The Relationship between Physical Activity and Body Mass Index: Issues in Model Specification

Objective: To investigate the best statistical models that describe the effect of physical activity on BMI.
Design: Cross-sectional analyses of physical activity and BMI data.
Subjects: 107 obese, overweight, and healthy college students (mean duration of physical activity for the normal, overweight, and obese students: 89, 59, and 24 months, respectively; mean BMI for the normal, overweight, and obese students: 21.61, 27.07, and 35.54 kg/m^2, respectively).
Measurements: Inverse linear, inverse logarithmic, and inverse logistics models were used to analyze survey data for physical activity (measured by both frequency and duration of exercise) and BMI. Gender, age, and physical intensity variables were also statistically controlled.
Results: Coefficients of determination, r-squared, showed the inverse logarithmic model is more accurate in describing the effect of physical activity on BMI than is the inverse linear model. The inverse logistic method also showed physical activity affects BMI.
Conclusions: Although the inverse logarithmic method can be used in some cases, the inverse logistic model seems to be theoretically and empirically best suited in describing the relationship between physical activity and body weight.

Key Words: Physical activity; Body Mass Index; Weight Reduction; Weight Stabilization; Obesity

Introduction

Researchers, health specialists, and public officials have long known that an increased level of exercise is negatively related with body fat or weight. Numerous empirical studies have confirmed such a relationship.[1-6] The relationship between physical activity and body fat or weight is derived from the assumption that a normal-weight person's energy intake is equal or nearly equal to his/her energy expenditure.[7,1,8] That is, a person becomes overweight or obese if his/her energy intake is greater than his/her energy expenditure, and one way of maintaining the energy balance is by getting rid of the extra calories by performing physical activity.[9] What are not clearly understood, however, are the statistical models that best describe the connection between physical activity and body fat or weight.[10] For instance, Hemmingsson & Ekelund (2007) find that the association between physical activity and body mass index (BMI) is stronger in obese individuals than in non-obese persons. Their findings led them to question the conventional inverse-linear effect of physical activity on BMI. Not inconsistent with Hemmingsson & Ekelund's (2007) finding, Dwyer et al. (2007) show that the shape of the relationship between physical activity and BMI is inverse logarithmic. The insight that an inverse logarithmic model describes the physical activity and body fat or weight linkage, however, is not new. Indeed, several decades ago, Mayer, Roy, & Mitra (1956; see also Bender & Bender, 1976), for instance, demonstrated an empirical pattern of a decreasing effect of physical activity on body weight. Subsequently, several other researchers have obtained similar results.[11-13] Such findings suggest the presence of a threshold of physical activity, which occurs when a person moves from an overweight to a normal-weight status.

Given the usage of both the inverse linear and logarithmic estimators in previous research, the question becomes, which of the two models is more accurate in describing the relationship between physical activity and body fat or weight? In this study, using a cross-sectional study and a sample including obese, overweight, and normal-weight individuals, we found that although the inverse linear model provides significant results between the two variables, more variance in body weight is explained by employing the inverse logarithmic model. Hypothetical inverse linear and logarithmic curves are shown in Fig. 1.

As will be made clear below, the inverse logarithmic model is very useful and can be employed in describing some aspects of the relationship between physical activity and body weight. However, previous research findings on the relationship between physical inactivity, as opposed to physical activity, and body fat or weight [14,1,2] lead us to conceive that the best model for testing the relationship between physical inactivity/activity and body fat or weight among obese, overweight, and normal-weight persons may not be inverse logarithmic but logistic or probit. A key point for our thesis in the inactivity-related studies is the argument that a threshold of physical activity exists between sedentary and non-sedentary life styles. This threshold is distinct from the threshold that is believed to exist after an overweight individual or group achieves a normal-weight status. Mayor et al. (1956), for instance, have empirically found that a "sedentary" range or threshold of physical activity is associated with obesity. Mayor et al.'s (1956) threshold argument has been supported by Schoeller's (1998) empirical findings. Consistent with Mayer et al.'s (1956) and Schoeller's (1998) threshold arguments, other researchers have provided various minimum thresholds of physical activity necessary to prevent a sedentary life style, including energy spent on steps per day [15,4,5], time spent on moderate or rigorous exercise [16], and weekly caloric-expenditure.[17]

Given the foregoing, we argue that the pattern of the relationship between physical inactivity/activity and body fat or weight, with its upper and lower thresholds, would be best described by the logistic or probit model. A hypothetical inverse logistic curve is shown in Fig. 2. The description of physical activity (or lack there of) and body fat or weight by the logistic or probit model, however, requires a modification in the specification of the two variables. For instance, we could specify physical inactivity and activity as one variable varying in a continuum. More often than that, researchers treat physical inactivity distinct from or as an aspect of physical activity. Physical inactivity is specified as a decreasing level of activity [17,18,9] or a variable that varies from little to high level of inactivity.[19-22] It is also sometimes assumed to take a value of zero (or considered as a non-varying variable). We believe that the description of physical inactivity as a decreasing level of activity is compatible with our specification of the inactivity-activity continuum. In other words, we prefer the description of inactivity as time lost in not exercising. Thus, time lost in things like television viewing and video-game playing should be considered only as aspects of inactivity. Similarly, the use of the logistic or probit model suggests the specification of body fat or weight as a variable that is continuous within and across the obese-overweight-normal weight categories. Thus, whereas physical inactivity would correspond to the obese, lesser and greater activities would fit the overweight and the normal-weight groups, respectively. And whereas the upper-flat part of the logistic or probit curve would describe obesity, the middle and the lower-flat portions would, respectively, represent an on-going weight loss and the maintenance of a healthy weight. Indeed, the empirical evidence in this study seems to provide support for our thesis.

In summary, this study will show that while the inverse logarithmic model is more accurate in testing the relationship between physical activity and body weight than is the inverse linear estimator, the logistic model is best suited in describing the linkage between the two variables.

Methods

Research Design and Specification of Variables

This study employs a cross-sectional research design and ordinary least square (OLS) and Logistic regressions to test the impact of physical activity on BMI. BMI is considered to gauge 'bodyweight' as opposed to 'body fat', but it is argued that there is a correlation between the two variables.[23,24] We calculated the BMI of the participants (the dependent variable) using the standard formula, weight / $height^2$. For the logistic models, the BMI data were specified as follows: we assign 1 to individuals who are obese or overweight and a 0 to those who are neither obese nor overweight. Physical activity is measured by two variables: the frequency of exercise (the number of hours that a person works out in a week) and the duration of exercise (how long a person has been doing his/her weekly workout). Yet, physical activity is not the only factor that affects BMI. A host of factors including occupational activity[25], stress[26], smoking and socioeconomic status[12], drinking[27], diet[28,29,11,27,22], being in school or not and seasonal variations[30], physical fitness[31], personal health[32], and genetics[7,27] seem to impact people's weight. The purpose of this study is not, however, the full specification of the variables that explain

BMI. It is rather the specification of the models that describe BMI. Nevertheless, this study will control for the intensity of physical activity, age, and gender of the participants.

While some find that vigorous exercise is key to lower body fat or weight [2,16,12,17,33,13,22], others show that moderate or light intensity is more important in achieving or maintaining a healthy body.[16,34,19] We classified the intensity of physical activity into low, moderate, and high categories. The low-intensity variable, which we expected to have the least benefits in affecting BMI, was used as a baseline. Moreover, it has been argued that individuals' age and gender affect BMI. As people age, their weights tend to increase.[12,35] Inactivity is also found to be positively related with body fat among boys but not among girls.[19] Moreover, Cameroon & Getz (1997) have found that adolescent females are more prone to obesity than males. Lastly, Weir, Ayers, Jackson, Rossum, Poston, & Foreyt (2001) have shown that gender is a predictor of long-term weight control.

Procedure and Data Collection

The participants in this study were undergraduate students at several U.S. universities. We collected two sets of data. For the first set (N=55), we administered a questionnaire to students at the University of Z. To make the data as nationally representative as possible, we collected a second set of data by administering an email-based questionnaire at 15 randomly selected universities by accessing the names of students through university directories. These universities are Rutgers, North Carolina, Florida, Auburn, Oklahoma, Texas, Oregon, Washington, Idaho, Utah, Colorado, South Dakota, Iowa, Ohio, and Memphis. The questionnaire was sent to about 25 students at each university. We received a total of 52 responses, a response rate of about five percent. The same questionnaire was used in both sets of data. The questionnaire asked students for their weight, height, sex, age, frequency, intensity, and duration of physical activity. The mean age of the combined data (N=107), which is skewed towards older continuing-education students, is 22.6. There were 53 male and 54 female students in the combined sample data. Of these students, 17 were obese, 15 were overweight, and 75 had weights in the normal range. The means for the duration of exercise for the obese, overweight, and normal-weight groups were about 24, 59, and 89 months, respectively. And the mean BMI for the obese, overweight, and normal-weight groups were 35.54, 27.07, and 21.61 kg/m^2, respectively. We administered the questionnaire at University of Z in the Spring of 2007, and the email-based-questionnaire was conducted in the Summer and Fall of 2007.

Results

We began, in Table 1, by analyzing the impact of physical activity as well as the control variables on BMI. In Model 1 and Model 2, we estimated the data for students at the University of Z. We logged the physical activity variables, Duration and Frequency (these variables will be called Logged-Duration and Logged-Frequency hereafter). Model 1 and 2 show the impact of the un-logged and logged physical activity variables on BMI, respectively. The only variables statistically significant in both models were Duration ($P = 0.009$) and Logged-Duration ($P = 0.006$). In Model 3 and 4, we analyzed the data for the other 15 universities. Model 3 and 4 show the impact of the un-logged and logged physical activity variables on BMI, respectively. In Model 3, the Duration and Age variables were significant (P = 0.005 and 0.004, respectively). The rest of the variables were insignificant. Model 4 shows that both the Logged-Duration and the Age variables are significant (P = 0.007 and 0.04, respectively). The rest of the variables were insignificant. We combined the data for the University of Z and the other 15 universities in Models 5 and 6. The results were very similar to those obtained in Model 3 and 4: the Logged-Duration and Age variables were significant in both models; the Age variable was, however, significant at the 0.10 level in Model 6. The rest of the variables were insignificant in both models. In analysis not shown here, we interacted the Frequency and Duration variables, but we found that the impact of the multiplicative effect on BMI was insignificant.

In Table 2, we compared the merits of the inverse linear and logarithmic models in describing the relationship between physical activity and BMI. The Duration and Logged-Duration variables represented the inverse linear and logarithmic models, respectively. We did not use the Frequency variable here since, as shown in Table 1, it showed little or no impact on BMI. Model 1 and 2 show the impact of physical activity on BMI for the data we obtained from the University of Z. Both Duration and Logged-Duration were significant (P = 0.007 and 0.002, respectively) and had negative signs, but the r-squared value of the latter (0.16) was higher than the former (0.13). In Models 3 and 4, we show the impact of Duration and Logged-Duration, respectively, on the BMI data of the college students at the other 15 universities. Whereas Duration failed to have any effect on BMI in Model 3 (P = 0.24), Logged-Duration was statistically significant in Model 4 (P = 0.03). In addition, the r-squared value was higher for the Logged-Duration variable (0.09) than was for Duration (0.03). Lastly, in Model 5 and 6, we combined the data for University of Z and the other 15 universities to compare the impact of Duration and Logged-Duration on BMI, respectively. Both the Duration and Logged-Duration variables were statistically significant (P = 0.006 and 0.0001, respectively) and had negative signs, but the r-squared value was higher for the latter variable (0.13) than was for the former (0.07). In sum, the analyses in Table 2 consistently showed that the inverse logarithmic model was more accurate in describing the relationship between physical activity and BMI than was the inverse linear model.

We noted earlier, however, that a theoretically sound description of the relationship between physical inactivity-activity and BMI when using samples that include obese, overweight, and normal weight individuals is the logistic or probit model. We employed both OLS and logistic models in Table 3 to verify the foregoing assumption. First, we used the Duration variable to explain BMI and run OLS regressions by parsing the BMI data into obese, overweight, and normal groups. We do this because if we are to use the inverse logistic model, we will need to observe that the correlation between physical activity and the overweight group is higher than it is on each of the other two groups. In other words, we were specifically interested in seeing the strength and sign of the correlation between physical activity and the BMI of each group. Model 1 shows that the correlation between Duration and obese individuals' BMI is only 0.08 (P = 0.76), and the sign of the association was positive. In Model 2, we regressed BMI on the Duration variable of the overweight group; the correlation was higher, 0.33, compared to the obese group, and the sign is negative. The Duration variable was not significant (P = 0.23), however, and this might be partly a consequence of the overweight group's small sample size (N=15). In Model 3, we regressed BMI on the Duration variable of the normal-weight group. Similar to the obese, the correlation was only 0.06 (P = 0.62) and the sign was positive. In other words, Models 1 through 3 suggest that the negative correlation between physical activity and BMI was due mainly to the overweight group. For comparison, we showed the results for the combined data (N=107) in Model 4. Although the correlation value (-0.27) was statistically significant (P = 0.006) in the combined data, it was lower than the correlation value of the overweight group (-0.33) shown in Model 2. In other words, the rate of weight reduction for the overweight seems to be higher than the rates for the obese or the normal-weight groups. The implication of these results is that the best model for describing the obese-overweight-normal weight continuum may be logistic or probit regression.

Given the foregoing, in Models 5 and 6, we used the logistic model to estimate the relationship between physical activity and BMI for the combined data (N=107). We first showed the sole impact of the Logged-Duration variable on BMI in Model 5. The Logged-Duration variable was significant (P = 0.002). More specifically, the model [L = 0.59 – 0.43 (Logged-Duration)] suggested that for one unit of increase in the Logged-Duration variable, the log of odds of being obese or overweight decreased by 0.43 units. That also meant that for one unit of increase in the Logged-Duration variable, the odds ratio of an individual being obese or overweight decreased by [e**-0.43-1= 0.65-1] 35 percent. In Model 6, we controlled for the Intensity, Gender, and Age variables. Because the logged-variables showed higher variances in explaining BMI than did their un-logged counterparts, we used Logged-Duration and Logged-Frequency as measures of physical inactivity-activity in this model. The only variables statistically significant were Logged-Duration and Gender (P = 0.001 and 0.03, respectively).

In addition, using the predicted model of the logistic regression, in Fig. 3 (in the inverted S-shaped curve) we showed the overall probability pattern of being obese or overweight for given Logged-Duration values. For instance, the probability of an undergraduate student being obese or weight when exercising for about 20 months (Logged-Duration = +3) was 0.33 or 33 percent. In contrast, if a student did not exercise (or was inactive) for about 20 months (Logged-Duration = -3), the probability of such an individual being obese or overweight was 0.87 or 87 percent. As shown in Fig. 3, a whole range of values for the inverse logistic curve were fitted across the negative and positive X-axis, because we were able to estimate or predict the probabilities for negative Logged-Duration values. In other words, the negative Logged-Duration values were derived from the model and only represented the opportunity cost of not exercising. We cannot, however, compare the merits of the logistic and logarithmic models merely by the variance of BMI explained by the physical activity variable; this is because the two models rely on dichotomous and continuous dependent variables, respectively. Thus, the choice of the logistic model over logarithmic should be based on theoretical considerations.

Moreover, we showed the rates of change in the probability of being obese or overweight for given Logged-Duration values in Fig. 3 (the bottom curve). The rates of change in probability with respect to X or Logged-Duration values [$dp/dx = b (p) (1-p)$; where b = slope] formed an inverted bell-shaped like curve. This curve mathematically is the inverse or derivative of the inverse logistic curve. The inverted curve shows that the highest probability of decrease in weight in this particular set of sample (10.8 percent) occurred when the Logged-Duration value was 1.37 or when a student exercises for about [e**1.37] 4 months. The middle of the inverse logistic curve also corresponds to a 0.50 or 50 percent probability of being obese or overweight.

Discussion

One substantial finding of this study was that the duration of exercise was that matters in lowering or maintaining the BMI of undergraduate-college students. Such a finding is, however, not surprising since a student who has just started exercising and another who has been doing so for a longer period of time should not be expected to gain the same benefits in weight reduction or maintenance. Far more surprising, however, was our finding that the intensity of physical activity did not matter in lowering or maintaining BMI. One has to be careful, however, when interpreting such a result. For instance, respondents in this study might not have accurately described the intensity of their physical activities. Experimental studies should verify this finding.

Ultimately, the use of statistical models should be guided by theoretical considerations and by the research questions raised. Theories of the link between physical activity and body fat or weight have long suggested the presence of an inverse relationship between the two variables. What has not been well clarified, however, is how the inverse linear, logarithmic, or logistic models describe the relationship between physical activity and body fat or weight. We found that the inverse logarithmic model is more accurate in describing the effect of physical activity on the BMI of obese, overweight, and normal-weight groups than is the inverse linear estimator. We also found some evidence that when a cross-sectional study includes obese, overweight, and normal weight individuals, the relationship between physical inactivity-activity and BMI could be best explained by employing the logistic model. The mathematical implication of the logistic curve (as it would be the case with the logarithmic model) is that the level of the BMI of an individual could decrease, albeit infinitesimally, indefinitely. In practice, the leveling off of BMI at the lower end of a curve is interpreted to mean just the stabilization and maintenance of a healthy weight by an individual. While such an interpretation is close to the truth, the mathematical insight also seems to be valid: even an individual with a healthy BMI needs to maintain or slightly lower his/her level of weight (preferably by continuously, albeit slightly, increasing his/her level of physical activity) until he/she is too old or sick to exercise. It is known that even a person with a normal weight could vary his/her weight to his/her lower and upper limits of acceptable weight by about 18 kilo grams. If physical activity is not sustained, even an individual with a healthy weight could easily regain some or all of it.[16,13]

Our findings also have several implications. For instance, experimental studies could be conducted using the logistic or probit model to measure the impact of physical activity on a group of obese individuals over time. Such longitudinal studies would show that the pattern of weight reduction of the obese group would initially be very slow, followed by a faster speed, and ending with a very slow (stabilization) period. If a longitudinal study is, however, interested in the weight reduction of an overweight group (but not the obese), a better estimator will be the inverse logarithmic model. This model would show that faster weight reduction of the overweight group would be followed by the group's slower weight-stabilization period. The inverse logarithmic model could also be used both in cross-sectional and longitudinal studies when a study consists of both overweight and normal-weight individuals. In such scenarios, the weight reductions of the latter group would be much slower than the former. Clearly, future research should replicate the findings and implications of this study. Future studies should also be done among all and different age groups, not just on college-age students.

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Table 1: OLS Regression Estimates; Dependent Variable: BMI

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
	B	B	B	B	B	B
Intercept	24.11**	27.13**	13.91**	21.11**	19.85**	23.97**
	(4.10)	(4.40)	(4.41)	(4.23)	(2.51)	(2.74)
Duration	-0.03**		-0.04**		-0.03**	
	(0.01)		(0.02)		(0.01)	
Logged-Duration		-1.32**		-1.69**		-1.39**
		(0.46)		(0.60)		(0.35)
Frequency	-0.03		0.35		0.01	
	(0.21)		(0.34)		(0.17)	
Logged-Frequency		-0.42		2.62		0.96
		(1.35)		(2.08)		(1.10)
Gender	0.44	0.57	1.21	1.40	0.89	1.00
	(1.60)	(1.56)	(1.68)	(1.69)	(1.10)	(1.10)
Age	0.14	0.60	0.54**	0.27**	0.32**	0.19*
	(0.18)	(0.18)	(0.18)	(0.12)	(0.11)	(0.10)
High Intensity	-0.96	-0.14	-0.66	0.03	-0.12	0.03
	(2.71)	(2.79)	(4.10)	(4.02)	(2.19)	(2.23)
Moderate Intensity	-0.43	-0.29	-2.55	-3.20	-1.44	-1.62
	(1.80)	(1.81)	(1.85)	(1.95)	(1.23)	(1.27)
N:	55	55	52	52	107	107
R^2	0.15	0.16	0.25	0.25	0.16	0.18

Note: **: $p < 0.05$; *: $p < 0.10$; Bs are unstandardized betas; standard errors in parentheses

Table 2: OLS Regression Estimates of Effect of Physical Activity on BMI

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
	B	B	B	B	B	B
Intercept	26. 85**	29.24**	25.24**	28.87**	26.05**	29.10**
	(1.00)	(1.56)	(1.14)	(2.17)	(0.75)	(1.27)
Duration	-0.03**		-0.01		-0.02**	
	(0.01)		(0.01)		(0.01)	
Logged-Duration		-1.30**		-1.25**		-1.29**
		(0.42)		(0.55)		(0.33)
N:	55	55	52	52	107	107
r	-0.36**	-0.39**	-0.17	-0.31*	-0.27**	-0.36**
R^2	0.13	0.16	0.03	0.09	0.07	0.13

Note: **: $p < 0.05$; *: $p < 0.10$; Bs are unstandardized betas; standard errors in parentheses

Table 3: OLS and Logistic Regression Estimates; Dependent Variable: BMI

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
	B	B	B	B	B	B
Intercept	35.24**	27.51**	21.49**	26.05**	0.59	-1.01
	(1.64)	(0.52)	(0.33)	(0.75)	(0.49)	(1.26)
Duration	0.01	-0.01	0.001	-0.02**		
	(0.04)	(0.01)	(0.003)	(0.01)		
Logged-Duration					-0.43**	-0.51**
					(0.14)	(0.16)
Logged-Frequency						0.50
						(0.47)
Gender						1.05**
						(0.49)
Age						0.03
						(0.05)
High Intensity						0.84
						(0.89)
Moderate Intensity						-0.57
						(0.57)
N:	17	15	75	107	107	107
r	0.08	-0.33	0.06	-0.27**		
R^2					0.08	0.16

Note: **: $p < 0.05$; *: $p < 0.10$; Bs are unstandardized betas; standard errors in parentheses

Fig. 1: Hypothetical Inverse Linear and Logarithmic Curves

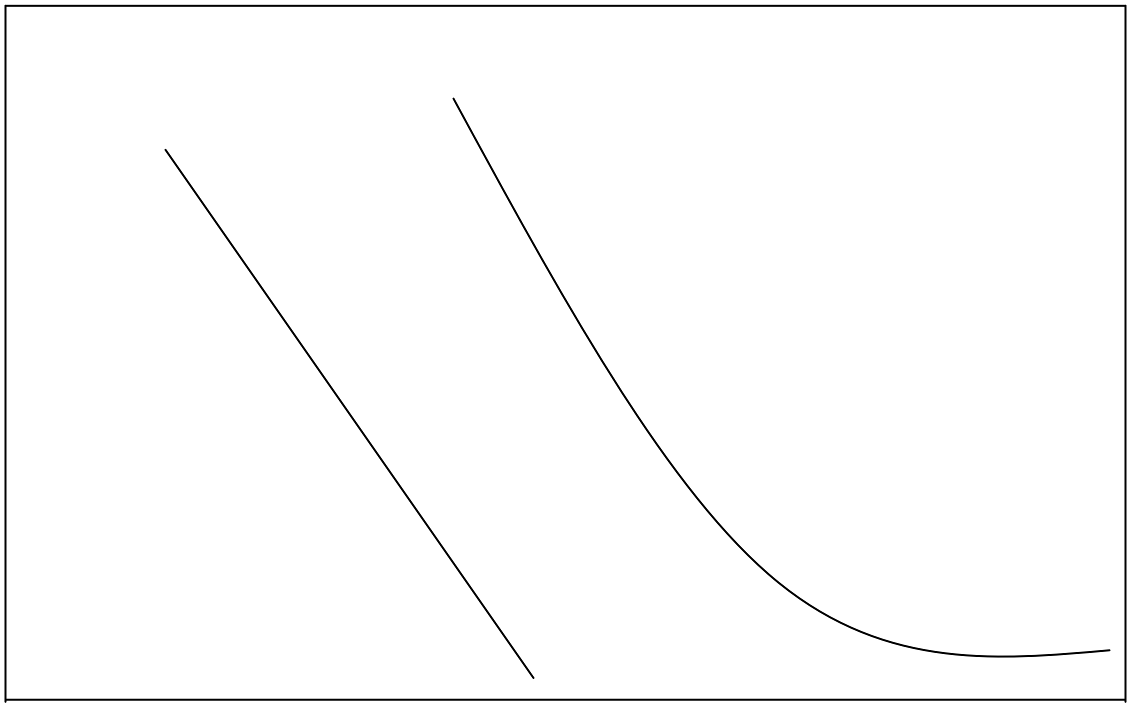

Fig. 2: Hypothetical Inverse Logistic or Probit Curve

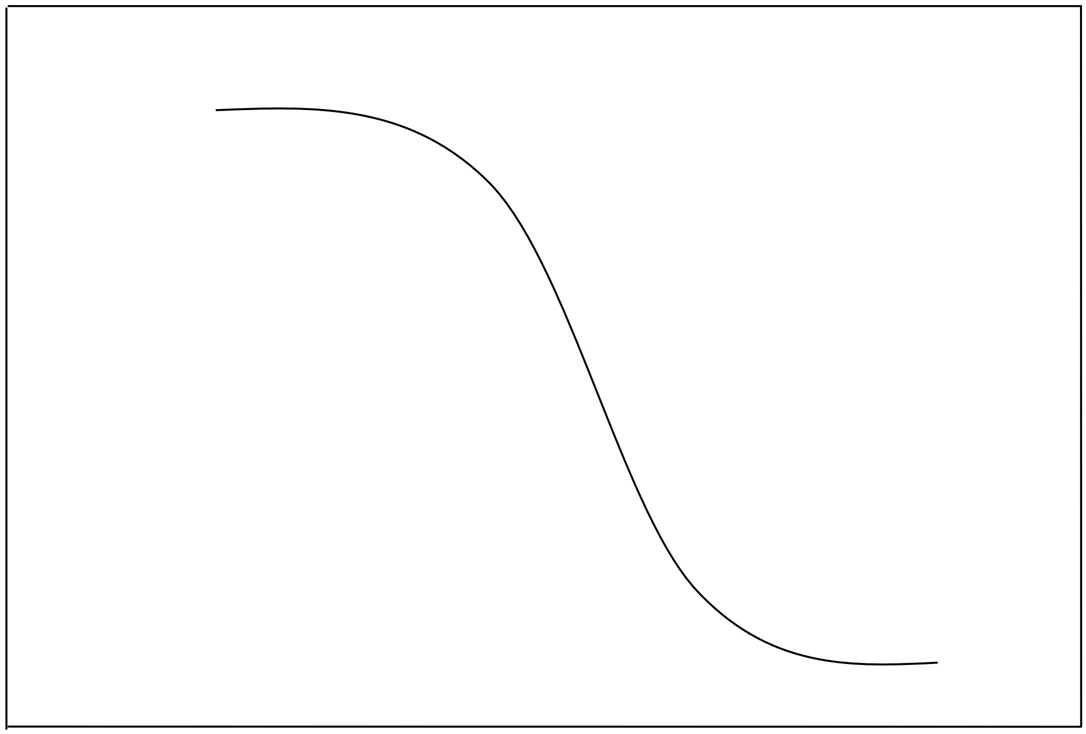

Fig. 3: Physical Activity and BMI