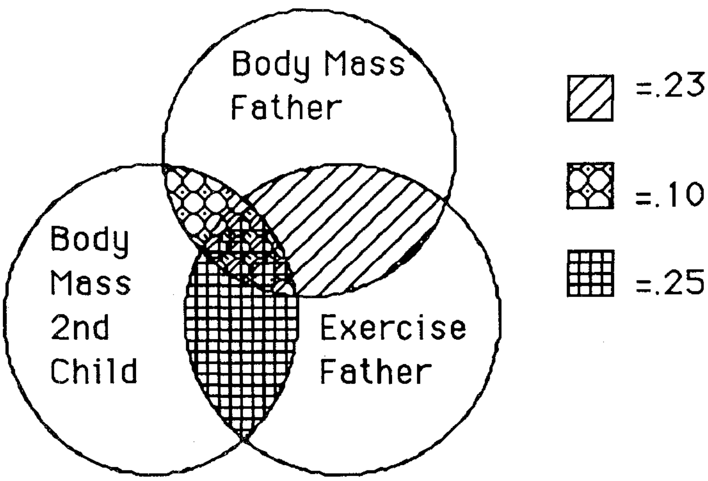

Fig. 4. Example of nonsuppressor relationship for father and second child. The multiply marked area shows areas of intersection. Figure is not exact to scale — in actual case, exercise removes effect of body mass aggregation.

health habits. Thus, we would expect that a family that exercises together will have a common low body mass. Some investigators prefer to use a common or aggregated habit score for adjustment, rather than individual scores.

The paradox is that statistically controlling for exercise habits does not explain family resemblance in body mass. We have observed cases in which family aggregation estimates were suppressed by exercise covariates. Underlying this problem is the observation that families may aggregate in health habits, but this aggregation may be independent of body mass aggregation.

Our data suggest that there is substantial family aggregation of body mass. Yet, diet and exercise factors may independently contribute to the body mass of each family member. When these influences are controlled for, particularly energy expended during exercise, the aggregation of body mass for some dyads improves. In other words, environmental and habit influences serve to suppress the estimate of family aggregation. Typically, controlling for diet or exercise will give an estimate of family aggregation independent of the influence of habits. However, these estimates can be affected when estimates of habits are correlated and when one person's habits are unrelated to the other's body mass (suppressor relationship).

In conclusion, habits can serve as a suppressor variable for estimates of genetic relationships. Although both genetic and environmental influences affect body mass, the assumption of family aggregation of habit variables is not clearly supported. Evaluating the contribution of environmental influences upon aggregation is complicated because body mass for each individual family member may correspond to a unique causal model. Once environmental influences are removed from estimates of individual body mass, there are some cases in which estimates of family aggregation are enhanced. The best solution to this problem requires obtaining estimates of body mass for each person, residualized for individual diet and exercise.

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