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RESEARCH ARTICLE

Physical Activity, Gender Difference, and Depressive Symptoms

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Objective. To investigate the roles of physical activity (exercise) and sociodemographic factors in depressive symptoms among men and women in the United States.
Data Source. 2011 U.S. Behavioral Risk Factor Surveillance System (BRFSS).
Study Design. Patient Health Questionnaire Depression Scale (PHQ-8) scores are aggregated and divided into five categories. An ordered switching probability model with binary endogenous physical activity is developed to accommodate ordinality of depression categories and ameliorate statistical biases due to endogeneity of physical activity.
Principal Findings. Average treatment effects suggest physical activity ameliorates depressive symptoms among mildly and moderately depressed individuals, most notably among mildly depressed women. Gender differences exist in the roles of sociodemographic factors, with age, income, race, education, employment status, and recent mental health condition playing differentiated roles in affecting depressive symptoms.
Conclusions. Regular physical activity reduces depressive symptoms among both men and women with mild to moderate depression, notably among women.
Key Words. Depressive symptoms, physical activity, gender difference, ordered probability model

Depression is a mental disorder involving the brain and is commonly characterized by sadness, loss of interest or pleasure, feelings of guilt or low self-esteem, disrupted sleep or appetite, feelings of tiredness, and poor concentration. Worldwide, it is estimated that 1 of 20 people reported having an episode of depression in the previous year (Kessler and Ustun 2008). Depression is expected to be the second leading cause of disability by 2020 (WHO 2001) and the largest contributor to disease burden by 2030 (WHO 2008).

Some researchers attribute depression primarily to biological factors (e.g., Ranga and Krishnan 2002; Riso, Miyatake, and Thase 2002), while others suggest that depression is mainly caused by social rather than biological factors (e.g., Jorm et al. 1997; Hansson, Chotai, and Bodlund 2009). The

literature has provided much evidence that physical activity (PA) is negatively related to the level of depressive symptoms (DS) (Salmon 2001; Miller 2008), and empirical analysts have employed a variety of methods and data from surveys or clinical samples. Farmer et al. (1988) find a negative association between PA and DS in white individuals using the National Health and Nutrition Examination Survey and logistic regressions. Camacho et al. (1991) apply a similar method to a different dataset and establish that high activity level can reduce the risk of depression in the long term. More recently, DeMoor et al. (2006) show that regular exercisers are on average less depressed than nonexercisers in the Netherlands. Focusing on leisure time PA, Sieverdes et al. (2012) find men in median and high PA categories are 51 percent less likely to have DS than men not participating in PA. In clinical research, PA is shown to be an effective treatment to alleviate mild and moderate DS. Babyak et al. (2000) show that, among individuals with a major depressive disorder, 60.4 percent of patients in the exercise group no longer meet the Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition (DSM-IV) criteria for the disorder after 4 months of physical treatment with exercise.[1] Mota-Pereira et al. (2011) suggest a 12-week exercise program of 30–45 minute walks five times a week results in improvement of all studied parameters of depression and that the improvement is not due to social interaction.

Sociodemographic factors are also found to play a role in depression. Using samples from the years of 1985 and 1990 in the United States, Mirowsky and Ross (1992) find a U-shape relation between age and depression, with depression reaching its lowest level around age 45, but Wade and Cairney (1997) find a steady decline across age groups after other sociodemographic factors are controlled for. Gender is another important factor, and most studies find women have higher risk than men of having depression. Kessler et al. (1993) find depressive disorders more common in women, who have a lifetime rate for major depressive episodes of 21.3 percent, compared with 12.7 percent in men. Van de Velde, Bracke, and Levecque (2010) estimate gender difference in depression with large datasets from 23 European countries, finding higher levels of depression in women than men in all countries. They also confirm a strong association between sociodemographic factors and depression in both men and women.

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Many previous studies suggest that income, race, education, marriage, and employment can affect depression. Zimmerman and Katon (2005) find a negative relation between income and DS with Kernel regression for both men and women. Somervell et al. (1989) use large samples from five communities in the United States to test the difference in major depression between white and black adults. Results show that in the 18–24 age group, white men have higher prevalence of major depression than black men, while white women have lower prevalence than black women. Craig and Van-Natta (1979) investigate the role of education and find less educated individuals more likely to exhibit DS. In Korea, Jang et al. (2009) find that men and women who are divorced, separated, or widowed have higher depression scores than their married counterparts. Using logistic regression with panel data from the U.S. Epidemiologic Catchment Area study, Dooley, Catalano, and Wilson (1994) find that unemployment increases the risk of DS. Using data from the National Health and Nutrition Examination Survey, Riolo et al. (2005) find prevalence of major depressive disorder significantly higher in white than African Americans.

Although accumulated findings have not been entirely consistent, many studies suggest that PA can reduce symptoms of mild to moderate depression (e.g., Babyak et al. 2000; Foley et al. 2008; Mota-Pereira et al. 2011). Most of these studies rely on small and targeted clinical samples not representative of the general population (e.g., Farmer et al. 1988; Camacho et al. 1991; Babyak et al. 2000; Foley et al. 2008). In addition, few have taken sociodemographic factors into account. Analysis not controlling for other factors can be misleading as both PA and sociodemographic factors can affect the level of DS. To our knowledge, no study has investigated the quantitative effects of PA and other sociodemographic factors simultaneously on categorical DS. This study fills this empirical gap.

METHOD

Empirical Model

Empirical approaches in previous studies of depression are primarily logistic and linear regressions. With a typically large proportion of nondepressed individuals in the sample, linear regression and a binary probability model cannot adequately accommodate depression levels. Endogeneity of PA, resulting from unobserved contributing factors of both PA and depression, can lead to biased estimates as well if not accommodated. For ordinal outcomes with an

endogenous covariate(s), recent studies in applied economics suggest more appropriate statistical procedures.

Following Li and Tobias (2008), Yen (2010), and Yen, Bruce, and Jahns (2012), we adopt the ordered probability model with binary endogenous switching for the analysis. For each individual, observation subscript suppressed for brevity, ordinal depression category is modeled with two separate processes, governed by a binary switching (selection) mechanism for PA (d):

$$\begin{aligned} d &= 0 \text{ if } z'\alpha + u \leq 0 \\ &= 1 \text{ if } z'\alpha + u > 0 \end{aligned} \tag{1}$$

and a set of ordered probability models of depression categories (y_h), for the seldom exerciser ($h = 0$) and regular exerciser ($h = 1$) regimes:

$$y_h = j \text{ if } \xi_{h,j-1} < x'\beta_h + v_h \leq \xi_{h,j}, j = 0, 1, \ldots J; h = 0, 1 \tag{2}$$

In contrast with conventional switching regression models with continuous outcomes (Amemiya 1985, pp. 399–400; Yen, Chen, and Eastwood 2009), the model above has an ordinal outcome variable. As in conventional switching regression models, only one outcome, denoted y, is observed for each individual and thus $y = y_0$ for seldom exercisers and $y = y_1$ for regular exercisers. In equations (1) and (2), z and x are vectors of explanatory variables with conformable parameter vectors α and β_h and, for $h = 0, 1$, the ξ's are threshold parameters such that $\xi_{h,-1} = -\infty$, $\xi_{h,0} = 0$, $\xi_{h,J} = \infty$, and $\xi_{h,1}, \ldots, \xi_{h,J-1}$ are estimable. Assume the error vector $[u, v_0, v_1]'$ is distributed as standard trivariate normal with correlations $\rho_{u0} = corr(u, v_0)$ and $\rho_{u1} = corr(u, v_1)$ such that $corr(v_0, v_1)$ is not estimated because the two sample regimes are mutually exclusive. Model parameters (α, β_0, β_1, $\xi_{0,1}, \ldots, \xi_{0,J-1}$, $\xi_{1,1}, \ldots, \xi_{1,J-1}$, ρ_{u0}, ρ_{u1}) are estimated by the maximum-likelihood procedure. Define dichotomous indicator $\kappa = 2d - 1$ such that $\kappa = -1$ if $d = 0$ and $\kappa = 1$ if $d = 1$. Then, the sample likelihood function is the product of joint probabilities (likelihood contributions) of outcomes for (d, y):

$$\begin{aligned} \Pr(y = j, d = h) = \Phi_2(\kappa z'\alpha, \xi_{h,j} - x'\beta_h, -\kappa\rho_{uh}) - \Phi_2(\kappa z'\alpha, \xi_{h,j-1} \\ - x'\beta_h, -\kappa\rho_{uh}),\ j = 0, 1, \ldots, J; h = 0, 1 \end{aligned} \tag{3}$$

where $\Phi_2(\cdot)$ is the cumulative distribution function of the standard bivariate normal distribution (Yen 2010; also see Online Appendix). A restricted form of the above model, when $\rho_{u1} = \rho_{u2}$ and all slope coefficients are equal between β_0 and β_1, corresponds to the ordered probability model

with binary treatment (Chib and Hamilton 2000; Yen 2010; Tan, Yen, and Feisul 2013).

An important methodological issue is identification of model parameters and endogenous treatment effects. For instrumental variable estimation, parameter identification requires presence in the switching equation of at least one variable which is correlated with the endogenous variable, uncorrelated with error terms of the outcome equations, and does not affect the outcome variable. For maximum-likelihood estimation of the current model, the nonlinear identification criteria are met without exclusion restrictions owing to distributional assumption of the error terms. Nonlinear functional form relying solely on distributional assumptions, however, often fails to generate sufficient variation to identify model parameters. We therefore impose an exclusion restriction, with recent physical health condition included solely in the PA equation.

To facilitate interpretation of the effects of explanatory variables, marginal effects of explanatory variables and treatment effects of PA, both on depression category probabilities, are calculated. For each individual, the marginal probabilities are $\Phi_1(-z'\alpha)$ for seldom exercise and $\Phi_1(z'\alpha)$ for regular exercise. It then follows from the joint probability (3) that the probabilities of depression category $j = 0, 1, \ldots J$ conditional on seldom ($h = 0$) and regular ($h = 1$) exercise are as follows:

$$\begin{aligned}\Pr(y = j, d = h|d = h) = [&\Phi_2(\kappa z'\alpha, \xi_{h,j} - x'\beta_h, -\kappa\rho_{uh}) \\ &- \Phi_2(\kappa z'\alpha, \xi_{h,j-1} - x'\beta_h, -\kappa\rho_{uh})]/\Phi_1(\kappa z'\alpha)\end{aligned} \tag{4}$$

Marginal effects of continuous (binary) explanatory variables are derived by differentiating (differencing) equation (4). Using equation (4), the treatment effects of PA on the depression category probabilities are as follows:

$$TE_j = \Pr(y = j|d = 1) - \Pr(y = j|d = 0), j = 0, 1..J \tag{5}$$

For statistical inference, standard errors of the marginal and treatment effects are derived by the delta method (Papke and Wooldridge 2005).

Data

Data come from the 2011 Behavioral Risk Factor Surveillance System (BRFSS) collected by state health departments in collaboration with the U.S. Centers for Disease Control (Centers for Disease Control and Prevention [CDC] 2014). The BRFSS is a state-based system of health surveys that

collects information on health risk behaviors, and the 2011 BRFSS is the most recent large national survey which provides adequate information for depression and sociodemographic factors. After removing observations with missing values for important variables, the final sample consists of 11,560 individuals (4,798 males, 6,762 females) age 18–99.

Dependent and Endogenous Variables

The outcome variable is current depression level, constructed from responses to the eight-item, self-reported Patient Health Questionnaire Depression Scale (PHQ-8). PHQ-8 covers eight of the nine criteria from the DSM-IV for diagnosis of major depressive disorders (CDC 2010). The ninth criterion in the DSM-IV is omitted because it reflects extreme DS, such as suicide, which is beyond the scope of this study. Compared with the Center for Epidemiologic Studies Depression Scale (CES-D) (Radloff 1977), the PHQ-9 (suicide item included) is reliable and advantageous because it is half the length of CES-D (Milette et al. 2010). PHQ-8 is one of the valid diagnostic and severity measures for depression in large clinical studies (e.g., Kroenke et al. 2009). Summing up component scores and following Dhingra et al. (2011), the resulting value is coded into one PHQ-8 score, from 0 (no DS) to 4 (severe DS). Further details on coding of PHQ-8 are presented in Online Tables A1–A2.

The endogenous variable is PA, coded as a binary indicator of regular exercisers versus seldom exercisers. The measurement for PA is drawn from BRFSS questionnaire item "How many times per week or per month did you take part in this activity during the past month?" A regular exerciser is defined as an individual who did PA at least 15 times, and seldom exerciser less than 15 times (none included), during the previous month.[2] About 39 percent of both male and female samples exercised regularly. Two-way frequency distributions of PA and depression level by gender are presented in Table A3 and Figure A1 online.

Explanatory Variables

Table 1 presents definitions and sample statistics of all variables. Demographic variables include age, income, race, education, number of children age <18, and dummy variables indicating home ownership, employment, and marital status. The measurement for recent physical health condition, our identification variable for the PA equation, is drawn from BRFSS's questionnaire item "For how many days during the past 30 days was your physical

Table 1: Definitions and Sample Statistics of Variables by Gender and Exercise Status

		Male		*Female*	
Variable	*Definition*	*Seldom Exercisers*	*Regular Exercisers*	*Seldom Exercisers*	*Regular Exercisers*
Endogenous variables					
DS: PHQ-8	DS categories: 0 = none, 1 = mild, 2 = moderate, 3 = moderately severe, 4 = severe	0.35 (0.78)	0.28 (0.74)	0.50 (0.91)	0.33 (0.76)
Physical activity (PA)	Did PA at least 15 times during past 30 days (yes = 1, no = 0)	0.00	1.00	0.00	1.00
Continuous explanatory variables					
Physical health	Days during past 30 days when physical health not good	4.51 (9.26)	3.53 (8.17)	5.13 (9.37)	3.31 (7.55)
Age	Age in years	53.52 (16.33)	55.54 (16.45)	54.41 (16.26)	54.52 (15.98)
Income	Annual household income level from 1 to 8	5.82 (2.08)	5.87 (2.12)	5.34 (2.19)	5.61 (2.16)
Children <18	Number of children in household age <18	0.56 (1.06)	0.47 (0.97)	0.59 (1.05)	0.55 (1.02)
Binary explanatory variables (yes = 1, no = 0)					
Fall	Data collected in the fall season (reference)	0.25	0.24	0.25	0.27
Winter	Data collected in the winter season	0.23	0.19	0.24	0.16
Spring	Data collected in the spring season	0.27	0.27	0.27	0.26
Summer	Data collected in the summer season	0.25	0.30	0.24	0.31
White	Race is white	0.70	0.72	0.70	0.75
Black	Race is black	0.01	0.01	0.01	0.01
Hispanic	Race is Hispanic	0.23	0.20	0.23	0.18
Other race	Other race (reference)	0.06	0.07	0.06	0.06
Base	Does not have a high school diploma	0.08	0.07	0.09	0.06
High school	Has a high school diploma or GED (reference)	0.30	0.26	0.29	0.22
Some college	Has some college but not a bachelor's degree	0.25	0.22	0.28	0.28
≥College	Has a bachelor's degree or above	0.37	0.46	0.35	0.43

Continued

Table 1: *Continued*

Variable	*Definition*	*Male*		*Female*	
		Seldom Exercisers	*Regular Exercisers*	*Seldom Exercisers*	*Regular Exercisers*
Employed	Employed	0.60	0.53	0.51	0.50
Unemployed	Unemployed	0.06	0.07	0.05	0.05
Retired	Retired	0.25	0.31	0.24	0.25
Student	Currently attending school	0.02	0.02	0.02	0.03
Unable	Unable to work	0.06	0.06	0.07	0.06
Homemaker	Homemaker (reference)	0.002	0.004	0.10	0.12
Homeowner	Homeowner	0.78	0.80	0.78	0.77
Married	Married	0.61	0.58	0.50	0.51
Divorced	Divorced	0.13	0.16	0.18	0.17
Widowed	Widowed	0.05	0.06	0.14	0.14
Separated	Separated	0.02	0.02	0.02	0.02
Single	Single (reference)	0.19	0.18	0.15	0.15
Sample size		2,951	1,847	4,151	2,611

Note. Standard deviations are in parentheses. Income is the annual household income reported as categories from 1 to 8: 1 = less than $10,000, 2 = $10,000 to $15,000, 3 = $15,000 to $20,000, 4 = $20,000 to $25,000, 5 = $25,000 to $35,000, 6 = $35,000 to $50,000, 7 = $50,000 to $75,000, and 8 = $75,000 or more.

health not good?" The variable has a sample mean of 4.5 days among seldom exercisers and 3.5 days among regular exercisers for men. Women on average have more (5.13) bad physical health days among seldom exercisers and fewer (3.31) days among regular exercisers compared to men. A total of 3,161 (65.9 percent) men and 4,162 (61.6 percent) women reported excellent recent physical health conditions (0 day with bad physical health).

Clinical research suggests that season can affect depression (Rosenthal et al. 1984; Harmatz et al. 2000) because mood is closely related to seasonal variation (Harmatz et al. 2000). Four dummy variables are used to indicate seasons in which the survey took place. Among men (women), average age is 53.52 (54.41) among seldom exercisers and 55.54 (54.52) among regular exercisers. On a scale from 1 to 8 (see Table 1), the means of annual household income level are about 5.8 for the male samples and 5.34 (5.61) among female seldom (regular) exercisers. About 70–72 percent of men are white, compared with 70–75 percent of women. Mean percentage of Hispanics ranges from 18 percent for female regular exercisers to 23 percent among seldom exercisers of both genders.

Results and Discussion

Gender Equality and Issue of Endogeneity

One important statistical test is for gender equality, that is that all parameters are equal between men and women. This is carried out with a likelihood-ratio (LR) test based on maximum log-likelihood values of the segmented and pooled samples. The hypothesis of equal slope coefficients between genders is rejected (LR = 126.33, df = 78, $p = .0004$), which suggests analysis by gender. Furthermore, as noted above, the model nests the ordered probit model for DS with binary endogenous PA treatment as a special case. This restricted specification is rejected for males (LR = 51.28, Wald = 46.93) and females (LR = 64.83, Wald = 56.64), both with df = 27 and $p < .01$, justifying use of the switching model in accommodating differences between regular and seldom exercisers.

A presumption of our switching probability model is endogeneity of PA and not depression, that is PA affects depression. To explore potential endogeneity of depression in the PA equation(s), we estimated several alternative models with such reverse causality, including the ordered probit model for PA with binary endogenous depression (switching and treatment), as well as a binary probit for PA with binary depression treatment (Online Tables A4–A6).

Endogeneity of depression is found with marginal significance in one case (Online Table A6). These results suggest PA affecting depression, as currently specified, is the more obvious causal relationship, and that specifications with alternative causality can produce very different results.

Maximum-Likelihood Estimates with Gender-Segmented Samples

Table 2 presents maximum-likelihood estimates. For both genders, all threshold parameter estimates are positive and significant at the 1 percent level of significance, suggesting both regime regressions are successful in delineating PHQ-8 categories. The error correlation estimates between the switching equation and both outcome equations are significant at the 1 percent level, suggesting endogeneity of switching (sample selection). These positive error correlations also suggest unobserved characteristics affect PA and PHQ-8 in the same direction.

Of the 24 variables in the switching equation, 13 are significant at the 10 percent level or lower for females. Statistical significance is scant for males—with only six variables significant. Recent physical health is significant in the PA equation at the 1 percent level of significance for both genders, rejecting the hypothesis of weak instrument in the PA equation. Qualifications for a good instrument include lack of correlation with the outcome variable, as discussed above. To check for such correlation, we recode the physical health variable by setting values of five and above to five, and calculate its polychoric correlation with PHQ-8 (Bonett and Price 2005). The correlation estimates are 0.51 for males and 0.49 for females, both with a standard error of 0.02, and are significantly different from zero with a p-value $<.0001$. Correlation of physical health with PHQ-8 weakens its strength as an instrument in the PA equation, but, despite the caveat, we continue to use physical health as an instrument to tighten parameter identification for lack of a better alternative.

Of the 23 variables in the outcome equations, about half (12 for seldom exerciser and 11 for regular exerciser) are significant at the 10 percent level for females. For males, seven variables are significant for seldom exercisers and five variables are significant for regular exercisers. The estimates also differ greatly in signs, magnitudes, and statistical are significance between male and female regular exercisers. These differences between genders would be masked in a pooled sample and highlight the importance of a segmented sample analysis.

To further explore effects of PA and explanatory variables on the level of DS, treatment effects and marginal effects of explanatory variables are presented below.

Table 2: Maximum-Likelihood Estimates of Ordinal DS Equation with Binary Endogenous PA Switching

	Males			*Females*		
Variable	*Switching: PA*	*DS Seldom Exercisers*	*DS Regular Exercisers*	*Switching: PA*	*DS Seldom Exercisers*	*DS Regular Exercisers*
Constant	0.298 (0.440)	0.876 (0.449)*	0.041 (0.489)	−0.272 (0.187)	0.163 (0.192)	−0.759 (0.277)***
Winter	−0.069 (0.055)	−0.049 (0.057)	−0.001 (0.091)	−0.240 (0.047)***	−0.156 (0.048)***	−0.236 (0.075)***
Spring	0.026 (0.051)	0.050 (0.054)	−0.023 (0.086)	−0.065 (0.043)	−0.053 (0.046)	−0.115 (0.066)*
Summer	0.149 (0.052)***	0.161 (0.054)***	0.179 (0.081)**	0.101 (0.043)**	0.056 (0.045)	0.009 (0.065)
Age/10	0.022 (0.073)	0.047 (0.077)	−0.232 (0.107)**	0.113 (0.066)*	0.249 (0.069)***	−0.058 (0.099)
Age^2/1,000	−0.001 (0.068)	−0.083 (0.073)	0.138 (0.105)	−0.114 (0.061)*	−0.309 (0.065)***	−0.072 (0.091)
Income	0.006 (0.012)	−0.024 (0.012)**	−0.073 (0.018)***	0.006 (0.010)	−0.040 (0.011)***	−0.052 (0.015)***
Children <18	−0.023 (0.021)	−0.008 (0.022)	0.011 (0.030)	−0.038 (0.018)**	−0.022 (0.019)	−0.009 (0.025)
White	−0.191 (0.078)**	−0.156 (0.078)**	−0.101 (0.105)	−0.030 (0.065)	−0.063 (0.066)	0.389 (0.115)***
Black	−0.023 (0.213)	−0.077 (0.224)	−0.152 (0.347)	−0.068 (0.164)	−0.227 (0.178)	−0.393 (0.333)
Hispanic	−0.178 (0.083)**	−0.199 (0.084)**	−0.164 (0.114)	−0.140 (0.071)**	−0.154 (0.071)**	0.371 (0.121)***
Base	−0.037 (0.078)	−0.125 (0.078)	0.145 (0.109)	0.047 (0.068)	0.033 (0.065)	0.162 (0.093)*
Some college	0.012 (0.052)	−0.043 (0.053)	0.152 (0.081)*	0.176 (0.043)***	0.137 (0.044)***	0.105 (0.067)
≥College	0.176 (0.049)***	0.016 (0.052)	0.106 (0.083)	0.270 (0.044)***	0.108 (0.046)**	0.035 (0.068)
Employed	−0.638 (0.392)	−0.624 (0.397)	−0.544 (0.415)	−0.215 (0.056)***	−0.179 (0.059)***	−0.149 (0.084)*
Unemployed	−0.386 (0.398)	−0.287 (0.402)	−0.166 (0.421)	−0.183 (0.086)**	0.085 (0.086)	0.266 (0.121)**
Retired	−0.386 (0.396)	−0.376 (0.401)	−0.335 (0.426)	−0.127 (0.064)**	−0.091 (0.069)	0.019 (0.100)
Student	−0.510 (0.415)	−0.486 (0.420)	−0.697 (0.450)	−0.050 (0.116)	0.058 (0.123)	−0.427 (0.177)**
Unable	−0.173 (0.400)	0.073 (0.404)	0.359 (0.428)	0.133 (0.085)	0.510 (0.088)***	0.608 (0.119)***
Homeowner	0.031 (0.053)	−0.047 (0.053)	−0.073 (0.081)	−0.133 (0.043)***	−0.181 (0.044)***	−0.151 (0.061)**
Married	−0.122 (0.060)**	−0.178 (0.060)***	0.060 (0.094)	0.008 (0.052)	0.026 (0.054)	−0.103 (0.082)
Divorced	0.062 (0.069)	0.117 (0.070)*	0.106 (0.104)	0.023 (0.059)	0.109 (0.060)*	0.059 (0.089)
Widowed	−0.116 (0.102)	0.000 (0.102)	0.148 (0.162)	0.071 (0.067)	0.124 (0.069)*	0.061 (0.102)
Separated	0.038 (0.149)	0.137 (0.151)	0.113 (0.214)	0.064 (0.106)	0.138 (0.104)	0.170 (0.143)

Continued

Table 2: *Continued*

	Males			*Females*		
Variable	*Switching: PA*	*DS Seldom Exercisers*	*DS Regular Exercisers*	*Switching: PA*	*DS Seldom Exercisers*	*DS Regular Exercisers*
Physical health	−0.024 (0.002)***	−0.024 (0.002)***	−0.024 (0.002)***	−0.028 (0.002)***	0.138 (0.104)	0.170 (0.143)
$\xi_{0,1}, \xi_{1,1}$		0.379 (0.027)***	0.539 (0.044)***		0.496 (0.026)***	0.622 (0.040)***
$\xi_{0,2}, \xi_{1,2}$		0.655 (0.046)***	0.872 (0.066)***		0.822 (0.042)***	0.992 (0.058)***
$\xi_{0,3}, \xi_{1,3}$		0.990 (0.077)***	1.181 (0.087)***		1.191 (0.065)***	1.408 (0.083)***
ρ_{u0}, ρ_{u1}		0.950 (0.013)***	0.895 (0.077)***		0.897 (0.020)***	0.818 (0.068)***
Log likelihood	−6,117.896			−9,510.936		

Notes. Asymptotic standard errors are in parentheses.
***$p < 1\%$, **$p < 5\%$, *$p < 10\%$.

Treatment Effects of PA on Depression

Average treatment effects (ATEs) are calculated to quantify the effect of PA on the probabilities of DS categories (see equation (5). Results in Table 3 suggest that regular exercise decreases the probabilities of some levels of DS among both men and women. For a randomly selected woman, regular exercise decreases the probabilities of mild (depressive) symptoms by 3.09 percentage points (henceforth, percent), moderate symptoms by 1.71 percent, and moderate severe symptoms by 0.74 percent. Regular exercise decreases the probability of moderate symptoms by 0.98 percent for men. Thus, in ameliorating depression, regular PA is most effective for women with mild DS. For severely depressed males, the treatment effect is positive (significant at the 10 percent level), suggesting regular exercise increases the probability of severe DS. The positive effect is likely due to the small sample size and abnormal sample distribution of this group.[3]

To check for robustness of ATEs with respect to PA cutoff, we estimate the model with alternative PA cutoff's of 5, 10, and 20 times per month. Using a 20 times cutoff produces fairly similar effects of PA on several probabilities of DS to those at the 15 times cutoff, while it tends to mask the benefits of PA among moderately depressed men and moderately severely depressed women. A 10 times cutoff produces very similar effects of PA for women on all DS categories. For men, it suggests significant and negative effects of PA on the probabilities of mild and moderately severe depression which are not found with the 15 times cutoff; further, the adverse effect of PA on severe depression is absent (insignificant). ATEs with alternative cutoff points are presented in Online Table A7.

Table 3: Average Treatment Effects of PA on Probabilities of DS Categories

	Average Treatment Effects (ATEs)	
Depressive Symptoms (DS) Category	*Males*	*Females*
No depressive symptoms (PHQ-8 = 0)	2.34 (1.12)**	5.77 (1.03)***
Mild depressive symptoms (PHQ-8 = 1)	−1.51 (0.99)	−3.09 (0.92)***
Moderate symptoms (PHQ-8 = 2)	−0.98 (0.59)*	−1.71 (0.55)***
Moderately severe symptoms (PHQ-8 = 3)	−0.46 (0.40)	−0.74 (0.40)*
Severe depressive symptoms (PHQ-8 = 4)	0.61 (0.34)*	−0.24 (0.29)

Notes. All effects on probability are multiplied by 100. Asymptotic standard errors are in parentheses.
***$p < 1\%$, **$p < 5\%$, *$p < 10\%$.

Marginal Effects of Explanatory Variables on Depression

Marginal effects of explanatory variables are calculated for all individuals and averaged over each sample. Conditional on exercise categories, these average marginal effects allow further exploration for the effects of explanatory variables on depression category probabilities. Results are presented in Table 4 for males and Table 5 for females.

Marginal Effects for Males. Age is a key determinant of depression, and it has a negative effect on all (positive) depression categories among men, exercise or not.[4] Conditional on seldom exercise, a 10-year increase in age is associated with a 1.32 (0.65, 0.35, 0.19) percent decrease in the probability of mild (moderate, moderately severe, severe) depression; conditional on regular exercise, the corresponding effects are 1.63, 0.65, 0.37, and 0.41 percent. Compared to men who seldom exercise, the effects of age on the probabilities of mild and severe depression are much larger among regular exercisers.

As expected, higher income ameliorates DS, in terms of probabilities for all depression categories. Thus, poor males are more easily depressed than rich ones. For a man who seldom exercises, a one-category increase in income level decreases the probabilities of mild, moderate, moderately severe, and severe depression by 0.65, 0.36, 0.20, and 0.10 percent; the corresponding decreases in probabilities are 1.26, 0.49, 0.28, and 0.30 percent among regular exercisers. In contrast with findings in clinical research (Rosenthal et al. 1984; Harmatz et al. 2000), we find no evidence of seasonal variations in DS among men.

Education has mixed affects among men. Most notable are effects of college education (or above) among men who seldom exercise, who have 2.35, 1.42, 0.78, and 0.38 percent lower probabilities of mild, moderate, moderately severe, and severe depression than their high school educated counterparts. These positive effects are likely due to easier access to health information and more efficient processing of such information among college educated men. These effects of regular PA are absent among college educated men who exercise regularly. Interestingly, sedentary men with less than high school education are also less likely to have DS compared to those with high school education, although the effects are small in magnitudes. For no obvious reason, men with some college who exercise regularly are more prone to depression than men with high school education, with percentage points from 0.56 percent (moderately severe symptoms) to 2.44 percent (mild symptoms).

Table 4: Average Marginal Effects of Explanatory Variables on Probabilities of DS Categories by PA Status: Male Sample

	DS Conditioned on Seldom PA					*DS Conditioned on Regular PA*				
Variable	*None*	*Mild*	*Moderate*	*Mod. Severe*	*Severe*	*None*	*Mild*	*Moderate*	*Mod. Severe*	*Severe*
Continuous explanatory variables										
Age/10	2.52 (0.63)***	−1.32 (0.34)***	−0.65 (0.18)***	−0.35 (0.10)***	−0.19 (0.06)***	3.06 (0.89)***	−1.63 (0.49)***	−0.65 (0.21)***	−0.37 (0.13)***	−0.41 (0.14)***
Income	1.32 (0.40)***	−0.65 (0.20)***	−0.36 (0.11)***	−0.20 (0.06)***	−0.10 (0.03)***	2.33 (0.50)***	−1.26 (0.28)***	−0.49 (0.12)***	−0.28 (0.08)***	−0.30 (0.08)***
Children <18	−0.37 (0.76)	0.16 (0.38)	0.11 (0.21)	0.06 (0.12)	0.03 (0.06)	−0.71 (0.85)	0.40 (0.46)	0.15 (0.18)	0.08 (0.11)	0.08 (0.11)
Physical health	−0.77 (0.06)***	0.36 (0.04)***	0.22 (0.02)***	0.13 (0.02)***	0.07 (0.01)***	−0.39 (0.05)***	0.23 (0.03)***	0.08 (0.02)***	0.04 (0.01)***	0.04 (0.01)***
Binary explanatory variables										
Winter	0.10 (1.90)	−0.12 (0.95)	0.01 (0.52)	0.01 (0.29)	0.01 (0.15)	−1.12 (2.70)	0.66 (1.45)	0.23 (0.57)	0.12 (0.33)	0.11 (0.35)
Spring	−1.48 (1.87)	0.76 (0.92)	0.39 (0.51)	0.22 (0.29)	0.11 (0.15)	1.11 (2.41)	−0.62 (1.31)	−0.23 (0.51)	−0.13 (0.29)	−0.13 (0.31)
Summer	−2.77 (1.91)	1.53 (0.94)	0.68 (0.53)	0.38 (0.30)	0.19 (0.15)	−3.11 (2.44)	1.53 (1.29)	0.68 (0.53)	0.41 (0.31)	0.49 (0.35)
White	1.12 (2.56)	−0.75 (1.30)	−0.22 (0.69)	−0.11 (0.38)	−0.05 (0.20)	0.01 (2.96)	0.15 (1.58)	−0.02 (0.63)	−0.04 (0.36)	−0.09 (0.39)
Black	2.69 (8.03)	−1.41 (4.28)	−0.70 (2.08)	−0.38 (1.12)	−0.19 (0.56)	3.91 (8.52)	−2.16 (4.88)	−0.82 (1.76)	−0.46 (0.95)	−0.48 (0.94)
Hispanic	3.49 (2.51)	−1.94 (1.29)	−0.85 (0.67)	−0.47 (0.38)	−0.23 (0.20)	2.01 (3.07)	−0.96 (1.69)	−0.44 (0.65)	−0.27 (0.37)	−0.34 (0.38)
Base	4.30 (2.32)*	−2.28 (1.26)*	−1.11 (0.60)*	−0.61 (0.32)*	−0.31 (0.17)*	−5.45 (3.50)	2.91 (1.81)	1.16 (0.78)	0.66 (0.46)	0.72 (0.51)
Some college	2.29 (1.68)	−1.15 (0.86)	−0.62 (0.45)	−0.35 (0.25)	−0.18 (0.13)	−4.60 (2.45)*	2.44 (1.29)*	0.98 (0.53)*	0.56 (0.33)*	0.62 (0.36)*
≥College	4.93 (1.66)***	−2.35 (0.88)***	−1.42 (0.46)***	−0.78 (0.26)***	−0.38 (0.12)***	−0.38 (2.37)	0.06 (1.27)	0.10 (0.50)	0.09 (0.28)	0.14 (0.32)
Employed	8.74 (12.46)	−5.04 (6.31)	−2.10 (3.57)	−1.11 (1.90)	−0.50 (0.73)	6.53 (12.70)	−2.95 (6.60)	−1.48 (2.77)	−0.95 (1.64)	−1.15 (1.76)
Unemployed	1.52 (10.91)	−1.20 (5.35)	−0.21 (3.00)	−0.08 (1.75)	−0.03 (0.87)	−1.70 (13.44)	1.25 (7.44)	0.31 (2.82)	0.12 (1.57)	0.03 (1.64)
Retired	5.10 (10.75)	−2.97 (5.68)	−1.19 (2.81)	−0.64 (1.54)	−0.30 (0.74)	3.73 (11.97)	−1.76 (6.72)	−0.83 (2.52)	−0.52 (1.39)	−0.62 (1.38)
Student	6.25 (9.67)	−3.71 (5.21)	−1.44 (2.50)	−0.75 (1.36)	−0.36 (0.64)	9.94 (7.98)	−5.55 (5.09)	−2.08 (1.54)	−1.14 (0.77)	−1.17 (0.67)*
Unable	−9.23 (13.78)	3.60 (5.18)	2.82 (4.24)	1.90 (3.13)	0.91 (1.46)	−18.09 (19.74)	9.42 (9.27)	4.01 (4.67)	2.29 (2.83)	2.37 (3.17)
Homeowner	3.23 (1.90)*	−1.55 (0.92)*	−0.91 (0.54)*	−0.51 (0.32)	−0.26 (0.15)*	2.79 (2.42)	−1.53 (1.31)	−0.59 (0.52)	−0.33 (0.30)	−0.34 (0.31)
Married	4.42 (2.03)**	−2.36 (1.04)**	−1.14 (0.56)**	−0.62 (0.30)**	−0.30 (0.15)**	−3.75 (2.59)	2.09 (1.37)	0.78 (0.55)	0.43 (0.33)	0.44 (0.37)
Divorced	−3.55 (2.47)	1.80 (1.18)	0.95 (0.69)	0.54 (0.42)	0.27 (0.21)	−2.27 (3.10)	1.16 (1.64)	0.49 (0.66)	0.29 (0.38)	0.33 (0.43)
Widowed	−3.65 (3.37)	1.57 (1.51)	1.08 (0.96)	0.66 (0.62)	0.35 (0.31)	−7.25 (5.79)	3.87 (2.89)	1.54 (1.28)	0.88 (0.77)	0.96 (0.91)
Separated	−5.47 (5.94)	2.59 (2.55)	1.52 (1.74)	0.90 (1.10)	0.47 (0.59)	−2.95 (6.54)	1.53 (3.38)	0.63 (1.41)	0.37 (0.82)	0.42 (0.95)

Notes. All effects on probabilities are multiplied by 100. Asymptotic standard errors are in parentheses.
***$p < 1\%$, **$p < 5\%$, *$p < 10\%$.

Table 5: Average Marginal Effects of Explanatory Variables on Probabilities of DS Categories by PA Status: Female Sample

	DS Conditioned on Seldom PA					*DS Conditioned on Regular PA*				
Variable	*None*	*Mild*	*Moderate*	*Mod. Severe*	*Severe*	*None*	*Mild*	*Moderate*	*Mod. Severe*	*Severe*
Continuous explanatory variables										
Age/10	3.43 (0.60)***	−1.81 (1.24)	−0.84 (1.22)	−0.48 (0.10)***	−0.31 (0.07)***	4.33 (0.74)***	−2.35 (0.42)***	−0.93 (0.18)***	−0.61 (0.13)***	−0.45 (0.11)***
Income	2.02 (0.38)***	−0.93 (0.18)***	−0.54 (0.11)***	−0.34 (0.07)***	−0.22 (0.05)***	1.80 (0.47)***	−0.98 (0.26)***	−0.39 (0.11)***	−0.25 (0.08)***	−0.19 (0.06)***
Children<18	−0.04 (0.66)	−0.03 (0.31)	0.03 (0.17)	0.02 (0.11)	0.02 (0.07)	−0.35 (0.80)	0.22 (0.43)	0.07 (0.17)	0.04 (0.12)	0.02 (0.08)
Physical health	−0.76 (0.05)***	0.32 (0.03)***	0.21 (0.02)***	0.14 (0.01)***	0.09 (0.01)***	−0.47 (0.05)***	0.27 (0.04)***	0.10 (0.02)***	0.06 (0.01)***	0.04 (0.01)***
Binary explanatory variables										
Winter	0.74 (1.71)	−0.64 (0.79)	−0.08 (0.45)	−0.01 (0.29)	0.00 (0.19)	3.56 (2.22)	−1.80 (1.26)	−0.79 (0.47)*	−0.54 (0.30)*	−0.43 (0.22)**
Spring	0.66 (1.68)	−0.38 (0.79)	−0.15 (0.44)	−0.08 (0.28)	−0.05 (0.18)	2.66 (2.01)	−1.41 (1.11)	−0.58 (0.43)	−0.38 (0.28)	−0.29 (0.21)
Summer	0.23 (1.68)	0.01 (0.79)	−0.11 (0.44)	−0.08 (0.27)	−0.05 (0.18)	1.39 (1.97)	−0.82 (1.07)	−0.29 (0.42)	−0.17 (0.28)	−0.11 (0.21)
White	2.11 (2.50)	−1.01 (1.15)	−0.55 (0.67)	−0.34 (0.43)	−0.22 (0.27)	−12.06 (2.88)***	6.37 (1.46)***	2.58 (0.66)***	1.73 (0.50)***	1.38 (0.43)***
Black	7.96 (5.74)	−4.11 (3.18)	−1.98 (1.37)	−1.16 (0.76)	−0.71 (0.44)	9.95 (7.27)	−5.76 (4.57)	−2.06 (1.44)	−1.26 (0.81)	−0.86 (0.50)*
Hispanic	3.22 (2.53)	−1.67 (1.20)	−0.78 (0.66)	−0.47 (0.41)	−0.30 (0.26)	−16.63 (4.63)***	8.52 (2.14)***	3.67 (1.13)***	2.48 (0.86)***	1.97 (0.72)***
Base	−0.22 (2.44)	0.16 (1.14)	0.04 (0.65)	0.02 (0.40)	0.01 (0.26)	−4.83 (3.14)	2.50 (1.60)	1.06 (0.71)	0.72 (0.48)	0.56 (0.38)
Some college	−1.43 (1.66)	0.87 (0.77)	0.30 (0.44)	0.16 (0.28)	0.10 (0.18)	−0.50 (2.09)	0.14 (1.12)	0.13 (0.45)	0.11 (0.30)	0.12 (0.23)
≥College	2.59 (1.65)	−0.90 (0.80)	−0.81 (0.44)*	−0.54 (0.27)**	−0.34 (0.16)**	3.32 (2.07)	−2.03 (1.16)*	−0.67 (0.44)	−0.39 (0.28)	−0.24 (0.21)
Employed	2.35 (2.21)	−1.34 (1.04)	−0.53 (0.59)	−0.30 (0.36)	−0.19 (0.22)	1.27 (2.66)	−0.54 (1.43)	−0.30 (0.58)	−0.23 (0.38)	−0.20 (0.28)
Unemployed	−9.09 (3.40)***	3.36 (1.21)***	2.62 (0.98)***	1.86 (0.75)**	1.25 (0.53)**	−14.09 (4.74)***	7.17 (2.17)***	3.13 (1.14)***	2.12 (0.83)***	1.68 (0.77)**
Retired	0.75 (2.47)	−0.50 (1.16)	−0.14 (0.65)	−0.07 (0.41)	−0.04 (0.26)	−2.87 (3.30)	1.61 (1.73)	0.61 (0.72)	0.38 (0.49)	0.27 (0.38)
Student	−4.14 (4.86)	1.74 (2.01)	1.15 (1.34)	0.76 (0.91)	0.50 (0.62)	10.97 (3.64)***	−6.37 (2.29)***	−2.27 (0.74)***	−1.39 (0.45)***	−0.94 (0.28)***
Unable	−22.46 (3.66)***	7.71 (0.88)***	6.51 (1.15)***	5.05 (1.13)***	3.20 (0.82)***	−22.04 (4.93)***	10.22 (2.00)***	5.16 (1.28)***	3.69 (1.07)***	2.96 (0.97)***
Homeowner	4.86 (1.74)***	−2.38 (0.78)***	−1.25 (0.48)***	−0.76 (0.31)**	−0.48 (0.19)**	2.82 (1.98)	−1.41 (1.06)	−0.63 (0.44)	−0.43 (0.29)	−0.34 (0.22)
Married	−1.00 (1.99)	0.47 (0.93)	0.26 (0.53)	0.16 (0.33)	0.10 (0.22)	3.58 (2.56)	−1.95 (1.40)	−0.77 (0.56)	−0.50 (0.36)	−0.36 (0.26)
Divorced	−4.50 (2.33)*	2.04 (1.01)**	1.20 (0.64)*	0.77 (0.43)*	0.49 (0.27)*	−1.59 (2.81)	0.83 (1.50)	0.35 (0.61)	0.23 (0.40)	0.18 (0.31)
Widowed	−3.87 (2.61)	1.82 (1.13)	1.01 (0.71)	0.63 (0.47)	0.41 (0.31)	−0.82 (3.20)	0.39 (1.70)	0.19 (0.69)	0.13 (0.46)	0.11 (0.35)
Separated	−4.78 (3.91)	2.18 (1.63)	1.26 (1.09)	0.81 (0.73)	0.53 (0.49)	−4.80 (4.84)	2.45 (2.44)	1.06 (1.07)	0.72 (0.75)	0.58 (0.61)

Notes. All effects on probabilities are multiplied by 100. Asymptotic standard errors are in parentheses.
***$p < 1\%$, **$p < 5\%$, *$p < 10\%$.

Marital status and home ownership play a role but only among men who seldom exercise. Among these sedentary men, marriage (home ownership) causes 2.36, 1.14, 0.62, and 0.30 percent (1.55, 0.91, 0.51, and 0.26 percent) lower probabilities of mild, moderate, moderately severe, and severe depression.

Marginal Effects for Females. As in men, age affects depression in women but in a slightly different pattern. Aging decreases only the probabilities of moderately severe and severe depression among sedentary women. Among women who exercise regularly, age decreases the probabilities of all categories of DS but in smaller magnitudes than men. Conditional on regular exercise, a 10-year increase in age is associated with 2.35, 0.93, 0.61, and 0.45 percent lower probabilities of mild, moderate, moderately severe, and severe depression. Wade and Cairney (1997), Schieman, Gundy, and Taylor (2002), and Streiner, Cairney, and Veldhuizen (2006) also find DS taper off as men and women get older.

Higher income decreases probabilities of DS, in greater magnitudes among sedentary women and in smaller magnitudes among regular exercisers, compared to their male counterparts. A one-category increase in income decreases the probabilities of mild, moderate, moderately severe, and severe depression by 0.98, 0.39, 0.25, and 0.19 percent among women who exercise regularly. The effects are smaller among the sedentary, by 0.93, 0.54, 0.34, and 0.22 percent. These ameliorating effects of income, also reported by Zimmerman and Katon (2005), are likely associated with better economic ways and means which come with higher income.

Unlike men, race plays a role among women. Most notable are the greater probabilities among white (Hispanic) women who exercise regularly, by 6.37, 2.58, 1.73, and 1.38 percent (8.52, 3.67, 2.48 and 1.97 percent), than physically active women of other races. Our finding that Hispanic women are more prone to depression is similar to that reported by Bromberger et al. (2004), while the higher probabilities of DS among white women stand in sharp contrast with opposite finding by Riolo et al. (2005) for the general U.S. population.

Effects of education are seen only among women with college education or beyond. Compared with those with only high school diplomas, women who have a bachelor's degree or above are less prone to depression. Seldom exercisers with a bachelor's degree or above are 0.81, 0.54, and 0.34 percent less likely to have moderate, moderately severe, and severe depression.

Among regular exercisers, effect of college education is found only in mild depression, at 2.03 percent lower. Our results for men and women echo findings by Craig and Van-Natta (1979) and Costa-i-Font and Gil (2008), who report lower risks of depression among the educated.

While employment status does not affect men, it plays important roles among women, exercise or not. Conditional on regular exercise, unemployed women have 7.17, 3.13, 2.12, and 1.68 percent higher probabilities of mild, moderate, moderately severe, and severe depression than homemakers. The effects among sedentary and unemployed women are slightly lower, by 6.37, 2.27, 1.39, and 0.94 percent. While being unemployed or unable to work does not affect men, women who are unemployed or unable to work are more likely to be depressed than homemakers. The effects on mild depression among women with regular exercise are particularly notable, at 10.22 percent higher among those unable to work and 7.17 percent higher among the unemployed, compared their homemaking counterparts.

While divorce does not affect men, it takes a toll on sedentary women. Divorced women who seldom exercise have 2.04, 1.20, 0.77, and 0.49 percent higher probabilities of mild, moderate, moderately severe, and severe depression than their single counterparts. Interestingly, divorce does not affect women who exercise regularly, corroborating our ATEs above that PA alleviates depression symptoms among women. As in men, home ownership decreases probabilities of depression among women who seldom exercise, likely due to the financial stability derived from home ownership.

Concluding Remarks

The relationship between PA and DS is a complicated one. We focus on a probability model of depression with endogenous PA, the presumption being that there is a causal effect of PA on depression, which is the more obvious causal structure following Miller (2008) and Salmon (2001) in the medical and clinical psychology literature. We investigate potential endogeneity of depression in the PA equation(s) as well, but we find little evidence of such endogeneity.

Our primary finding is that regular PA ameliorates DS, decreasing the probability of moderate DS among men, and the probabilities of mild, moderate, and moderately severe DS among women. Mildly and moderately depressed women will benefit the most from regular PA. Our results echo findings in previous studies, mostly with small and sectorial

samples, that PA can reduce symptoms of mild to moderate depression (Farmer et al. 1988; Camacho et al. 1991; Babyak et al. 2000; Foley et al. 2008). The use of a switching probability model allows quantification of these effects of PA and, more important, the segmented sample analysis uncovers important differences between men and women in the effects of PA on the probabilities of DS.

By comparing marginal effects of sociodemographic variables, we find some differences in other mechanisms of depression between men and women and by PA status. For instance, whereas education plays a notable role in depression among men, the effects of education are seen only among women with college education or beyond. The effects of race, divorce, and employment status, on the other hand, are found in women only, with white, Hispanic, divorced, and unemployed women having higher probabilities of depression. These important findings can inform policy deliberation by policy makers and doctors concerned about public health issues related to depression. For instance, as the low income, less educated, unemployed, and individuals who are unable to work are more susceptible to depression, policy makers should address the needs of these less privileged individuals in an effort to improve living standards and social statuses of these individuals. Furthermore, as divorce take its toll primarily on sedentary women, and that being unemployed and unable to work poses higher risks of depression for women than for men, it is worth promoting PA, job training, and employment opportunities for these underprivileged women. Finally, as we find solid evidence that PA ameliorates depression among women as well as men, PA could be an effective clinical tool to combat depression, and doctors can recommend regular PA for mildly or moderately depressed individuals. But for individuals with a record of bad physical health, PA or exercise is no longer an effective way to reduce DS, so amelioration of depression would have to be accomplished by (along with) other means.

While this article represents one of the first attempts to investigate the role of endogenous PA in categorical depression, further studies might consider the use of panel data and investigation of depression issues among various subpopulations, such as teenagers, minorities, and the disabled. Our investigation of the effect of depression on PA is also perfunctory, and this reverse causality is worth further investigation with other samples. Further, PA and other sociodemographic factors are likely to be important for general health besides depression, and interesting insights may emerge from a similar study for general health.

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NOTES

1. DSM-IV is short for the *Diagnostic and Statistical Manual of Mental Disorders*, 4th edition (American Psychiatric Association 1994).
2. This 15 times per month cutoff corresponds to exercise frequency for approximately the top 40 percent of both male and female samples. Use of alternative cutoff points is discussed below.
3. Among severely depressed males, the number of seldom and regular exercisers are very close (27 and 28). Since more male regular exercisers are severely depressed than seldom exercisers in our dataset, such positive treatment effect is reasonable. This ambiguous result may be caused by the small sample of this category (PHQ-8 = 4) and the nearly equal number of regular and seldom exercisers in this category.
4. For remainder of the analysis, depression categories relate to presence of depression, with PHQ-8 ≥1.

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SUPPORTING INFORMATION

Additional supporting information may be found in the online version of this article:

Appendix SA1: Author Matrix.

Data S1: Sample Likelihood Function.

Figure A1: Frequency Histograms of PA and DS Categories by Gender.

Table A1: Patient Health Questionnaire Eight-Item Depression Measures (PHQ-8).

Table A2: Coding of PHQ-8 Scores and DS Categories.

Table A3: Two-way Frequency Distribution of PA and DS Categories.

Table A4: ML Estimation of Ordinal PA with Binary DS Switching.

Table A5: ML Estimation of Ordinal PA with Binary DS Treatment.

Table A6: ML Estimation of Binary PA with Binary DS Treatment.

Table A7: Average Treatment Effects of PA on DS Category Probabilities with Alternative PA Cutoff Points.