THE INFLUENCE OF PHYSICAL ACTIVITY ON HEALTH

Master Thesis

Erasmus School of Economics

Economics & Business

MSc Health Economics

Author:	Tufan Kiziltekin
Student number:	483576
Year:	2017-2018
Supervisor:	prof. dr. ir. J.C. van Ours

ERASMUS UNIVERSITEIT ROTTERDAM

THE INFLUENCE OF PHYSICAL ACTIVITY ON HEALTH

ABSTRACT:

The primary goal of this study is to enhance the knowledge about the causal impact of physical activity on health. In fact, health can be quantified by numerous variables. Our specification for being healthy is having a healthy Body Mass Index (BMI). Although the positive association between physical activity and health outcomes is well acknowledged, the causality between them is quite doubtful. Namely, it is plausible that an extreme BMI value, i.e. obesity, harms the intensity or/and frequency of exercising. Further, it is likely that unobserved genetic factors, family background and risk aversion correlate with both BMI and physical activity. These elements illustrate the potential endogeneity of physical activity. In particular, we distinguish three physical activity categories: strenuous, moderate - and low intensity. Then, for our empirical analysis, we utilize the Longitudinal Internet Studies for the Social Sciences (LISS) panel, which consists of 4500 Dutch households. Further, we exploit both Ordinary Least Squares (OLS) – and fixed effect (FE) estimations to examine whether time-invariant unobservables lead to biased estimations. Also, we add lagged physical activities to control for the reverse impact from BMI on physical activity. Our results show that an OLS approach overestimates the beneficial impact of physical activity on BMI. Moreover, the overall FE estimation indicates that an additional day of strenuous physical activity throughout the week significantly lowers BMI with 0.029. In addition, it is surprising that the significant impact from low intensity physical activities on BMI disappears when we separate the regressions by gender. The causality of our findings is however debatable.

Table of contents

1. Introduction

Physical inactivity is a global health problem in the 21st century (Brechot et al., 2017). The government of the UK recognizes an alarming trend in which the population of the UK is 20% less active now compared to the 1960s, while this value is expected to rise further to 35% by 2030. Nowadays, according to the World Health Organization (WHO), 3.2 million deaths per year are attributable to insufficient physical activity, while in 2009, 17% of the world population suffered from the global prevalence of inactivity (Kohl et al., 2012). Physical inactivity does not only concern population health but has economic consequences as well. In 142 countries, representing 93.2% of the world population, the economic burden imposed by physical inactivity is quantified as $67.5 billion, which reflects the aggregation of direct – and indirect health care costs and productivity losses (Ding et al., 2016).

Past studies from the 1980s already acknowledged the importance of physical activity on public health. The WHO (2003), Physical Activity Guidelines Committee (2008) and numerous other official reports confirm that physical activity is an essential determinant of health, which is defined as a state of complete physical -, mental – and social wellbeing (World Health Organization, 2003). Downward et al. (2015) even suggest a positive causality rather than an association by controlling for lagged sport activities in a time series framework. Overall, physical activity reduces all-cause mortality, makes people fitter and prevents several diseases such as cardiovascular diseases, diabetes, high blood pressure, obesity and mental health problems, which all contribute to a higher (healthy) life expectancy (Colman & Dave, 2013). Lechner (2009) takes a different perspective and examines the link between sport activities and long-term labor market behavior. He establishes the 'health is wealth' principle: on average, at least monthly engagement in sport activities over 16 years, compared to less than monthly participation, significantly increases the gross monthly income of individuals with approximately 122$.

Hence, it is not a surprise that there is growing international attentiveness on public interventions to raise awareness of the importance of physical activity. There is a global shift from curing diseases to health promotion with an emphasis on lifestyle choices. In the last three decades, community-based informational interventions focused on educating people with respect to the benefits of sports, while nowadays behavioral -, social -, environmental – and policy approaches to enhance physical activity have become essential tools to promote physical activity (Heath et al., 2012). The main goal is to encourage physical activity, consider healthier lifestyle behaviors, restrict motor vehicle usage and stimulate physical activity in the workplace.

Although there is overwhelming evidence that physical activity and health are positively correlated, a major part of the research fails to recognize the potential endogeneity of physical activity. First, the association between physical activities and health could be due to reverse causality. Health status can either be a barrier – or a stimulus for physical activity. Namely, individuals without any health problems may participate in physical activities with a higher frequency or/and greater intensity compared to individuals with poor health. Second, physical activities are prone to confounding. Individuals who are forward looking or risk averse may concern more about their (future) health status compared to myopic individuals, which motivates them to get physically active (Colman & Dave, 2013). Moreover, psychological factors such as a lack of self-confidence or a poor body image due to a poor health status can either stimulate – or limit the engagement in sport activities, depending on how an individual deals with those factors. Another limitation of existing research is that there is no clear evidence-based threshold for the intensity -, duration – or frequency of physical activities to secure good health. The aim of this paper is to point out these gaps and shed light on the causality of physical activity on health by taking advantage of the Longitudinal Internet Studies for the Social Sciences (LISS) dataset.

This paper is organized as follows. Section 2 builds the conceptual framework and describes the key factors to clarify the relationship between physical activity and health. Based on this conceptual framework, section 3 delineates the LISS panel dataset and elaborates the empirical strategies to approximate the causality between physical activity and health. Then, section 4 reveals the main findings of the empirical analysis. Finally, section 5 concludes this paper, discusses the limitations - and validity of the results and provides recommendations for further research.

2. Literature framework

I. Terminology

The terms 'physical activity' and 'exercise/sports' are often confused with one another (Caspersen et al., 1985). Nowadays, scientific papers identify plentiful terminologies such as fitness, sports, leisure time sport activities, exercising, jogging, walking etc. to categorize physical activity. These categories can be summarized as follows.

To begin with, physical activity is a broad term and can be any daily life activity in which there is bodily movement produced by the skeletal movement resulting in caloric (energy) expenditure, e.g. sports, occupational - or household activities (WHO, 2018). So, physical activity is an umbrella name for the combination of both planned – and unplanned physical movement. On the other hand, physical inactivity reflects a state in which bodily movement is minimal. So then, the total calorie expenditure is nearly equal to the basal metabolic rate (BMR), which represents the amount of energy expenditure at rest (Dietz, 1996). The last category of physical activity is leisure time sport activity (exercising), which only captures planned **-**, consistent **-** and structured physical activity with the main objective to improve physical fitness, the ability to perform physical activity. The focus of this paper is on any physical activity rather than only concerning exercising.

II. Health benefits

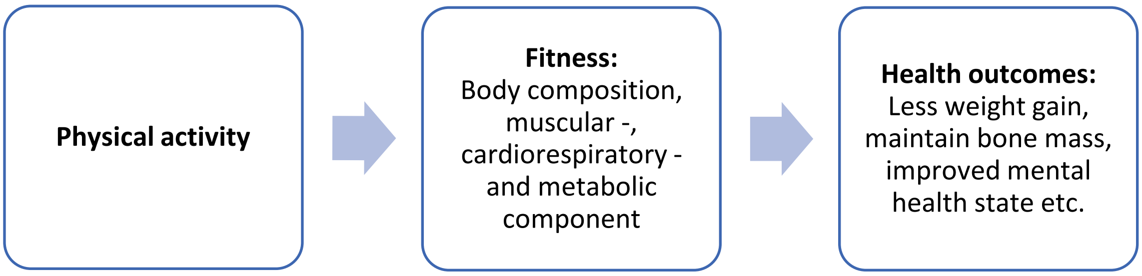
Physical activity is associated with a variety of health benefits (Miles, 2007). First, related to the previous paragraph, physical activity increases the total daily energy expenditure (TDEE), which is an accumulation of the BMR, physical activity and thermic effect of food (the energy required to digest – and process food), see equation (**1**). The key rule regarding TDEE is as follows. When the caloric consumption exceeds the TDEE, it leads to weight gain and vice versa (Müller et al., 2016). With this in mind, physical activity reduces the probability of gaining weight since it boosts the TDEE and therefore permits a higher caloric consumption to compensate for the expenditure. Colles et al. (2008) agree with the idea that physical activity plays a major role in weight loss and ask 129 bariatric surgery patients to fill in questionnaires related to their overall health, diet and physical activity with a follow-up data of 4 and 12 post-surgical months. This method allows them to compare the lifestyle changes and associated changes in weight over time. It appears that incorporating consistent physical activities in daily life, which mainly exists of regular walking, positively contributes to the caloric balance by increasing the caloric expenditure.

Second, physical activity encourages better eating behavior by reducing 'emotion eating', a phenomenon in which people try to shelter their stressful – and negative feelings by turning to food and consequently tend to indulge in overeating. Wing et al. (2001) add a new perspective in this discussion and report that the combination of healthier eating behavior, proper nutrition and physical activity is more effective for permanent weight loss maintenance than just physical activity alone. Combining this statement with the paper of Colles et al. (2008), physical activity encourages healthier eating behavior, which in the end leads to more persistent weight loss and weight maintenance than just physical activity alone.

$$TDEE = \ Basal\ Metabolic\ Rate\ (BMR) + Physical\ Activity + Thermic\ effect\ of\ Food \qquad \textbf{(1)}$$

Then, Warburton et al. (2016) stress that physical fitness has more prognostic value for health outcomes compared to physical activity. Figure 1 illustrates the mechanism for how physical activity can contribute to physical fitness and consequently influence health outcomes. It shows that physical activity stimulates the musculoskeletal -, cardiorespiratory and metabolic systems. Moreover, when an individual is persistent in physical activities, the human body will adapt to these activities resulting in a reshaped – , more efficient -, stronger – and fitter body, which usually characterizes itself with a changed body composition: lower fat mass & higher lean body mass (Miles, 2007). The amount of lean body mass is positively associated with the BMR (Stiegler & Cunliffe, 2006) and from equation (**1**), it follows that a higher BMR correspondents with a higher TDEE. Thus, physical activity does not only directly boost TDEE by the activity alone but has the potential additional benefit of sculpting a fit body, which pushes the TDEE to an even higher level via the channel of BMR.

Figure 1: health contribution of exercising, derived from Miles (2007)



The health benefits of physical activity go beyond the impact on weight maintenance and weight loss. Namely, there is overwhelming evidence that physical activity is associated with a decreased risk of diabetes, cardiovascular diseases, anxiety, depression and a number of cancers such as colon -, lung – and breast cancer (Miles, 2007). All in all, physical activity is associated with a plethora of health benefits. It contributes to a complete physical -, social – and mental wellbeing, which is the definition of being healthy according to the WHO (2018). Hence, it is obvious that physical activity is a powerful medicine for various health issues but the fact is that it is still an underappreciated tool to improve the quality of life (Bailey et al., 2013).

III. Health production

a. Economic fundamentals

One of the main contributions for an economic analyses regarding health production is the framework of Grossman (1972). In this model, health is a consumption - but also an investment good. Economic agents are willing to pay for health, because they directly derive utility from the consumption of health, while an investment in the health stock is expected to yield a flow of healthy time on the long run. In the end, the accumulation of the stock of health leads to a higher healthy life expectancy. It is not possible to directly boost the health stock, economic agents can only augment their stock by investing in its input factors. Then, Grossman identifies the following significant input factors for the production of health: a vector of lifestyle choices (L), non-medical care consumption (X), medical care consumption (M), environmental inputs (N), initial endowment of health (H[t-1]) and education (E), see equation (**2**). On the contrary, the stock of health tends to decline over time due to ageing, which harms the healthy life expectancy. In the end, the direction of the change in the stock of health depends on whether its accumulation dictates its depreciation or vice versa.

$$H = h\ (L, X, M, N, H[t-1], E) \qquad (\mathbf{2})$$

b. Lifestyle choices: physical activity & smoking

Related to the equation (**2**), numerous studies explored the link between lifestyle choices and health. As an illustration, Contoyannis & Jones (2004) define lifestyle choices as a set of behaviors which are considered to affect health a priori and exploit their link with subjective health and socioeconomic status by taking advantage of the panel nature of the British dataset from 1984 and 1991. As a proxy for lifestyle choices, they incorporate a binary variable for exercising (1 if individual participates in in exercise, 0 otherwise).

To begin with, when they do not control for unobserved individual heterogeneity, it seems that exercising, compared to not exercising, significantly increases the probability of better subjective health outcomes. However, when they do account for unobserved individual heterogeneity, this impact becomes insignificant. Even though Contoyannis & Jones (2004) discover the importance of unobserved individual heterogeneity with their finding, the robustness of their results is doubtful. Namely, there is no separation in the intensity, duration or frequency of the sport activities, individuals either exercise or they do not. Moreover, it is likely that the health benefits of exercising need time to accumulate and show up, whereas this approach does not control for past sport activities.

Colman & Dave (2013) recognize – and help to fill these gaps and elaborate the discussion about the causality between sport activities on health. As stressed out by Contoyannis & Jones (2004), Colman & Dave note the importance of unobserved individual heterogeneity and eliminate the confounding problem for time consistent unobservables by applying a fixed effect approach. Then, instead of using one binary variable for exercising, they split up physical activity in recreational exercise and other types of physical activity and put them into different intensity categories (high level exercise, moderate level exercise; very active exercise, moderately active exercise). Their empirical analysis reveals that individuals who perform higher levels of exercising or other forms of physical activity always enjoy more health benefits compared to lower levels of physical activity, which indicates a 'dose-response relationship': the higher the dosage of physical activity, the bigger its reward in terms of health outcomes. Besides, by accounting for lagged physical activity, it appears that lagged physical activities have a greater impact than current physical activities. So then, to relate to Grossman (1972), physical activity tends to show more characteristics of an investment good instead of a consumption good.

These findings are our main motivation to observe physical activity as a lifestyle choice. We are a huge proponent of long-term thinking and believe that physical activity would be a more effective tool to enhance health when it is performed on a regular bases rather than a one-time hit. Namely, when physical activity becomes a lifestyle habit, its dosage accumulates over the years and allows time for the related health advantages to show up. This may translate itself into better health outcomes and consequently result in a higher quality of life compared to inconsistent events of physical activity. With this in mind, the statement of Bailey et al. (2013) that physical activity is an underappreciated tool to boost quality of life becomes more interpretable. If individuals are inconsistent with physical activity, they might not experience its optimal health advantages. Generally speaking, the major part of society is myopic and would like to derive fast results from physical activity. The lack of immediate results would harm the consistency of physical activities since people may feel demotivated to involve in such activities. A final point of emphasis is that even existing research wonders whether low intensity physical activities are sufficient to secure good health (Haskell et al., 2007).

Another lifestyle choice is cigarette smoking, for which its relationship with health is well-established. In particular, the Centers for Disease Control and Prevention (CDC) reports that in the United States, 480.000 deaths a year are attributable to cigarette smoking, while Edwards (2004) approximates that smoking will be the primary cause of 450 million deaths worldwide in the following 50 years. Then, compared to non-smoking, cigarette smoking contributes to a higher risk of cardiovascular heart diseases, stroke and different types of cancer such as lung cancer. In sum, cigarette smoking is associated with a plethora of adverse health consequences. Contoyannis & Jones (2004) confirm the negative association between smoking and health by discovering that smoking significantly reduces the likelihood of reporting an excellent – or good self-assessed health status by 64%.

On the other hand, we would expect that smoking is negatively associated with physical activity as well. It is plausible that the participation in physical activity, especially in activities which require a stable physical condition such as athletes, decreases the probability of smoking simply because it may harm sport performance. A different perspective to back up our statement is that people who choose to get physically active are usually characterized by a low marginal rate of time preference (Rosin, 2008). Someone with a low marginal rate of time preference attaches more value to the future compared to the present and therefore are more 'future conscious'. Then, we may argue that the more serious the engagement of an individual is in physical activity in the sense that he - or she exercises at a high frequency or/and high intensity for example, the lower the marginal rate of time preference and thus the higher the value of future health. With this in mind, a low marginal rate of time preference may be the primary reason which forces a person to not be a smoker or at least reduce – or quit cigarette smoking.

c. Ageing

Grossman (1972) identifies ageing as the key factor responsible for the depreciation of the stock of health, while health economists and decision makers concern about the health and upward trend of medical care expenditures of the elderly. Generally speaking, age is negatively correlated with health: as individuals get older, they become more likely to struggle with poor health (Philip, 2005). However, the WHO (2015) reports that poor health during the later stages in life may not be the direct (causal) impact of ageing but rather is due to the accumulation of chronic disease conditions during the early stages of life. Coupled with this finding, Jamison et al. (2006) recommend to incorporate 'healthier' lifestyle habits to prevent such conditions. In particular, they advise to avoid tobacco use, maintain a healthy Body Mass Index (BMI), limit sugar consumption and increase physical activity. So, although there is consensus about the negative impact of ageing on health, healthier lifestyle habits can minimize this influence.

On the other hand, many papers underline how ageing can indirectly affect the health of an individual. As an illustration, Schutzer & Graves (2004) argue that age forms a barrier to physical activity. As individuals get older, the physical activity levels tend to drop. In fact, the highest prevalence of physical inactivity is among individuals aged 65 or older. Following the intuition of Philip (2005), an explanation for this observation can be that older people suffer from poor health, which limits their capability to actually perform physical activities and therefore stay sedentary. Moreover, by utilizing cross-sectional - and longitudinal data for 24 OECD countries during the period 1960-1988, Getzen (1992) reports that population ageing leads to a higher demand for health care. Without government budget constraints, this would cause a significant rise in medical care expenditures. Consequently, under the general assumption within (health) economics that individual economic agents deal with budget constraints as well, ageing would restrict the resources available for the consumption of non-medical care, which is the other type of consumption good within the model of Grossman (1972). For now, it is unclear which factor will dominate the other. The number of units forgone or gained and the marginal utility of both consumption types with regards to health production should be identified first to determine the aggregated impact of ageing on the stock of health.

In follow up studies, Gregersen & Godager (2013) confirm that age is a key indicator of medical care expenditures, while Schutzer & Graves (2004) indicate that ageing is indeed associated with a higher frequency of physician visits. So, both papers support the earlier study of Getzen. But then, Zweifel et al. (1999) criticize Getzen's findings. In their view, it is true that the elderly need more health care than younger people but rather than ageing, the remaining life expectancy (time to death) determines the magnitude of health care expenditures. Namely, the closer someone gets to the time of death, the higher the health care expenditures will be.

In sum, the overall relationship between ageing and population health is quite ambiguous. Ageing may lead to higher medical care expenditures, which consequently reduce non-medical care consumption due to budget constraints, while lifestyle habits tend to limit the negative impact of ageing on health. Grossman (1972) observes ageing as the key determinant for the depreciation of the stock of health but it may be an innovative idea to replace ageing with the number of chronic diseases, which is introduced in the first paragraph, or/and remaining life expectancy to increase the predictability of health production.

d. Education & gender

Contoyannis & Jones (2004) reveal that more educated people and higher social classes are more likely to exercise, which is in coherence with the evidence-based public health paper of Wainwright et al. (2007). On the other hand, Trost (2007) reviews a sample of 58000 students in the period 1967-2006 and discovers that regular physical activity improves cognitive ability and therefore leads to better academic performance. So, there seems to be a dual relationship between education and physical activity: high educated individuals tend to exercise more compared to low educated individuals, while consistent physical activity has the potential benefit of boosting academic performance and therefore result in higher education. With this in mind, the causality between education and physical activity may be doubtful but it is obvious that there is a strong correlation.

Then, Cutler & Muney (2006) apply an Ordinary Least Squares (OLS) analysis on a sample derived from the National Health Interview Survey (NHIS) in the United States and indicate that education is positively associated with life expectancy: the higher the level of education, the higher the life expectancy. Although this is a well-established relationship in existing research, it is debatable how many of those additional life years gained due to higher education would be lived in good health. A higher life expectancy does not immediately translate itself into better health outcomes. It would be more interesting to know the concrete link between education and health production. So then, the main topic of interest becomes healthy life expectancy rather than life expectancy alone.

Existing research frequently discusses the gender inequalities in health and healthy life expectancy. Typically, conditional on age, the health-related quality of life (HRQOL), which is the key factor to derive the healthy life expectancy from the life expectancy, appears to be significantly lower for girls than boys (Michel et al., 2009). Then, Denton et al. (2004) report that in general females tend to suffer from poorer health than males. A more robust meta-analysis of 229 studies on gender differences in caregiver health confirms that females suffer from a lower self-assessed -, physical - and mental health compared to males (Pinquart & Sörensen, 2006). On the other hand, Azevedo et al. (2006) perform a cross-sectional analysis on a Brazilian sample of 1530 households to explore gender differences in leisure-time physical activity. They mark that the participation rate of males in moderate-intensity -, vigorous-intensity - and total leisure-time physical activity is higher compared to the participation rate of females. However, overall, we note that the evidence regarding gender inequality in physical activity is quite ambiguous and limited.

IV. Summary and final thoughts

Before we present the next chapter, it is helpful to recapitulate the main findings related to the relationship between physical activity and health outcomes. Overall, there is consensus about the positive impact of physical activity on health. Colman & Dave (2013) make this relationship more concrete and report that there is a dose-response relationship between them: the higher the dosage of physical activity, the greater the health benefits will be. However, the relationship between physical activity and health outcomes is likely to be two-sided. To illustrate the reverse impact from health status to physical activity, a powerful indicator to evaluate health status would be the Body Mass Index (BMI). This index measures someone's weight with respect to his - or her height. As a general rule, the higher someone's BMI, the higher the probability of having overweight (Built Lean, 2016). One of the adverse consequences of being overweight is that it makes physical activity more (physically) demanding and taxing, which may harm the intensity or/and frequency of physical activities. Thus, an increased BMI may tend to negatively influence physical activity. This reverse causation might be the first indicator of the potential endogeneity of physical activity, which is an obstacle to approximate the causal effect of physical activity on health. In the next chapter, we will point out the endogeneity of physical activity and delineate the empirical strategies to tackle this problem.

3. Data and empirical strategy

I. Data description

In this paper we make use of the dataset of the LISS panel administered by CentERdata (Tilburg University, The Netherlands). This is a fully randomized sample drawn from population registers in partnership with Statistics Netherlands (CBS) and consists of 4500 Dutch households and approximately 8000 individuals aged 16 and above. Each household member has a personal identifiable number (PID). The panel members are asked to fill in an online questionnaire on a monthly basis of about 15-30 minutes for which they get a financial compensation of €10 to maximize the response rates. Panel members who initially do not have internet access are provided with a computer and Internet connection to secure participation in the questionnaire.

Overall, the LISS panel consists of three types of studies: Background Variables, Core Studies & Assembled Studies. The most relevant dataset for our study is the Core Studies, which is project number 2 within the LISS Core Studies. Namely, this survey provides information regarding health, health perception, physical activity measures and other lifestyle patterns. The data for this study is collected annually. The data collection period starts in November 2007 and ends in November 2017 (excluding 2014), which results in 10 waves. The only limitation of this study is that it does not include any information regarding the education, marital status and urban characters of the living area of the respondents. We fill this gap by merging the dataset of the Background Variables with the Health Study by taking advantage of the household member ID. Our data is thus the combination of the Background Variables & Core Studies.

II. Variables

The main economic foundation for our research is the model of Grossman (1972), which is already presented in the literature review, see equation (**2**). Based on this framework and the information from the literature review, we integrate – and refine a number of variables by utilizing STATA 15.

$$H = h\ (L, X, M, N, H[t-1], E) \qquad (\mathbf{2})$$

One of the major benefits of our dataset is that it displays a variety of health measurements. First, the participants of the panel are asked to rate their own health, generally speaking, based on 5 categories: poor, moderate, good, very good and excellent. So, this reflects a subjective measurement of health status. Second, the panel members are asked to fill in whether he or she suffers from any specific disease such as diabetes, which should have been reported by a physician and is represented by a binary variable (1=Yes, 0=No). Since it is a physician who indicates a disease, it is a more objective impression of health status compared to a subjective indication. The last indicator of objective health is BMI. The LISS panel does not explicitly measure this variable but given the age and length of the respondents, it is possible to quantify it by applying equation (**3**) (Utah, 2010). Then, from table 1, it follows that BMI scores have different health implications. To begin with, BMI scores 18.5 - 24.9 reflect the range for normal weight, whereas ratings between 25.0 and 29.9 indicate overweight. Finally, a person suffers from the mild forms of obesity, i.e. class I, if his - or her BMI varies between

30.0 and 34.9, while obesity gets more severe (class II) when the BMI exceeds these values. So, as a general rule, we can conclude that a lower BMI suggests better health.

$$BMI\ ({}^{kg}/_{m^2}) = {}^{Weight}/_{Length^2} \quad (3)$$

Table 1: BMI categories (Utah, 2010)

BMI	Health Implication
18.5 – 24.9	Normal
25 – 29.9	Overweight
30.0 – 34.9	Obese, class I
≥ 35.0	Obese, class II

Then, in this paper, the key variable to explain health outcomes is physical activity. The dataset classifies physical activities into different intensity levels: ‘strenuous’ (lifting heavy loads, aerobics or cycling), ‘moderate’ (lifting light loads, cycling at a normal pace) and ‘low’ (walking). This allows us to separate the impact of different intensities of physical activity on health outcomes. In particular, each of the panel members are asked to indicate how many days he or she spent on each of the intensity levels over the past 7 days. The only restriction for reporting any physical activity is that it should have been lasted for at least 10 minutes. If someone engaged in physical activities for less than 10 minutes or did not perform any type of physical activity at all, the corresponding answer is zero. On the other hand, marriage is likely to affect physical activity – and eating behavior of people, since it creates a shared environment. Therefore, we represent the marital status of the respondents by a dummy variable for being married (1=Married; 0=Not married).

Moreover, to reflect other lifestyle choices than physical activity alone, we incorporate a dummy variable for smoking (1=Currently smoking, 0=Currently not smoking). It would also be interesting to understand the relationship between health outcomes and socioeconomic status. Therefore, we add a categorical variable for education, which reflects the highest educational status with diploma. Further, we control for the age of the respondents since Grossman (1972) perceives ageing as the key factor for the depreciation of the health stocks. Finally, Grossman also emphasizes the importance of environmental factors for health production. In light of this, we incorporate a categorical variable for the urban characteristics of the place of residence.

Then, we apply a few modifications to get rid of outliers and clean up our dataset. Table 2 provides a full overview of descriptive statistics. First, regarding the length of the respondents, we only focus on the values between 1.60 – and 2.05 m. Second, we only restrict ourselves to body weights between 50 - and 120 kg. Third, we only consider BMI values of 18 – 40. Finally, we only focus on individuals aged between 25 and 64. The primary reason for this age restriction is that adults are likely to be forced to engage in physical activities such as gymnastics due to their educational obligation. On the other hand, the health status of the elderly may hinder their physical activity, as Schutzer & Graves (2004) hypothesize. So, our age restriction partially corrects for the reverse impact from health status on physical activity.

Table 2 shows the descriptive statistics. It seems that the mean of BMI within our sample is 25.35. From table 1, it follows that this BMI value indicates overweight. Moreover, the descriptive statistics reveal that the average number of days engaged in strenuous physical activities throughout the week is 1.21, while the participation during a week equals 2.94 days for moderate intensity - and 4.08 days for low intensity physical activities. The definition of all variables are elaborated in Appendix A.

Table 2: Descriptive statistics

Variable	**Mean**	**Min.**	**Max.**	**Observations**
POOR	0.014	0	1	N=42945 n=11734
MOD	0.155	0	1	N=42945 n=11734
GOOD	0.586	0	1	N=42945 n=11734
VERYGOOD	0.194	0	1	N=42945 n=11734
EXCELLENT	0.051	0	1	N=42945 n=11734
LENGTH	1.75	1.60	2.05	N=40504 n=11111
WEIGHT	76.94	50	120	N=41982 n=11555
BMI	25.35	18.01	39.91	N=39208 n=10878
DIABETES	0.054	0	1	N=40814 n=11296
SMOKING	1.68	1	2	N=24641 n=6933
STRENUOUS	1.21	0	7	N=42797 n=11697
MODERATE	2.94	0	7	N=42785 n=11696
LOW	4.08	0	7	N=42776 n=11694
AGE	47.00	25	64	N=28178 n=8431

PRIMARY	**0.052**	**0**	**1**	**N=42949 n=11734**
VMBO	0.243	0	1	N=42949 n=11734
HAVOVWO	0.111	0	1	N=42945 n=11734
MBO	0.230	0	1	N=42949 n=11734
HBO	0.230	0	1	N=42949 n=11734
WO	0.090	0	1	N=42949 n=11734
OTHER	0.028	0	1	N=42949 n=11734
NOTCOMPLETED	0.135	0	1	N=42949 n=11734
NOTSTARTED	0.002	0	1	N=42949 n=11734
MALE	0.464	0	1	N=42949 n=11734
MARRIED	0.563	0	1	N=42949 n=11734
EXTRURBAN	0.138	0	1	N=42738 n=11698
VERYURBAN	0.262	0	1	N=42738 n=11698
MODURBAN	0.231	0	1	N=42738 n=11698
SLURBAN	0.215	0	1	N=42738 n=11698
NOTURBAN	0.154	0	1	N=42738 n=11698

III. Empirical framework

The primary goal of this study is to enhance the knowledge about the causality between physical activity and health. Therefore, the dependent variable is health, which is a general term and can be quantified by many variables. From the literature review, it follows that Contoyannis & Jones (2004) prefer self-assessed health outcomes as the main outcome variable. On the contrary, Colman & Dave (2013) favor a more objective perspective and evaluate health by the risk factors for heart diseases.

Although the choices of Contoyannis & Jones and Colman & Dave regarding the dependent variable differ from each other, they both recognize the potential endogeneity of physical activity. One of the proposals is to exclude time constant unobservables by utilizing a fixed effect estimation. From our point of view, this approach is indeed one of the necessary steps to approximate the causal effect of physical activity on health since it is likely that there are unobservable confounders. To illustrate, psychological factors such as a poor body image - or having a lazy attitude due to poor health can either motivate – or hamper someone to exercise, depending on how a person deals with it. Also, as have been discussed in the literature review, individuals with a low marginal rate of time preference are more future conscious and therefore tend to be healthier and more active compared to someone who cares less about his – or her future health, i.e. high marginal rate of time preference. Then, Mustelin et al. (2009) report that obesity and exercise behavior are affected by genetic - and environmental factors. It makes sense that someone who lives in a 'healthy' environment with many fitness centers in the neighborhood is more likely to exercise compared to someone who has no access to a gym nearby, while it is thinkable that someone is more tempted to prefer junk food when there is a huge supply of fast food delivery in the local area in comparison to a region with a limited accessibility to fast food. All of these factors describe potential unobservable confounders. But then, it is debatable whether all of them are fixed over time. For example, it is unclear whether the marginal time preference of an individual changes when a person ages. It is plausible that the older someone gets, the less value he – or she puts on the future since the remaining expected life expectancy tends to decrease. This would be an argument for why the marginal rate of time preference would be time varying. However, genetic impacts do not fluctuate over time, and considering the fact that our dataset reflects a period of approximately 10 years, it is pretty likely that environmental factors remain pretty fixed as well. Moreover, it is imaginable that variables such as family background and parental investments affect both physical activity and health outcomes, which are two other examples to illustrate time-invariant confounding. For example, if being overweight is a common phenomenon in a family, this may explain the high BMI - and lower physical activity levels of the other family members. We can remove a substantial part of the omitted variable bias problem, namely the part which is caused by time-invariant unobservables, by utilizing a fixed effect approach.

However, the issue of unobservable confounders is not the only threat for the cause-effect pathway between physical activity and health. As discussed in the literature review, it is likely that there is a dual relationship between them. For example, if we measure health by BMI, it is imaginable that an obese individual, i.e. someone with an extreme BMI value, may tend to engage in physical activities with a lower intensity or/and frequency compared to someone with a relatively healthy BMI. For such individuals, it is namely more (physically) demanding and taxing to involve in intense physical activities. Considering their limited capability to handle intense activities, i.e. low fitness level, it would be a more rational expectation that obese individuals prefer a low intensity walk rather than heavy weightlifting multiple times a week. To account for this reverse causation, we incorporate the lagged variables (t-1) of each physical activity category (strenuous, moderate & low). This will also clarify whether physical activity has more influence on current - or future health. In other words, it will provide better understanding whether physical activities show more characteristics of an investment – or consumption good.

With this in mind, our empirical approach looks as follows. Our model considers BMI as the main health outcome. The primary motivation for this choice is that BMI reflects a more objective measurement for being healthy compared to subjective health. It is plausible that different individuals have different health expectations from a certain subjective health category. For example, compared to a low educated individual, a high educated person may have higher expectations from a good subjective health. Moreover, factors such as age and race may also influence the interpretation of being healthy. So, the same score for subjective health may not indicate a fixed level of health (Colman & Dave, 2013). The health implications of BMI however are clear, as can be seen in table 1 within the section Variables. Then, to examine whether time-invariant unobserved variables lead to biased estimations, we first perceive our data as cross sectional and exploit an ordinary least squares (OLS) analysis and then apply a fixed effect (FE) estimator, see equation (**4**) and (**5**). As has been mentioned before, a FE estimator removes all time-constant unobserved variables, which leaves us with the idiosyncratic -, time varying error term (u).

Model A (OLS):

$$BMI\ (t) = \propto\ + \beta 1 * STRENUOUS(t) + \beta 2 * MODERATE\ (t) + \beta 3 * LOW\ (t) + \beta 4 * STRENUOUS(t-1) + \beta 5 * MODERATE\ (t-1) + \beta 6 * LOW\ (t-1) + \beta 7 * SMOKING\ (t) + \beta 8 * URBAN\ (t) + \beta 9 * EDUCATION\ (t) + \beta 10 * DIABETES\ (t) + \beta 11 * AGE\ (t) + \beta 12 * MARRIED\ (t) + \beta 13 * MALE\ (t) + \varepsilon\ (t) \quad \textbf{(4)}$$

Model B (FE)

$$BMI\ (i,t) = \propto\ + \beta 1 * STRENUOUS(i,t) + \beta 2 * MODERATE\ (i,t) + \beta 3 * LOW\ (i,t) + \beta 4 * STRENUOUS(i,t-1) + \beta 5 * MODERATE\ (i,t-1) + \beta 6 * LOW\ (i,t-1) + \beta 7 * SMOKING\ (i,t) + \beta 8 * URBAN\ (i,t) + \beta 9 * EDUCATION\ (i,t) + \beta 10 * DIABETES\ (i,t) + \beta 11 * AGE\ (i,t) + \beta 12 * MARRIED\ (i,t) + \beta 13 * MALE\ (i,t) + u\ (i,t) \quad \textbf{(5)}$$

An alternative strategy to isolate the causal effect of physical activity on the BMI would be an Instrumental Variable (IV) approach. This approach requires an acceptable instrument, which has to be relevant, strong and valid. In our framework, this means that the instrument should be highly correlated with physical activity, while it does not affect the BMI and any other (unobserved) determinant of it. So, the impact from the instrument on the BMI should only go through physical activity. One potential candidate for this requirement would be the distance to the gym. We hypothesize that a gym at a small distance, e.g. 5 – 10 km, would stimulate physical activity as opposed to a gym which is located further away due to the fact that the opportunity costs (travelling time) to engage in physical activity are lower. On the other hand, it is unlikely that an individual's BMI is directly related to the distance to the gym. So, it is reasonable that the instrument's impact on BMI only goes through physical activity and that is exactly what is demanded from a suitable instrument. However, the LISS questionnaire does not reflect such variable and in fact it does not contain an adequate instrument at all. Thus, in our context, a satisfactory instrument is not present.

4. Results

I. OLS - & FE estimations

Table 3: Regression results OLS & FE

Pooled OLS:

R^2 (within): *0.046*

R^2 (between): *0.058*

R^2 (overall): *0.057*

RHO: *0.902*

Fixed Effect:

R^2 (within): *0.055*

R^2 (overall): *0.001*

RHO: *0.919*

BMI	OLS Coefficient	FE Coefficient
STRENUOUS	-0.033	-0.029
	(0.00)*	(0.00)**
MODERATE	-0.013	-0.007
	(0.05)***	(0.31)
LOW	-0.017	-0.012
	(0.01)**	(0.09)**
LAGSTRENUOUS	-0.014	-0.013
	(0.09)***	(0.11)
LAGMODERATE	-0.004	-0.001
	(0.53)	(0.85)
LAGLOW	-0.007	-0.003
	(0.53)	(0.57)
SMOKING	0.733	0.684
	(0.00)*	(0.00)*
URBAN		
VERY	0.282	0.278
	(0.17)	(0.27)
MODERATELY	0.107	-0.139
	(0.57)	(0.67)
SLIGHTLY	0.249	-0.009
	(0.14)	(0.98)
NOT	0.064	-0.063
	(0.73)	(0.84)

EDUCATION		
VMBO	-0.177	
	(0.56)	
HAVO/VWO	-0.326	
	(0.33)	
MBO	-0.425	
	(0.17)	
HBO	-0.853	
	(0.01)**	
WO	-0.694	
	(0.07)***	
OTHER	-0.109	
	(0.77)	
NOT COMPL.	-0.518	
	(0.11)	
NOT STARTED	-0.650	
	(0.11)	
DIABETES	0.219	-0.417
	(0.33)	(0.10)
AGE	0.046	0.061
	(0.00)*	(0.00)*
MARRIED	0.271	0.250
	(0.00)*	(0.02)*
MALE	0.674	
	(0.00)*	

*Notes: p-values in parentheses, where *, **, *** denote significance at 1%, 5% and 10%. Number of observations equals 13999 for both regressions.*

The relationship between physical activity and the BMI is the primary focus of this study. The estimations for the coefficients of the physical activity variables follow quite an interesting pattern among the regressions. To begin with, in both models, it appears that strenuous physical activity significantly lowers the BMI. This is in consensus with the general expectation that physical activity leads to better health outcomes. Specifically, an additional day of strenuous physical activity during the week decreases BMI with 0.033 in the OLS estimation, which is a cross-sectional view on our dataset , whereas the FE estimation reveals a magnitude of 0.029. Thus, eliminating time-invariant unobservables shows that an OLS approach leads to biased estimations, which in this case translates itself into an overestimation of the beneficial impact of strenuous physical activities on health outcomes. To put it differently, a FE estimation of strenuous physical activities leads to a smaller decrease in BMI compared to an OLS estimation. As has been expected in Chapter 3, this already indicates that there are time-invariant unobservable confounders.

Further, we notice that an additional day of moderate intensity physical activity significantly lowers the BMI in the cross sectional analysis. To specify, the OLS estimation indicates that an extra day of moderate intensity physical activity throughout the week significantly drops the BMI with 0.013. However, the significance of this variable disappears in the FE estimation. This is a second confirmation for the assumption that an OLS approach leads to biased estimations for physical activity.

Moreover, from both regressions, it follows that an additional day of low intensity physical activity significantly decreases the BMI with 0.017 in the OLS – and 0.012 in the FE estimation. Similar to the findings of previous physical activity variables, it appears that a cross sectional perspective overestimates the beneficial impact of moderate intensity physical activity on the BMI.

Then, looking at the FE estimations, we can draw the following conclusions. First, our results show that an additional day of strenuous intensity physical activity is a more powerful tool to lower the BMI compared to an additional day of low intensity physical activity. In fact, the association between strenuous physical activities and BMI is nearly 2.5 times as big than the estimated impact from low intensity physical activity on the BMI. As has been mentioned in the literature review, Colman & Dave (2013) argue that there is a dose-response relationship between physical activity and health: the higher the dosage (intensity) of physical activity, the greater its health benefits will be. Thus, it seems that our estimates confirm their dose-response relationship theory. However, it is surprising that low intensity physical activities significantly lower the BMI, whereas there is no significant influence from moderate intensity physical activities on the same outcome. This contradicts the dose-relationship argument. Hence, our results imply that there is mixed evidence for the dose-response assumption. The comparison between strenuous – and low intensity physical activities accepts the hypothesis, whereas the move from low – to moderate intensity physical activities rejects it.

Moreover, the OLS estimations indicate that strenuous physical activity is the only type among the physical activity variables with a significant lagged impact on BMI. However, the accuracy of this estimation is pretty doubtful since it gets insignificant in the FE estimations. And even if the OLS estimations would be robust, we see that current strenuous activities have more health advantages, i.e. lead to a lower BMI, than lagged strenuous physical activities. The insignificance of all lagged physical activities makes the robustness of current physical activity estimates quite uncertain. Namely, in the previous chapter it is hypothesized that there may be a reverse causation from BMI to physical activity. Because of the fact that the lagged variables show an insignificant influence, it is arguable that this reverse impact leads to biased estimations for current physical activities. Such impact is namely eliminated in the case of lagged activities. A counter-argument would be that physical activity simply does not show characteristics of an investment good and therefore is a perfect illustration of a consumption good.

Another lifestyle choice within our empirical model is smoking. It appears that individuals who smoke have a significantly higher BMI compared to persons who stopped smoking. Specifically, the OLS estimation indicates that the BMI of smokers is 0.733 higher in contrast to the BMI of individuals who quitted smoking, while the value of this impact is 0.684 in the FE estimation. So, it seems that an OLS estimation overestimates the harming impact of smoking, while it overestimates the beneficial influence of physical activity.

Then, compared to an extremely urban area, none of the urbanization categories significantly changes the BMI. Initially, as explained in Chapter 3, our hypothesis was that an extremely urbanized area would have a better gym accessibility compared to a rural area and therefore may lead to a lower BMI. Ex-post, our results reject this hypothesis.

Besides, it follows that the only significant variables related to education are HBO and WO. In particular, it seems that individuals who obtained a HBO diploma, compared to finishing primary school, experience a better health (lower BMI) compared to persons who obtained a WO diploma. In particular, the estimated coefficient of HBO equals -0.853, whereas the coefficient of WO is -0.694. As have been discussed in the literature review, Cutler & Muney (2006) conclude that the higher the level of education, the higher the life expectancy. However, when we look at our results, it is questionable how many of those additional years will be lived in good health. It may be that individuals with a WO diploma have a higher life expectancy than persons with a HBO diploma, but such individuals also tend to face a higher BMI. Therefore, rather than the life expectancy alone, it is interesting to examine the relationship between education and healthy life expectancy.

Further, it appears that having diabetes, compared to not having diabetes, does not significantly change the BMI outcomes. This is quite a counter-intuitive finding. We would initially expect that diabetes boosts the BMI since it spikes the blood glucose, i.e. blood sugar (Peppa et al., 2003). But on the other hand, from Chapter 3, it follows if the BMI increases, the probability of getting overweight rises as well. One of the adverse health consequences of being overweight is an increased risk of developing diabetes. Thus, this illustrates that instead of a one-way impact from diabetes on the BMI, the BMI is also likely to enlarge the probability of facing diabetes. Therefore, it is reasonable that the estimations for diabetes are biased due to reverse causation.

In addition, we notice that age significantly increases the BMI in both regression models, for which the magnitude equals 0.061.Since a rise in BMI is considered as a worsening health status, our result exposes that Grossman is right with his theory that ageing depreciates the health stock. Moreover, we see that married individuals face a significantly higher BMI compared to persons who are not married. Specifically, being married rises the BMI with 0.271 in the OLS – and 0.250 in the FE estimation. With this in mind, we conclude that the positive contribution of marriage to BMI is notably greater than the impact of ageing. With this in mind, an additional comment on the theory of Grossman (1972) would be that if the health stock is measured by BMI, marriage is a more powerful factor to diminish it compared to ageing.

Finally, our results imply that there are gender differences in BMI. Namely, being a male, compared to being a female, significantly boosts the BMI with 0.674. Then, it would be interesting to split up – and reevaluate the association between physical activity and BMI by gender. We will discuss the implications of such method in the next section.

II. Sensitivity Analysis

a. Gender separation

Table 4: FE regressions separated by gender

BMI	FE Coefficient Males	FE Coefficient Females
STRENUOUS	-0.028 (0.02)**	-0.028 (0.07)***
MODERATE	-0.013 (0.14)	-0.003 (0.81)
LOW	-0.009 (0.33)	-0.015 (0.15)
LAGSTRENUOUS	0.015 (0.17)	-0.008 (0.55)
LAGMODERATE	-0.010 (0.17)	-0.005 (0.57)
LAGLOW	-0.013 (0.12)	-0.020 (0.23)

*Notes: p-values in parentheses, where *, **, *** denote significance at 1%, 5% and 10%. Number of observations equals 7082 for females and 6917 for males.*

When we compare table 4 with the estimates in the previous chapter, we note the following. First, it appears that the estimates for strenuous physical activities are pretty close to the one of the overall model, in which there is no gender separation in the regressions. Considering the impact of moderate intensity physical activities on BMI, it remains insignificant. But then, it appears that low intensity physical activity loses its significance when we separate the regressions by gender. So then, this table fully confirms the dose-response relationship theory of Colman & Dave (2013). In our overall model, it was namely contradictory that low intensity physical activities significantly lower BMI, whereas there is no significant impact from moderate intensity activities on this outcome. Overall, splitting the regressions for both genders result in more intuitive estimates.

b. Frequency impacts

Table 5: FE regression with the number of days of physical activity during a week as dummies

BMI	FE Coefficient
STRENUOUS	
1	-0.044
	(0.26)
2	0.107
	(0.80)
3	-0.027
	(0.62)
4	-0.161
	(0.02)**
5	-0.168
	(0.02)**
6	-0.169
	(0.09)***
7	-0.240
	(0.04)**
MODERATE	
1	0.101
	(0.02)**
2	-0.023
	(0.63)
3	-0.022
	(0.66)
4	-0.052
	(0.34)
5	-0.045
	(0.37)
6	-0.025
	(0.69)
7	-0.020
	(0.71)

LOW	
1	-0.018
	(0.75)
2	-0.027
	(0.66)
3	-0.129
	(0.03)**
4	-0.077
	(0.24)
5	-0.054
	(0.36)
6	-0.085
	(0.20)
7	-0.087
	(0.12)

*Notes: p-values in parentheses, where *, **, *** denote significance at 1%, 5% and 10%. Number of observations equals 13999 for both regressions.*

As have been pointed out in the first section of this chapter, the dose-response relationship between physical activity and BMI is quite doubtful. Namely, when we compare strenuous - with low intensity physical activity, it seems that there is indeed a dose-response relationship. But a comparison between low intensity – and moderate intensity physical activity contradicts this theory. This is our main motivation to review the number of days engaged in each physical activity during a week as separate dummy variables instead of one overall variable. With this in mind, we do not consider the dosage of an activity as just the level of intensity but relate it to its frequency as well.

Then, table 5 shows that, compared to no strenuous physical activity at all, 4 -, 5 – , 6 - and 7 days of strenuous physical activity throughout the week significantly reduces the BMI with 0.161, 0,168, 0.169 and 0.240 respectively. So, the impact of strenuous physical activities gets more powerful when there is an increased frequency. The only restriction is that in order to experience these health benefits of strenuous physical activity, an individual should engage in it for at least 4 times a week.

Moreover, performing a moderate intensity physical activity just once a week is the only category which significantly impacts BMI outcomes. But then, it is surprising that this estimate has a positive value. In particular, we find that an additional day of moderate intensity physical throughout the week significantly boosts BMI with 0.101. There is no rational explanation for this finding and it is pretty likely that this is a measurement error.

Finally, the estimates for low intensity physical activities show that an individual can only experience the positive health consequences of such activity, when he – or she has a participation of 3 times a week. Namely, compared to 0 days of low intensity physical activity in a week, a frequency of 3 times per week significantly lowers the BMI with 0.129.

5. Conclusion

Nowadays, we observe a global shift from curing diseases to health promotion with an emphasis on lifestyle choices, especially on physical activity. With this in mind, the main goal of this study was to shed light on the causality between physical activity and health outcomes. Previous studies extensively debated about the interplay between them and concluded that, overall, physical activity is positively associated with health outcomes. It is however a common mistake to fail to recognize the potential endogeneity of physical activity, which is a challenge to determine its causal effect on health outcomes. Namely, it is plausible that the health status itself affect someone's physical activity level or/and frequency, i.e. reverse causality, while genetic impacts and family background are likely to be correlated with both health outcomes and physical activity. In this study, we made the interpretation of being healthy more concrete by linking it to a healthy BMI. Then, we categorized physical activity according to intensity: strenuous, moderate – and low intensity. Our data is derived from the LISS panel administered by CentERdata (Tilburg University, The Netherlands), which is a fully randomized sample consisting of 4500 Dutch households and reflects approximately 8000 individuals aged 16 and above. Our empirical strategy to tackle the endogeneity issue of physical activity was as follows. We exploited both OLS – and FE estimations to examine whether time consistent unobservable factors lead to biased estimations for physical activity. In addition, to remove the reverse impact from BMI on physical activity, we incorporated lagged physical activities. Finally, we also went through a sensitivity analysis, in which we separated the regressions per gender and broke down the impact of the participation frequency (number of days throughout the week) for each physical activity type.

Then, our findings indicated that simple OLS estimations tend to overestimate the beneficial impact from physical activities on BMI. This method also overestimated the harming influence of smoking on BMI. So, in this study, an OLS approach resulted in biased estimations for lifestyle choices. Therefore, a FE estimation was already an improved method to approximate the causal contribution of physical activity on BMI. From this perspective, our analyses revealed that an additional day of strenuous physical activities, compared to no strenuous physical activity at all, significantly lowers the BMI with 0.029. In fact, this was the most powerful impact among the physical activity categories. We also noticed a strange finding that moderate intensity physical activity has no significant impact on BMI, whereas the opposite is true for low intensity physical activities. By separating our regressions per gender, we determined that the influence of low intensity physical activities on BMI becomes insignificant. Therefore, our results fully confirmed the dose-response relationship between physical activity and BMI, for which the first evidence came from Colman & Dave (2013). Also, by breaking down the frequency of physical activity, we showed that an individual should perform at least 4 days of strenuous activity throughout the week to experience its health benefits.

The main limitation of our results is that the causality between physical activity and BMI is still questionable. Namely, it seemed that lagged physical activities do not show any significant impact on BMI. We discussed that this finding has two possible explanations. One option is that we found significant coefficients for current physical activities due to the reverse impact of BMI. So then, this would imply that our estimations are biased. The alternative option is that lagged physical activities are insignificant because of the characteristics of physical activity. That is, rather than an investment good, physical activity is a perfect example of a consumption good. These statements need further research. As have been mentioned in Chapter 3, an alternative strategy to find more robust outcomes is an Instrumental Variable method. The downside of the LISS panel is that it does not provide a suitable instrument to apply this method. In fact, we have a suitable instrument in mind for possible future research: distance to the gym. It is imaginable that someone who lives close to a gym or sport club is more motivated to use the facilities and engage in physical activity due to the low opportunity costs (travelling time), while it is unlikely that this instrument is directly related to BMI. So, most likely the impact of the distance to the gym on BMI goes only through physical activity. But on the other hand, income may be a factor which still influences someone's gym choice. For example, for a relatively rich person it is more tempting to prefer a high-class gym, and if this is not available in the local area, this person would be willing to travel further away to fulfill his – or her wishing. So, the distance to the gym may be positively correlated with income, which makes the validity of our proposed instrument questionable. On the other hand, it is pretty likely that there are income inequalities in BMI and physical activity. With this in mind, it is plausible that our models suffer from omitted variable bias caused by income. Hence, the strict exogeneity assumption of a FE estimation to indicate a causal effect is unlikely to hold.

Finally, it would be interesting to examine the impact of the combination of healthy eating – and physical activity behavior. When we separated our regressions by gender, it seemed that moderate – and low intensity physical activities alone do now significantly change BMI. But it may be that the combination of healthy eating behavior and low - / moderate intensity physical activities contribute to a lower BMI outcome. In fact, physical activity is just one tool to sustain a healthy BMI. And this is also the main message of this study. Although strenuous physical activity significantly lowers the BMI, a person should at least perform it with a frequency of 4 days a week to experience this health benefit. This requires enormous discipline. In our opinion, physical activity would be a more powerful tool when it is supported by proper nutrition. Lifestyle choices reflect more than just physical activity alone.

6. References

Azevedo, M. R., Araújo, C. L. P., Reichert, F. F., Siqueira, F. V., da Silva, M. C., & Hallal, P. C. (2007). Gender differences in leisure-time physical activity. *International Journal of Public Health*, *52*(1), 8.

Bailey, R., Hillman, C., Arent, S., & Petitpas, A. (2013). Physical activity: An underestimated investment in human capital?. *Journal of Physical Activity and Health*, *10*(3), 289-308.

Brechot, M., Nüesch, S., & Franck, E. (2017). Does sports activity improve health? Representative evidence using local density of sports facilities as an instrument. *Applied Economics*, *49*(48), 4871-4884.

Built Lean (November, 2016). Retrieved from: http://www.builtlean.com/2013/07/17/bmi-chart/#fn-17539-4

Caspersen, C. J., Powell, K. E., & Christenson, G. M. (1985). Physical activity, exercise, and physical fitness: definitions and distinctions for health-related research. *Public Health Reports*, *100*(2), 126.

CDC Fact Sheet (2017). Health Effects of Cigarette Smoking. Retrieved from: https://www.cdc.gov/tobacco/data_statistics/fact_sheets/health_effects/effects_cig_smoking/index.htm

Colles, S. L., Dixon, J. B., & O'Brien, P. E. (2008). Hunger control and regular physical activity facilitate weight loss after laparoscopic adjustable gastric banding. *Obesity Surgery*, *18*(7), 833.

Colman, G. J., & Dave, D. M. (2013). *Physical Activity and Health* (No. w18858). National Bureau of Economic Research.

Contoyannis, P., & Jones, A. M. (2004). Socio-economic status, health and lifestyle. *Journal of Health Economics*, 23(5), 965-995.

Cutler, D. M., & Lleras-Muney, A. (2006). *Education and Health: Evaluating Theories and Evidence* (No. w12352). National bureau of economic research.

Denton, M., Prus, S., & Walters, V. (2004). Gender differences in health: a Canadian study of the psychosocial, structural and behavioural determinants of health. *Social Science & Medicine*, *58*(12), 2585-2600.

Dietz, W. H. (1996). The role of lifestyle in health: the epidemiology and consequences of inactivity. *Proceedings of the Nutrition Society*, *55*(3), 829-840.

Ding, D., Lawson, K. D., Kolbe-Alexander, T. L., Finkelstein, E. A., Katzmarzyk, P. T., Van Mechelen, W., ... & Lancet Physical Activity Series 2 Executive Committee. (2016). The economic burden of physical inactivity: a global analysis of major non-communicable diseases. *The Lancet*, *388*(10051), 1311-1324.

Downward, P., Dawson, P., & Mills, T. C. (2016). Sports participation as an investment in (subjective) health: a time series analysis of the life course. *Journal of Public Health*, *38*(4), e504-e510.

Edwards, R. (2004). ABC of smoking cessation: the problem of tobacco smoking. *BMJ: British Medical Journal*, *328*(7433), 217.

Getzen, T. E. (1992). Population aging and the growth of health expenditures. *Journal of Gerontology*, *47*(3), S98-S104.

Gregersen, F. A., & Godager, G. (2013). *Hospital Expenditures and the Red Herring Hypothesis: Evidence From a Complete National Registry* (No. 2013: 3). Oslo University, Health Economics Research Programme.

Grossman, M. (1972). On the concept of health capital and the demand for health. *Journal of Political Economy*, *80*(2), 223-255.

Haskell, W. L., Lee, I. M., Pate, R. R., Powell, K. E., Blair, S. N., Franklin, B. A. & Bauman, A. (2007). Physical activity and public health: updated recommendation for adults from the American College of Sports Medicine and the American Heart Association. *Circulation*, *116*(9), 1081.

Heath, G. W., Parra, D. C., Sarmiento, O. L., Andersen, L. B., Owen, N., Goenka, S. & Lancet Physical Activity Series Working Group. (2012). Evidence-based intervention in physical activity: lessons from around the world. *The Lancet*, *380*(9838), 272-281.

Jamison DT, Breman JG, Measham AR, et al. (2006) *Disease Control Priorities in Developing Countries. 2nd edition*. Washington, DC: The International Bank for Reconstruction and Development / The World Bank; New York: Oxford University Press.

Kohl 3rd, H. W., Craig, C. L., Lambert, E. V., Inoue, S., Alkandari, J. R., Leetongin, G. & Lancet Physical Activity Series Working Group. (2012). The pandemic of physical inactivity: global action for public health. *The Lancet*, *380*(9838), 294-305.

Lechner, M. (2009). Long-run labour market and health effects of individual sports activities. *Journal of Health Economics*, *28*(4), 839-854.

Melnyk, B. M., Jacobson, D., Kelly, S., O'Haver, J., Small, L., & Mays, M. Z. (2009). Improving the mental health, healthy lifestyle choices, and physical health of Hispanic adolescents: A randomized controlled pilot study. *Journal of School Health*, 79(12), 575-584.

Michel, G., Bisegger, C., Fuhr, D. C., & Abel, T. (2009). Age and gender differences in health-related quality of life of children and adolescents in Europe: a multilevel analysis. *Quality of Life Research*, *18*(9), 1147.

Miles, L. (2007). Physical activity and health. *Nutrition Bulletin*, 32(4), 314-363.

Müller, M. J., Enderle, J., & Bosy-Westphal, A. (2016). Changes in energy expenditure with weight gain and weight loss in humans. *Current Obesity Reports*, *5*(4), 413-423.

Mustelin, L., Silventoinen, K., Pietiläinen, K., Rissanen, A., & Kaprio, J. (2009). Physical activity reduces the influence of genetic effects on BMI and waist circumference: a study in young adult twins. *International Journal of Obesity*, *33*(1), 29.

Peppa, M., Uribarri, J., & Vlassara, H. (2003). Glucose, advanced glycation end products, and diabetes complications: what is new and what works. *Clinical Diabetes*, *21*(4), 186-187.

Physical Activity Guidelines Advisory Committee Report of the Physical Activity Guidelines Advisory Committee (2008). Retrieved from: https://health.gov/paguidelines/report/pdf/CommitteeReport.pdf

Philp, I. (2005). Ageing and health. *Community Practitioner*, *78*(1), 9.

Pinquart, M., & Sörensen, S. (2006). Gender differences in caregiver stressors, social resources, and health: An updated meta-analysis. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, *61*(1), P33-P45.

President's Council on Fitness, Sports & Nutrition: Physical Activity Guidelines for Americans (2018) Retrieved from: https://www.hhs.gov/fitness/be-active/physical-activity-guidelines-for-americans/index.html

Public Health England (2016). Health matters: getting every adult active every day. Retrieved from: https://www.gov.uk/government/publications/health-matters-getting-every-adult-active-every-day/health-matters-getting-every-adult-active-every-day

Rosin, O. (2008). The economic causes of obesity: a survey. *Journal of Economic Surveys*, *22*(4), 617-647.

Schutzer, K. A., & Graves, B. S. (2004). Barriers and motivations to exercise in older adults. *Preventive Medicine*, *39*(5), 1056-1061.

Stiegler, P., & Cunliffe, A. (2006). The role of diet and exercise for the maintenance of fat-free mass and resting metabolic rate during weight loss. *Sports Medicine*, *36*(3), 239-262.

Trost, S. G. (2007). Active education: Physical education, physical activity and academic performance. Retrieved from: https://folio.iupui.edu/bitstream/handle/10244/587/Active_Ed.pdf?sequence=2

University of Utah Health Care (2010). Utah Health Status Update: Obesity and Associated Chronic Conditions. Retrieved from: http://health.utah.gov/opha/publications/hsu/10May_Obesity.pdf

Wainwright, N. W., Surtees, P. G., Welch, A. A., Luben, R. N., Khaw, K. T., & Bingham, S. A. (2007). Healthy lifestyle choices: could sense of coherence aid health promotion?. *Journal of Epidemiology & Community Health*, *61*(10), 871-876.

Warburton, D. E., Nicol, C. W., & Bredin, S. S. (2006). Health benefits of physical activity: the evidence. *Canadian Medical Association Journal*, *174*(6), 801-809

Wing, R. R., Goldstein, M. G., Acton, K. J., Birch, L. L., Jakicic, J. M., Sallis, J. F., ... & Surwit, R. S. (2001). Behavioral science research in diabetes: lifestyle changes related to obesity, eating behavior, and physical activity. *Diabetes Care*, *24*(1), 117-123.

World Health Organization (2003). *Health and Development Through Physical Activity and Sport.* Geneva: World Health Organization. Retrieved from: http://apps.who.int/iris/bitstream/10665/67796/1/WHO_NMH_NPH_PAH_03.2.pdf

World Health Organization (2018). *Phyisical Activity for Health.* Geneva: World Health Organization. Retrieved from: http://www.who.int/topics/physical_activity/en/

World Health Organization. (2015). *World Report on Ageing and Health*. World Health Organization.

Zweifel, P., Felder, S., & Meiers, M. (1999). Ageing of population and health care expenditure: a red herring?. *Health Economics*, *8*(6), 485-496.

7. Appendix

Appendix A

Table 5: Definition of variables

Variable	Variable label
PID	Number of the household encrypted
WAVE	Year and month of administration
WEIGHT	How much do you weigh, without clothes and shoes? (kg)
LENGTH	How tall are you? (m)
BMI	Weight (kg) / length^2 (m^2)
SUBHEALTH	How would you describe your health, generally speaking? 1=Poor; 2=Moderate; 3=Good; 4=Very good; 5=Excellent
DIABETES	Do you suffer from diabetes or too high blood sugar level 1=Yes; 0=No
STRENUOUS	If you look back on the last 7 days, on how many of those days did you perform a strenuous physical activity such as lifting heavy loads, digging, aerobics or cycling? If you did not perform any strenuous physical activity, enter zero (0).Think only of activities that you performed for at least 10 minutes per occasion.
MODERATE	If you look back at the last 7 days, on how many of those days did you perform a moderately intensive physical activity such as carrying light loads, cycling at a normal pace or a doubles game of tennis? If you did not perform moderately intensive physical activities, enter zero (0). Think only of activities that you performed for at least 10 minutes per occasion.
LOW	If you look back at the last 7 days, on how many of those days did you perform a low intensity physical activity such as going for a walk? If you did not perform low intensity physical activities, enter zero (0). Think only of activities that you performed for at least 10 minutes per occasion.

SMOKING	Do you smoke now? 1=Yes; 2=No, I stopped
MALE	What is your gender? 1=Male; 0=Female
AGE	What is your age? (years)
EDUCATION	What is your highest education level with a diploma? 1=Primary school; 2=VMBO (junior high school); 3=HAVO/VWO (prepatory university); 4= MBO (junior college); 5=HBO (college); 6=WO (university); 7=Other; 8=Not completed any education; 9=No education
MARRIED	Are you married? 1= Yes; 0=No
URBAN	What is your urban character of residence? 1=Extremely urban; 2=Very urban; 3=Moderately urban; 4=Slightly urban; 5=Not urban

Appendix B

In part B, we show the development of the BMI and the number of days involved in a certain physical activity type and a distributional plot of BMI.

Figure 1: Development of the BMI and the number of days within a week of strenuous physical activity

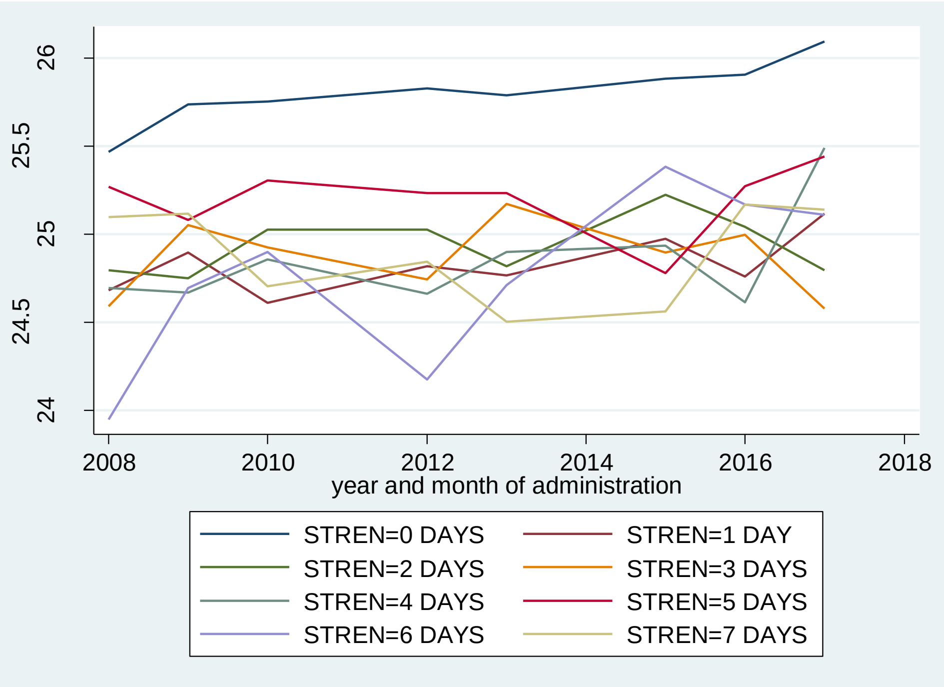


Figure 2: Development of the BMI and the number of days within a week of moderate intensity physical activity

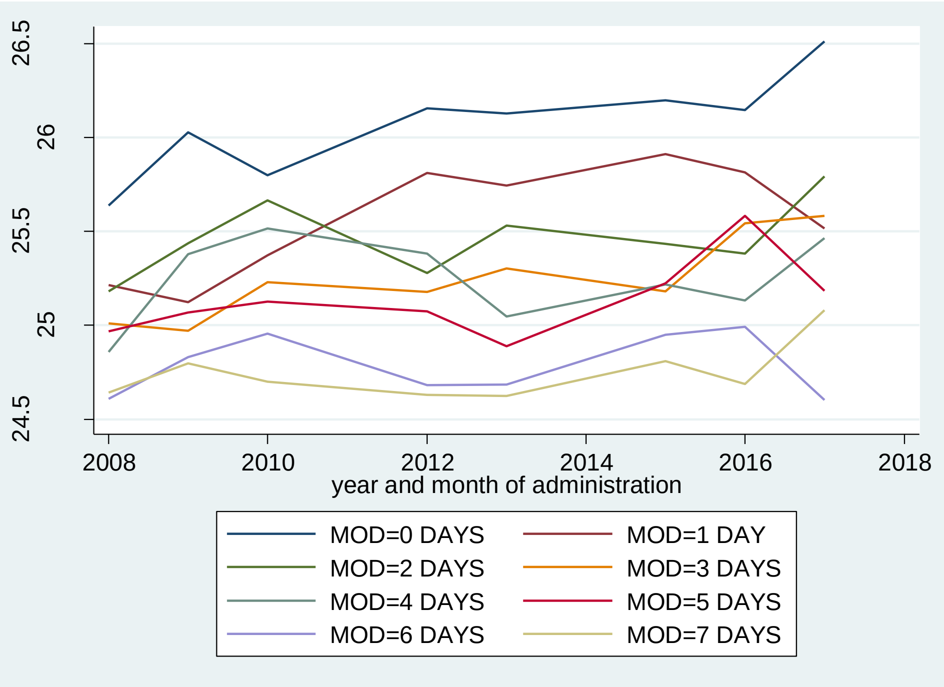


Figure 3: Development of the BMI and the number of days within a week of low intensity physical activity

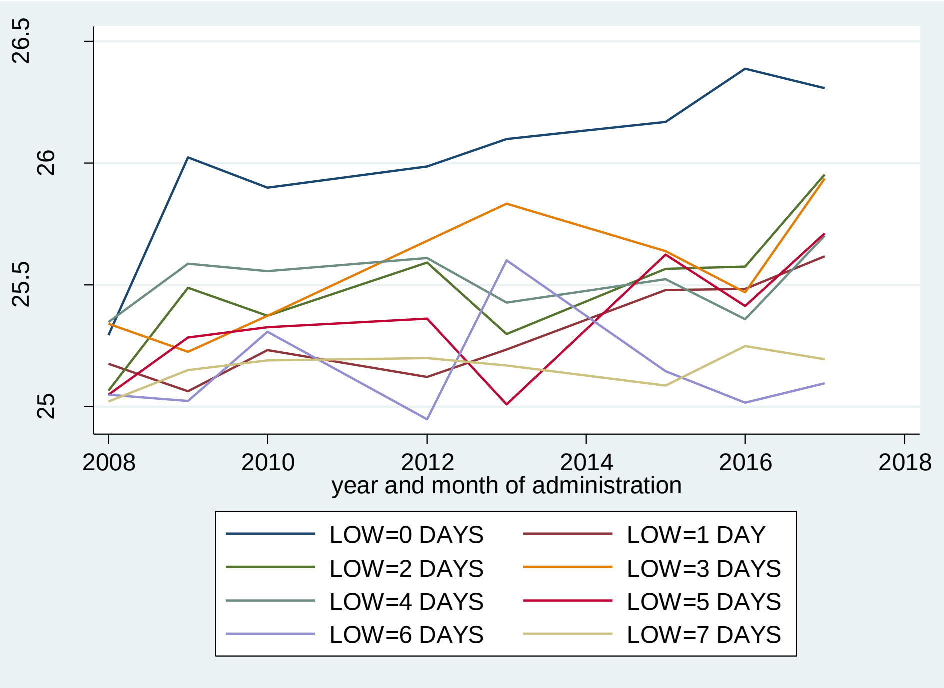
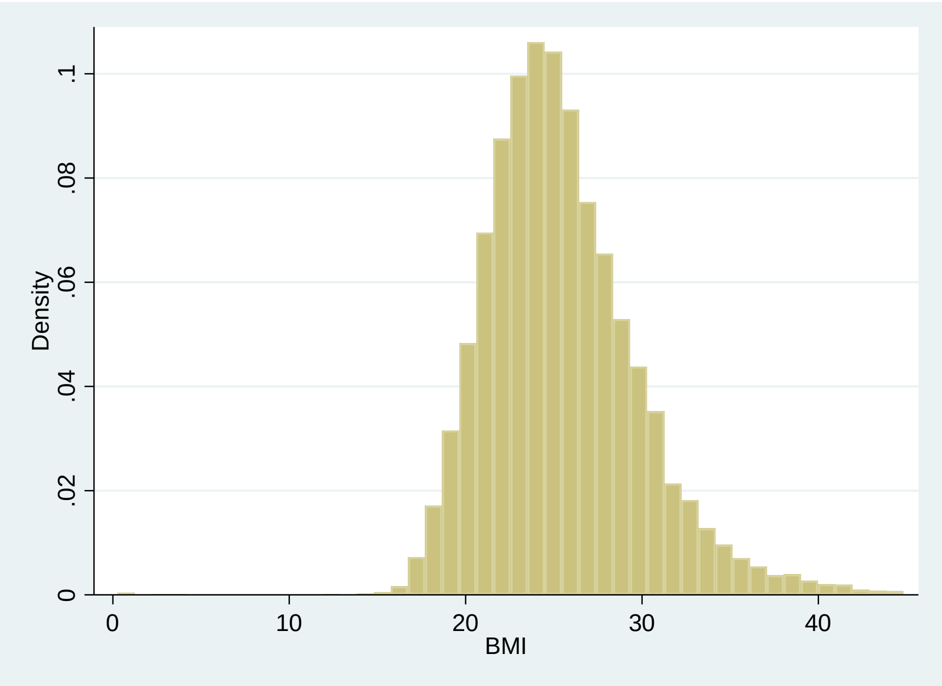


Figure 4: Distributional plot of the BMI



Appendix C

In part C, we show all regression outcomes of the sensitivity analysis.

Table 6: Regression results of the sensitivity analysis (separation by gender)

BMI	OLS Coefficient Males	FE Coefficient Males	OLS Coefficient Females	FE Coefficient Females
STRENUOUS	-0.029	-0.028	-0.038	-0.028
	(0.01)**	(0.02)**	(0.01)**	(0.07)***
MODERATE	-0.021	-0.013	-0.006	-0.003
	(0.11)	(0.14)	(0.58)	(0.81)
LOW	-0.011	-0.009	-0.023	-0.015
	(0.21)	(0.33)	(0.02)**	(0.15)
LAGSTRENUOUS	-0.015	0.015	-0.012	-0.008
	(0.16)	(0.17)	(0.37)	(0.55)
LAGMODERATE	-0.014	-0.010	-0.005	-0.005
	(0.11)	(0.17)	(0.56)	(0.57)
LAGLOW	-0.011	-0.013	-0.026	-0.020
	(0.15)	(0.12)	(0.25)	(0.23)
URBAN				
VERY	0.360	0.230	0.180	0.151
	(0.08)***	(0.34)	(0.41)	(0.64)
MODERATELY	0.465	0.405	-0.245	-0.705
	(0.08)***	(0.41)	(0.32)	(0.08)***
SLIGHTLY	0.725	0.441	-0.219	-0.522
	(0.00)*	(0.218)	(0.37)	(0.18)
NOT	0.287	0.205	-0.013	-0.376
	(0.23)	(0.63)	(0.61)	(0.32)

EDUCATION				
VMBO	-0.261		-0.123	
	(0.59)		(0.73)	
HAVO/VWO	0.002		-0.652	
	(0.98)		(0.14)	
MBO	-0.285		-0.583	
	(0.57)		(0.12)	
HBO	-0.589		-1.076	
	(0.23)		(0.01)**	
WO	-0.670		-0.666	
	(0.26)		(0.15)	
OTHER	-0.107		-0.150	
	(0.86)		(0.71)	
NOT COMPLETED	-0.500		-0.601	
	(0.32)		(0.13)	
NOT STARTED	-0.922		0.413	
	(0.13)		(0.26)	
AGE	0.036	0.038	0.057	0.083
	(0.00)*	(0.00)*	(0.00)*	(0.00)*
MARRIED	0.308	0.250	0.236	0.259
	(0.00)*	(0.06)***	(0.06)***	(0.11)
DIABETES	0.103	-0.431	0.517	-0.281
	(0.72)	(0.18)	(0.16)	(0.47)

Table 7: Regression results of the sensitivity analysis (frequency impact)

BMI	OLS Coefficient	FE Coefficient
STRENUOUS		
1	-0.074	-0.044
	(0.06)*	(0.26)
2	-0.015	0.107
	(0.72)	(0.80)
3	-0.055	-0.027
	(0.41)	(0.62)
4	-0.208	-0.161
	(0.00)*	(0.02)**
5	-0.187	-0.168
	(0.01)**	(0.02)**
6	-0.196	-0.169
	(0.06)***	(0.09)***
7	-0.238	-0.240
	(0.03)**	(0.04)**
MODERATE		
1	0.09	0.101
	(0.05)***	(0.02)**
2	-0.044	-0.023
	(0.35)	(0.63)
3	-0.048	-0.022
	(0.31)	(0.66)
4	-0.091	-0.052
	(0.09)***	(0.34)
5	-0.070	-0.045
	(0.15)	(0.37)
6	-0.063	-0.025
	(0.31)	(0.69)
7	-0.065	-0.020
	(0.20)	(0.71)

LOW		
1	-0.040	-0.018
	(0.47)	(0.75)
2	-0.054	-0.027
	(0.36)	(0.66)
3	-0.169	-0.129
	(0.01)**	(0.03)**
4	-0.104	-0.077
	(0.11)	(0.24)
5	-0.076	-0.054
	(0.19)	(0.36)
6	-0.133	-0.085
	(0.04)**	(0.20)
7	-0.135	-0.087
	(0.01)**	(0.12)
URBAN		
VERY	0.284	0.285
	(0.07)***	(0.26)
MODERATELY	0.114	-0.123
	(0.54)	(0.71)
SLIGHTLY	0.254	0.000
	(0.14)	(0.98)
NOT	0.064	-0.062
	(0.73)	(0.84)

EDUCATION		
VMBO	-0.018	
	(0.56)	
HAVO/VWO	-0.326	
	(0.33)	
MBO	-0.433	
	(0.16)	
HBO	-0.854	
	(0.01)**	
WO	-0.699	
	(0.07)***	
OTHER	-0.106	
	(0.77)	
NOT COMPLETED	-0.506	
	(0.12)	
NOT STARTED	-0.667	
	(0.08)***	
AGE	0.046	0.061
	(0.00)*	(0.00)*
MALE	0.674	
	(0.00)*	
MARRIED	0.275	0.255
	(0.00)*	(0.01)**