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ABSTRACT

Reports of pain differ markedly across socioeconomic groups and are correlated with outcomes such as functional limitations and disability insurance receipt. This paper examines the differential experience of pain by education. We focus on knee pain, the most common musculoskeletal complaint. Comparing clinical interpretation of knee x-rays of people with and without pain, there are few differences in presence or clinical severity of arthritis across education groups. In contrast, less educated people report more pain for any given objective measure of arthritis. After confirming that reported pain maps to objective measures like walking speed and range of motion, we test four theories for differential experience of pain: differences in obesity, physically demanding occupations, psychological factors, and medical treatment differences. We find that physical demands on the job and obesity each explain about one-third of the education gradient in knee pain. There is an interaction between the two; physical requirements on the job are associated with knee pain primarily in those who are obese. In contrast, psychological traits and access to medical care explain little of the difference in reported pain by education level. These findings imply that educational gradients in pain are likely to persist or even widen as the need for physically demanding occupations—like home health aides and personal service workers—grows in importance with the aging population, and the working population continues to be obese.

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There is a pronounced socioeconomic gradient in pain among middle aged and older adults (Case, Deaton, and Stone, 2020; Case and Deaton, 2017, 2020; H. Grol-Prokopczyk, 2017). For example, among people aged 60-64, those with a high school degree or less are 9 percentage points more likely to report musculoskeletal pain (joint, back, or neck pain) and 18 percentage points more likely to report a functional limitation. Not surprisingly, people with fewer years of education are more likely to leave the labor force for health reasons and more likely to apply for disability insurance compared with more educated peers.

Our goal in this paper is to understand the differential experience of pain by education. We focus in particular on knee pain. We chose knee pain because of its leading role in disability—knee pain is the top joint problem for Americans—and because there are clinical measures of knee anatomy that allow us to measure physical injury well.

Conceptually, differences in knee pain by education could arise from multiple sources. Those with fewer years of education may have more underlying structural knee damage than people with more years of education. And, for any given physical difference in knee damage, behavioral or environmental factors could exacerbate pain in less educated groups. Examples of such factors include: greater obesity, more physically demanding occupations, greater degrees of depression and other measures of psychological well-being, and less access to medical treatment.

Most knee pain is related to arthritis. Our first analysis thus examines whether higher rates of knee pain among those with fewer years of education is associated with increased prevalence of arthritis. Surprisingly, we find that x-ray assessments of structural knee damage are very similar for those with more and fewer years of education. Less than one-quarter of the difference in pain reports by education are a result of differential rates of knee arthritis; the vast bulk is due to less educated people experiencing more pain at every level of knee arthritis.

The finding may lead some to question whether the pain reports are 'real' or affected by social processes that may incline those with fewer years of education to report more pain. Multiple pieces of evidence refute that notion. For example, reported pain correlates well with performance on various physical activities such as walking time and leg strength, and pain is related to subsequent medical interventions such as receipt of a knee replacement.

Beyond differential rates of arthritis, we consider four other hypotheses for the disparity in knee pain by education. The first hypothesis is behavioral: knee pain differs because people with fewer years of education weigh more, and excess weight affects arthritic joints. The second hypothesis is occupational: physical requirements of jobs differ systematically by education, and these differences lead to differential rates of knee pain. The third hypothesis is psychological: mental health is worse for the less educated, and this translates somatically into greater pain. The fourth hypothesis is about access to medical care resources: people with more years of education have greater access to medical care that tempers pain.

We test these hypotheses empirically using several sources of data. The primary data source used to test the role of obesity and job demands is the National Health and Nutrition Examination Survey (NHANES). Using NHANES data from 1999-2004, we relate knee pain to current and maximum BMI and physical demands in the individual's longest job. Both physical demands on the job and obesity help explain the education gradient in knee pain, each accounting for roughly one-third. There is an interaction between these two effects. More physically demanding jobs are associated with knee pain primarily for people with a history of obesity. This interaction helps explain why knee pain has increased over time, even as physical demands in many jobs have moderated.

A key question about the job demands measure is whether it is really capturing physical activity, or if instead it signals other aspects of jobs, which affect knee pain for other reasons besides physical demands. We present several pieces of evidence suggesting that physical job demands are not just a proxy for more and less desirable jobs. The effect of job demands that we find is independent of the measures of abstract, routine, and manual jobs considered by Autor, Levy, and Murnane (2003), none of which have any meaningful relationship with knee pain. In addition, job demands affect pain in weight-bearing joints such as the knee and hips more than non-weight-bearing joints such as the fingers and wrists. Finally, knee pain declines for the less educated when they are not at work, while remaining constant for the better educated.

We examine the role of psychological factors in the experience of knee pain using data from the Midlife in the US study (MIDUS). MIDUS is a longitudinal survey of people conducted over ~20 years from the 1990s through the 2010s. The second and third waves of the survey have information on chronic knee pain along with a host of psychological metrics: life satisfaction, positive and negative affect, sense of control over life, and overall well-being. We consider whether these psychological attributes affect the onset of knee pain in people free of pain at baseline. We find some evidence that a more optimistic outlook reduces the incidence of knee pain, but the magnitude of the effect is small. Only about 11% of the development of knee pain is related to psychological factors, much less than the one-third resulting from each of physical demands and obesity.

To test the theory about access to medical care, we use the Health and Retirement Study to examine how arthritis treatment changes when people become eligible for Medicare. Insurance coverage changes greatly at age 65, but treatment for arthritis does not. Neither medication use nor joint surgery increase discontinuously for the less educated when they reach age 65.

Our overall conclusion is that the primary factors influencing the education gradient in pain are having worked in a more physically demanding job and being obese. We explore the implications of these findings in the last section, where we note increases in the number of physically demanding jobs such as home health aides and personal care aides. As a result, the educational gradient in knee pain may increase over time.

The paper is structured as follows. Section I presents background information on differences in pain by education group. Section II relates knee pain to the degree of arthritis and considers performance differences for people with different degrees of pain. Sections III-V examine the role of obesity, physical demands on the job, psychological health, and access to medical care in explaining differential knee pain. Section VI concludes. There are many data sets that we employ; these are detailed in an online appendix.

I. Socioeconomic Differences in Pain

We start by presenting basic information on socioeconomic differences in pain. The analysis uses data from the 2009-16 waves of the National Health Interview Survey (NHIS), a random sample of the non-institutionalized US population. Education is coded by highest year of schooling completed, which we categorize into three groups: <=high school degree, including a GED; some college, which includes an Associate degree but no four-year degree; and college graduates. We sample people aged 25 and older, so that education is largely complete. The combined sample contains just over 235,000 individuals.

The NHIS has measures of functional status and of pain. To measure functional status, people are asked whether they have one or more of 12 functional limitations: difficulty walking ¼ mile; climbing 10 steps; standing for 2 hours; sitting for 2 hours; stooping, bending, or kneeling; reaching over head; grasping small objects; lifting/carrying 10 pounds; pushing large objects;

going out to events; participating in social activities; and relaxing at home.[1] As noted in the introduction, rates of functional limitations decline with more years of schooling.

For people who report a functional limitation, the NHIS asks what conditions cause the limitation. Eighteen choices are given, with people allowed to choose more than one. Figure 1 shows the self-reported causes of functional limitations by education. For both more and less educated people, musculoskeletal impairments are the most common cause of functional limitations, selected by nearly two-thirds of people. The primary musculoskeletal impairments are joint pain (i.e. arthritis) and back/neck pain. The burden caused by musculoskeletal impairments is not surprising in the context of federal disability insurance; musculoskeletal impairments accounted for 37% of new Social Security Disability Insurance awards in 2018 (Social Security Administration 2019).

Separate NHIS questions ask more detail about joint and muscle pain. People are asked whether they have had pain in their neck (18%) or lower back (33%) in the past three months, and whether they had symptoms of joint pain, aching, or stiffness in the past 30 days (45%). Figure 2(a) shows the percent of people with pain in any of these areas by age and education. There is a pronounced education gradient in pain apparent at age 25 that persists until about age 70. At age 60 for example, people with a high school degree or less are 6 percentage points more likely to report musculoskeletal pain than are people with a college degree. Musculoskeletal pain plateaus at about two-thirds of the population, reaching this rate at roughly age 60 for those with fewer years of education and after age 70 for those with more years of education.[2]

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[1] The exact question is: "By yourself, and without using any special equipment, how difficult is it for you to…" Possible answers are not at all difficult; only a little difficult; somewhat difficult; very difficult; can't do at all; and do not do this activity. We count people as functionally limited if they report any level above not at all difficult, with the exception that people who do not do the activity are counted as not having difficulty. The qualitative pattern is similar limiting to only more severe levels of difficulty.

[2] Because educational attainment grew over time, one might worry that educational differences in outcomes at older

People who report joint pain are asked which joints are affected. The most common response is knee pain (62%). The second most common joint, shoulder pain, is only half as large prevalent (31%). Figure 2(b) shows the variation in chronic knee pain by age and education, where chronic pain is pain that began more than three months prior to the interview (93% of those with knee pain). The figure again shows large differences by education. At age 60, the education gap in chronic knee pain is about 10 percentage points. Rates of knee pain equalize about age 70, when roughly one-third of both education groups report chronic knee pain.

There is essentially no cure for knee pain. Treatment generally involves medication – either prescription (opioids) or non-prescription medications (NSAIDS such as acetaminophen or ibuprofen). These medications reduce the pain but do not cure the disease. Knee replacement has become more common in recent years but was rare during the time period of most of the data we examine. For example, in the 1988-94 NHANES III, 10 times more people have moderate or severe arthritis than report having had a knee replacement. And even among individuals reporting severe knee pain (as in the top decile of reported pain on the Knee Injury and Osteoarthritis outcome Score in the OsteoArthritis Initiative, a 2004 study of osteoarthritis), only 15% received a knee replacement. As a result, the rates of knee pain that we observe likely reflect true differences in knee pain in the population.

Figure 3 shows the percent of people with chronic knee pain by more detailed levels of education.[3] The data indicate a generally declining trend in knee pain with education, with the biggest break between those with a college degree and those without.

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ages are greater than would be true for a constant educational distribution. The appendix shows a simulation where we reallocate people across education groups so that people in each five-year age-sex cell have the same education distribution as does the population aged 55-59. Trends in knee pain by education are very similar in this counterfactual.

[3] These rates are adjusted for differences in the age-sex composition by education.

A. Changes in the Education Gradient in Knee Pain Over Time

A first question that arises is whether the link between education and knee pain is a recent development or a longstanding situation. If the relationship is recent, it would rule out some theories, such as long-term differences in work environments. To analyze trends in knee pain, we supplement the NHIS with data from four National Health and Nutrition Examination Surveys (NHANES): NHANES I (1971-74); NHANES II (1976-80), NHANES III (1988-94), and the continuous NHANES (1999-2004).[4] We analyze people aged 45-74 in all surveys except NHANES III, where only those aged 60 and older were asked about knee pain.[5] Table 1 shows that the sample sizes range from 4,100 to 6,500 per NHANES survey.

The questions about knee pain have become somewhat broader over time (see Table 1). NHANES I asked about knee pain, while later surveys also asked about stiffness and swelling. Thus, one should thus interpret the trend in knee pain with some caution. However, these question changes would have no obvious relationship with the education differential in knee pain.

The third and fourth rows of Table 1 show the rate of knee pain for people aged 45-74 unadjusted and adjusted to the age distribution in the NHIS. Roughly 10% of the population in the early 1970s had knee pain. That rose to about 18% in the late 1990s and further increased to 25% between 2009-16. The next two rows show the trend for people aged 60-74, for whom we also include data in the late 1980s. Knee pain jumped greatly between the late 1970s and the late 1980s. The next row shows that obesity increased along with knee pain, though the growth in knee pain exceeded the growth in obesity: 147% v. 77%. We return to this below, where we show that a

[4] The continuous NHANES is ongoing, but only the 1999-2004 waves have the pain questionnaire.
[5] We limit the upper age to 74 to avoid differential mortality at older ages. In addition, Figure 2 shows that most of the difference in reports of knee pain by education are at ages below 75. To account for missing data on younger ages in NHANES III, we assume that knee pain at ages 45-60 in NHANES III bears the same relationship to knee pain at ages 60-74 as in the NHIS.

person's history of obesity affects knee pain in addition to current obesity.

Figure 4 shows the education differential in knee pain for the five surveys, in each case weighting the data to the age-sex distribution in the NHIS. In 1971-74, there was no gap in knee pain by education. By the late 1970s, a gap of 3% had appeared. This rose to 9% in the early 1990s and has remained at 5% to 6% since. Thus, the link between education and knee pain has been a feature of the US for about 40 years and has grown over time.

II. The Presence and Impact of Arthritis

There are two primary causes of knee pain: acute injuries and chronic knee damage. Common injuries include torn cartilage and ligaments, as in the case of many sports injuries. The extent of acute damage is generally determined by magnetic resonance imaging (MRI) and these injuries are treated surgically or with pharmaceuticals.

The most common cause of knee pain, especially in the older population, is arthritis.[6] Arthritis is a chronic condition characterized by a breakdown of the cartilage that cushions the space between bones.[7] With the cartilage worn down, bones rub against each other, creating pain and leading to stiffness and limited motion. Half of people aged 65 and older report having been diagnosed with arthritis.

The severity of arthritis can be measured by x-ray. Radiologists look for narrowing of the space between bones (joint space narrowing), bone spurs (osteophytes), sclerosis (hardening or thickening of the bone), and loose bodies in the knee. The most widely used scale of arthritis severity is the Kellgren-Lawrence Scale (KL scale or KL grade), named after the two researchers

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[6] Injuries can lead to later development of osteoarthritis.

[7] Osteoarthritis is the most prevalent form of arthritis. Rheumatoid arthritis is second most common but has a much lower prevalence. Other causes of arthritis include gout, Lyme disease, lupus, and ankylosing spondylitis.

who developed it (Kellgren and Lawrence, 1957). The KL scale ranges from 0 to 4: 0 (normal); 1 (doubtful/questionable); 2 (mild arthritis); 3 (moderate arthritis); 4 (severe arthritis). Arthritis is defined as a KL score of 2 or higher. The final KL score is subjective, but has been shown to have high inter-rater reliability (Kohn et al., 2016).

The KL grade is highly predictive of pain. In comparison to people with a KL grade of 0, the relative risk of reporting knee pain is 9 for people with a KL grade of 4 and 4.9 for people with a KL grade of 3 (calculated from NHANES III data). The presence of the KL scale is a major advantage of analyzing knee pain, since it allows us to divide knee pain into an observable component (related to visible structural damage) and a component comprised of individual characteristics (i.e. obesity, job demands, psychological well-being) that could cause higher pain for a given level of arthritis.[8]

During the second part of the NHANES III data collection (1992-94), knee x-rays were taken for those aged 60 and older and scored using the KL scale.[9] We use these data to determine whether the greater rate of knee pain for people with fewer years of education is a result of having more arthritic knees or of feeling more pain given the degree of arthritis.

Figure 5(a) shows education differences in KL grade of the knee, where the education groups are weighted to a common age and gender mix of the population. Knees of college graduates display slightly less arthritis than knees of people with a high school degree or less. However, the differences are not large. The share of knees with no sign of arthritis is 2 percentage points higher for those with a college degree. In contrast, Figure 5(b) shows reports of pain

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[8] There is no common grading for back or neck pain. Many people with back pain have no abnormalities detectable on imaging, and many people with image abnormalities report no back pain (Brinjikji et al., 2015). For this reason, guidelines suggest not obtaining images for patients with non-specific lower back pain (Chou et al., 2007).

[9] The x-rays were first read by one reader. All x-rays showing any evidence of disease, and a sample of those without disease, were read by a second reader. In cases of discrepancy, the two radiologists concurred to form a consensus.

conditional on knee arthritis. At every level of knee arthritis – including no sign of arthritis at all – people with fewer years of school report more knee pain.

We quantify these findings in Table 2. Column (1) of the table shows the relationship between education and knee pain reports, adjusted for basic demographic data: five-year age-sex cells, race [White/Black/Other], Hispanic ethnicity, a dummy variable for whether the person was born in the US, a dummy variable for whether the person is a veteran, and a dummy variable for side of the body. Demographically adjusted, people with a college degree are 7.3 percentage points less likely to report knee pain. The second column includes controls for x-ray findings and other measures of knee anatomy formed from clinical observation: the presence of crepitus (a cracking, crunching, or popping feeling when the knee is bent), whether the knee is swollen, and the maximum range of motion (included as a dummy variable for <115°; Skinner et al., 2006). The coefficient on college education declines by only 14% with these additional controls.

Not all structural knee problems will be apparent on an x-ray. Deficiencies in cartilage or ligaments can only be observed with an MRI. Further, the binary measure of knee pain in NHANES is not well graded. To validate these findings with richer data, we analyze information from the OsteoArthritis Initiative (OAI). The OAI is a multi-center longitudinal study of people with knee osteoarthritis. The survey enrolled 4,796 people at five sites in 2004 and followed them annually for the next decade. About one-third of the sample had arthritis and knee pain at baseline. Essentially all of the remainder were considered at risk for arthritis and pain, based on weight, knee activities, and the like. A small sample of enrollees were healthy at baseline.

Most people enrolled in the OAI after being contacted by mail or seeing a flyer about the study. Thus, it is non-random.[10] Further, many people enrolled when their knee pain was high. As

[10] For example, about 60% of the sample has a college degree. The survey does not have sample weights.

a result, knee pain is much higher at enrollment than in the subsequent waves. In our analyses of the OAI, we omit observations in the enrollment wave of the survey to account for this.[11] That said, there is no indication that enrollment is differentially selected based on the relationship between knee pain and arthritis severity, the focus of our analysis.

X-rays for the OAI sample are available in many waves, and MRI results are available for about 1,700 people in various waves, yielding evidence on 2,494 knees once we restricted to observations in wave 1 (the first wave after enrollment). There is no single summary of the MRI image the way the KL score summarizes x-ray findings. We thus code several MRI findings: whether cartilage loss was >10% in the medial, lateral, or patella-femoral areas; whether there was evidence of a meniscal tear or moderate extrusion in the medial or lateral areas; and whether there were bone marrow lesions of at least 33% in the medical, lateral, or patella-femoral areas. We also include clinical observation of crepitus.

We use two measures of knee pain. The first is a dummy variable for whether the person had pain on most days of a month in the past year, somewhat similar to the question in the NHANES. The second measure, which we focus on more, is the detailed pain score from the Knee Injury and Osteoarthritis Outcome Score (KOOS), a grading of knee pain based on a 9-item questionnaire (see the appendix). The activities asked about are very specific, for example pain bending the knee fully or twisting/pivoting the knee. As generally scored, the KOOS scale ranges from 0-100, where a higher number denotes less pain. To be consistent with our other metrics of pain, where higher numbers are greater pain, we reverse the order so that 0 is no pain and 100 is maximum pain. The average person reports a pain score of 13.5 with a standard deviation of 16.2.

Column (3) of Table 2 relates the binary pain metric to standard demographics: five-year

[11] The appendix shows that a large reduction in knee pain takes place between the enrollment wave and the first follow-up wave.

age-sex cells, race, Hispanic ethnicity, side of the body, survey site, and education. To control for selection into the sample, we include dummy variables for the ways in which people heard about the survey (doctor, flyer, etc.). Column (5) estimates the same model for the KOOS score. Using the binary measure of knee pain, people with a college degree report 6.7 percentage points less pain than people with a high school degree or less. This is close to our estimate in the NHIS and NHANES, suggesting that the non-random sample selection does not bias these results. Using the continuous KOOS score, the gap is 46% of the mean score for people with a high school degree.

Columns (4) and (6) add the x-ray, MRI, and observational measures of knee impairment to the regression. Adding these measures reduces the education disparity in pain reports by 34% using the binary measure of pain and 14% using the KOOS measure. Neither of these are particularly large; at least 2/3 of the education gap in knee pain reports is not due to structural differences in knee anatomy. We thus conclude that the difference in knee pain by education is not primarily due to different rates of structural knee damage.

Is the pain real?

The finding that differential knee pain for those with fewer years of education is not associated with structural damage to the knee could lead some to question whether the pain is real. For example, the determination of eligibility for federal disability benefits requires "objective medical evidence" from an "acceptable medical source" (Social Security Administration 2020). Such requirements are designed to discourage people from reporting more pain as a way to qualify for disability insurance. It is often emphasized that higher replacement rates among workers with lower wages (who typically have lower levels of education) act as an incentive to claim disability benefits (Autor and Duggan 2003).

To test for objective evidence to support differences in pain reports among people with similar structural damage based on x-rays, we correlate reports of knee pain with several physical performance tests conducted in the OAI. The OAI measures the time required to walk 20 meters, whether the person can do a chair stand with their arms folded (thus using only their legs), and the maximum force a person can exert on knee extension. We relate walking time and the ability to do a chair stand to the average pain report across the two knees[12] and force exertion in each knee to the pain report in the relevant knee.

Figures 6(a)-(c) show the relationship between knee pain and performance in these three dimensions. In each case, pain is negatively related to performance. People in the highest vingtile of pain have a walking speed that is about 20% slower than people in the lowest vingtile of pain. The difference in force exertion is about 40%. The ability to do a chair stand is universal in the lowest pain groups but only 85% of people can do so in the highest pain group.

Further, knee pain is predictive of medical intervention. Figure 6(d) shows that subsequent knee replacements are far more common for people with higher initial levels of knee pain than people with lower levels. Thus, the pain reports seem to be accurate assessments of perceived pain.

Possible Explanations

If degree of knee pain is not explained by arthritis, what might cause it? There are three explanations in the literature. A first set of theories stresses the load placed on the affected joint. Both excess weight (Okifuji and Hare, 2015) and repetitive stressful motion (Vignon et al., 2006) have been linked to development of joint pain.[13] One way that load affects joints is through the development of arthritis, but there are other paths as well. For example, both obesity and repetitive

[12] The results are qualitatively similar if we use the maximum pain reports in the two knees.
[13] For example, studies show higher rates of hip arthritis in loggers, construction workers, and firefighters.

motion may increase inflammation, which can make any given level of arthritis more painful (Sokolove and Lepus, 2013). Obesity may also lead to other impairments such as sleep loss, which has been associated with greater pain reports.

A second set of theories is psychosocial. Depressed mood is often manifest as diffuse pain—back and joint pain being classic examples. In part, this may be because the same neurotransmitters influence both pain and mood (Marsala et al., 2015); thus, dysregulation of one may affect the other. Some studies also suggest that depressed mood leads to a more intense feeling of pain in response to the same stimulus, a hypothesis termed somatic sensitivity (Nakao and Barsky, 2007). Since rates of depression tend to be higher in people with lower levels of socioeconomic status this is one possible explanation for differential pain reports by education.

Finally, differential receipt of medical care is a possible cause of differences in pain reports. As noted above, there is no cure for most knee pain. But medication and other therapies may help reduce the pain, which could show up in self-assessments of limitations due to pain. In the next three sections, we test these theories for the link between education and knee pain. We start by examining stress put on the knee.

IV. Obesity and Physical Demands on the Job

Our methodology for examining the impact of physical stress on knee pain is similar to Cutler and Lleras-Muney (2010). We start with a model relating knee pain to education and demographics (X_D):

$$\text{Knee Pain}_i = \text{Education}_i\, \alpha^E + X_{D,i}\, \alpha^D + \varepsilon_i \quad (1)$$

Each element in the vector α^E, is the impact of education (α^c = college grad, or α^s=some college) relative to high school, the reference group, on knee pain adjusted only for demographics. We then modify equation (1) to include measures of obesity (BMI) and physical demands associated with the person's job (Phys):

$$\text{Knee Pain}_i = \text{Education}_i\ \beta^E + X_{D,i}\ \beta^D + \text{BMI}_i\ \beta^{BMI} + \text{Phys}_i\ \beta^{Phys} + \xi_i \quad (2)$$

Provided BMI and physical demands on the job are exogenous to knee pain, the change in the coefficient on education, $1-\beta^E/\alpha^E$, indicates how BMI and job demands taken together mediate the relationship between education and knee pain.[14] Further, we can estimate the impact of each variable independently using the individual regression coefficients. For example, the impact of differences in job demands between two groups, c and h, in mediating the education difference in pain is given by $(\text{Phys}_c\text{-Phys}_h)\ \beta^{Phys}/\alpha^c$, where α^c indicates the gap in knee pain relative to the reference group, h in equation (1).

The primary data that we use for this analysis is the population aged 45-74 in the continuous NHANES, 1999-2004, since these data have the richest collection of information on pain, obesity, and job history. The job history information is particularly important because people may change jobs as their physical health declines (for example moving into a desk job instead of one that involves standing). The reporting of past jobs allows us to minimize the impact of health-related changes in occupation.

Knee pain is defined in Table 1 and is reported as pain, aching, or stiffness most days in the past six weeks, or as seen for the NHANES, 1999-2004, it refers to the past 12 months. BMI is formed from self-reported height and weight. In addition to current BMI, NHANES asks about maximum weight, weight one year prior to the survey, weight ten years prior to the survey, and weight at age 25. We compared results including all of these BMI variables. Current and maximum

[14] Equations (1) and (2) are linear in knee pain. In some of our data, knee pain is a binary variable. We have explored using logit and probit analysis for these equations, with very similar marginal effects. Estimating the models linearly helps with the decomposition of the education effect.

BMI are both related to knee pain controlling for the other measures of obesity, while BMI at other ages was not. Thus, our regressions include current and maximum BMI. We divide the population into five BMI groups: underweight (<18.5); normal weight (18.5-25); overweight (25-30); obese (30-35); and morbidly obese (35+).[15] Twenty-eight percent of people are obese at the time of the survey, and 40% were obese at maximum weight (see the appendix). Obesity rates are higher for those with fewer years of education than for those with more years of education.

Figure 7(a) shows the relationship between BMI at maximum weight and knee pain. There is a strong, graded relationship between the two. At low levels of maximum BMI, roughly 10% of the population reports knee pain. This is about the same share of the population that reported knee pain in the NHANES I survey in the early 1970s, suggesting that a good share of the growth of knee pain is due to the increase in maximum weight. For the top 5% of people by weight, maximum BMI averages nearly 50, and 40% of that group reports knee pain.

The data on job characteristics are similar to those in Autor, Levy, and Murnane (2003) and Autor and Dorn (2013). The original source is the 1977 Dictionary of Occupation Titles (DOT), which estimated task requirements for over 12,000 detailed occupations.[16] These occupations were matched to 495 3-digit 1980 Census occupations, which we compress into the 40 occupation codes provided in the NHANES.[17] For the population that we analyze, data from the 1970s is roughly coincident with the period of longest employment. Even so, the physical requirements of jobs do not change greatly over time (Autor, Levy, and Murnane, 2003).

To form a measure of physical demands by occupation, we use a factor analysis to combine

[15] About two percent of people are missing information on height or weight. They are included in the regression with a missing BMI dummy variable.

[16] Job characteristics are not available for people in the armed forces. In addition, some people never worked and others do not report a longest occupation. In the regressions, we create dummy variables for being in each of these groups.

[17] The variability of job requirements within the NHANES categories is small. 82% of the employment weighted variation in physical demands across 3-digit occupation codes is explained by the 40 occupation groups.

four attributes in the DOT: a five-point strength score (sedentary, light, medium, heavy, very heavy); the percent of workers whose job involves climbing and/or balancing; the percent whose job requires stooping, kneeling, crouching, and/or crawling; and the percent whose job requires reaching, handling, fingering, and/or feeling (see the appendix). Empirically, these four variables are highly correlated, so the results are similar if we use other combinations of the data. The difference in job demands between college graduates and people with a high school degree or less is about one standard deviation of the difference across jobs at a point in time.

A central concern is whether the physical demands measure is truly capturing physical demands, or whether instead it is simply an indicator for jobs which may have undesirable characteristics, like low pay or monotonous repetition, but which cause little direct wear and tear on knees. To test this, we compare the impact of physical demands to that of three other job characteristics, taken from Autor and Dorn (2013): abstract work (a combination of math utilized and direction, control, and planning of activities), routine work (a combination of finger dexterity and situations requiring precise attainment of set limits, tolerances, or standards), and manual work (eye-hand-foot coordination).[18] Table 3 shows the correlation between the different measures of job attributes. The physical demands measure is most correlated with manual work (ρ=0.61). Physical demands and routine work are not highly correlated (ρ=0.23), and physical demands are negatively correlated with abstract work (ρ=-0.44). Thus, physically demanding jobs do not seem to be a proxy for other undesirable characteristics common in jobs held by less educated workers.

Figure 7(b) shows the relationship between physical demands on the job and knee pain.

[18] We have examined other job attributes as well. For example, the DOT contains data on the percent of workers in each occupation whose job involves exposure to extreme cold, extreme heat, wet or humid conditions, noise or vibrations, hazards, and atmospheric conditions. Including a measure of environmental exposure formed from a factor analysis of these variables has no qualitative and virtually no quantitative impact on the results. For example, using the specification in column (5) of Table 4, the coefficient on environmental exposure is .001 (.014), and the coefficient on physical demands is .021 (.011).

Each data point is weighted by the number of people with that 'longest held job' in the NHANES. The relationship is positive and statistically significant; we discuss the magnitude below.

Table 4 shows regression equations relating physical demands and obesity to knee pain. All regressions include demographic controls ($X_{D,i}$): five-year age-sex dummy variables, dummy variables for race/ethnicity, a dummy variable for being a veteran, and a dummy variable for being U.S. born. The first column presents estimates of equation (1), controlling for demographics only. Adjusted for demographics, people with a college degree are 4.5 percentage points less likely to report knee pain than those with a high school degree or less.

The second column includes the measure of physical demands. Since this variable is formed from a factor analysis, a one-unit increase represents a one standard deviation increase in job demands. The coefficient on physical demands is positive, statistically significant, and sizeable. A one standard deviation increase in physical demands leads to a 2.6 percentage point increase in the probability of having knee pain. As the penultimate row of the table shows, differing physical demands on the job account for 48% of the difference in knee pain by education.[19]

The third column adds the measures of abstract, routine, and manual work to the model. Including these variables does not materially change the coefficient on physical demands. Indeed, even controlling for these other job attributes, physical demands explain 42% of the education gradient in knee pain. The coefficient on abstract work is positive (people with more abstract jobs are more likely to report knee pain), although not statistically significant. The measure of routine work is positively associated with knee pain at the 10% level; however, the coefficient is only half as big as the coefficient on physical demands. Manual work is not associated with knee pain.

[19] The difference between the $1-\beta^E/\alpha^E$ estimate of a 49% difference and the 48% impact of job requirements is because there are slight differences in rates of having been in the armed forces, not having worked, and not reporting a longest job across education groups, dummy variables for which are included in Table 4.

Column (4) omits the job characteristics variables and examines the relationship between obesity and knee pain. People with higher current BMI as well as higher maximum BMI are more likely to experience knee pain. The effect is graded throughout the distribution of maximum BMI, and the coefficients are large. Compared to people of recommended weight, people who were obese at maximum weight are about 10 percentage points more likely to report knee pain. Conditional on maximum BMI, those who are currently morbidly obese are another 13 percentage points more likely to experience knee pain. Because obesity declines with education, the obesity results help explain the education gradient in knee pain. And because maximum BMI has an independent effect on current knee pain, controlling for current BMI, the link from BMI to knee pain (rather than from some other factor that causes both pain and weight gain) appears more likely to be causal. As the last row shows, current and maximum obesity explain 36% of the education gradient in knee pain, roughly comparable to the impact of more physically demanding jobs.

The final column includes job characteristics along with obesity in the regression. The two sets of variables have generally independent effects. In total, job characteristics and obesity explain 70% of the education gradient in pain, with roughly one-third of the total accounted for by each.

The link between obesity and pain could reflect the fact that carrying extra weight places extra strain on joints like knees. Alternatively, individuals could have health issues that cause an increase in obesity and in pain, independent of one's weight. If unobserved factors contributed to low education individuals holding physically demanding jobs, to be obese, and to experience pain, we would then expect people in physically demanding jobs to be more obese compared with those not in physically demanding jobs at some point over the life cycle. Figure 8 shows that is not the case. At age 25, 10 years earlier, at the survey, and at the maximum BMI, obesity did not differ much according to whether a job was physically demanding.

Finally, we tested whether physically demanding jobs were associated with a higher probability of reporting pain if the person is also obese. Table 5 presents regression results like those in Table 4, adding interactions of obesity with the scale of physical demands of the longest job. For comparison purposes, the first column repeats the results of the last column of Table 4. The second column includes an interaction between physical demands and obesity status at maximum weight. The omitted category is people of recommended weight. For people of recommended weight, the impact of physical demands is much smaller—only half the magnitude—and not statistically significant. In contrast, people who were heavier at maximum weight have much higher impacts of physically demanding jobs on knee pain. The remaining columns include interactions with other measures of weight. Only the interaction between physical demands on the longest job and maximum BMI has a significant effect on knee pain.

Taken together, the results help to explain a finding that seems, at first glance, surprising. Even as the share of workers in physically demanding jobs declined over time, pain related to physical demands increased. The data here suggest that pain caused by physically demanding jobs went up with the rise in obesity.

Robustness of the Results

We examined the robustness of the results in Table 4 in several ways. One concern is that people who have knee pain from other activities may be more likely to take physically demanding jobs. For example, people who play contact sports as youths may suffer more knee injuries and also pursue more physically demanding jobs. We test this by estimating the regression in column (5) of Table 4 for people aged 25-34, relating knee pain to current occupation. The results, shown in the appendix, show no significant or substantive relationship between knee pain and current occupation for the younger aged population.[20]

We have also estimated the relationship between job characteristics and knee pain at other periods of time. Both NHANES III (1988-94) and the 2010 and 2015 waves of NHIS have information on the individual's occupation in their longest job, which we match to the same job attributes.[21] We estimate models for these data sets similar to those in the continuous NHANES, with the exception that NHIS does not have information on maximum weight.

The coefficients on job attributes are similar across surveys. Relative to the coefficient on physical demands of 0.022 (0.009) in column (5) of Table 4, the coefficient in NHANES III is 0.033 (0.011) and the coefficient in NHIS is 0.037 (0.011). These coefficients are statistically different from zero and not statistically distinguishable from each other. Obesity also has a similar effect across surveys. Being morbidly obese at the time of the current survey (and thus at maximum BMI) raises the probability of having knee pain by 23 percentage points in the continuous NHANES, 31 percentage points in NHANES III, and 26 percentage points in NHIS.

A third robustness test includes other health conditions in the regression. Equations (1) and (2) omit conditions such as heart disease or cancer because they would not be expected to directly affect knee pain but might instead proxy for other factors, such as history of obesity, which we wish to capture directly. As a specification test, we added a series of dummy variables for self-reports of having been diagnosed with respiratory disease, coronary heart disease, congestive heart failure, stroke, cancer (divided into skin cancer and other cancers), thyroid disease, liver disease, diabetes, and osteoporosis. The appendix shows that controlling for these conditions increases the percent of the gradient in knee pain explained by both job-related physical demands and obesity—to 59% and 44% respectively. The regression also shows that almost all of these conditions affect

[20] The coefficient on physical job characteristics is -0.004 (0.012).
[21] We created appropriate cross-walks to the 1980 Census occupations to do so.

knee pain, including conditions for which there is no physiological relationship with knee pain. We thus believe that the more accurate model excludes additional health conditions.[22]

A fourth robustness test considers how physical demands and obesity affect other types of pain. Both physically demanding jobs and obesity should have a greater effect on weight-bearing joints (especially hips and knees) than non-weight bearing joints (for example, figures and wrists). Table 6 shows the education gradient in eight joints and two muscular areas: the lower back and neck. Panel A shows estimates of the impact of years of education on pain controlling only for demographics; panel B adds controls for obesity and job characteristics. The results for knee pain in the first column are the same as in Table 4 and are repeated for ease of comparison.

As panel A shows, there is an education gradient in every measure of musculoskeletal pain examined with the exception of toe pain. In panel B, both obesity and physical requirements on the job are related to pain in the way one would expect. Obesity has its greatest impact on weight-bearing joints in the lower body – hips, knees, and ankles, where it explains 19-36% of the education gradient in pain.[23] Obesity explains far less of the education gradient for pain in the toes, wrists, fingers, and neck, elbows, and shoulders, where obesity is expected to exert less physical strain. Physical demands on the job also have the largest explanatory power for knee and hip pain, explaining 40% and 57% of the education gradient. The absence of a relationship between physical demands and pain in the toes, wrists, fingers, and neck is also consistent with the theory. Physical demands have a significant effect on the education gradient in shoulder pain (26%) and elbow pain

[22] Some arthritis is due to inflammation. To examine differences in inflammation, we have run alternate regression models that included the level of C-reactive protein (a marker of inflammation), and also included the composition of the diet, specifically the amount of carbohydrates, proteins, and fats, which may be related to inflammation. None of these variables were statistically significant at the 5% level and including these variables had very little impact on the coefficients for obesity and job demands. Thus, they are not included in our final models.

[23] Somewhat surprisingly, obesity does not explain a large share of the education gradient in lower back pain. This may be related to the short-term nature of the back pain question, which is defined as pain in the lower back pain in the past 3 months that lasted a day or longer. Thus, much acute back pain is included along with chronic pain.

(26%), possibly because these jobs require more reaching and carrying objects.[24]

The final robustness test is to examine how knee pain changes with labor force exit. If physical demands on the job are related to joint pain, then joint pain for the less educated should ease when they are not working. We use the panel nature of the OAI to examine this. In each wave of the OAI, people report whether they are working for pay, doing unpaid work in a family business, not at work due to health reasons, and not at work for other reasons. Few people report unpaid work in a family business, so we include that with working for pay.

For people aged 45-64, we relate knee pain to labor force status interacted with education, allowing us to estimate whether labor force status has a differential effect on knee pain for different education groups. We control for knee pain in the prior year and its square, each of those interacted with education, to pick up any differential mean reversion in pain.[25] As in Table 2, we drop observations in the enrollment wave and first follow-up wave and also control for the demographic covariates in Table 2. The results, shown in Table 7, are strongly consistent with the theory. For all education groups, not working due to health reasons is associated with much higher knee pain. However, when people with a high school degree or less leave the labor force for reasons other than health, knee pain falls by a statistically significant 2 points. In contrast, when people with some college or college graduates leave the labor force for reasons other than health, knee pain is unaffected. Thus, a number of empirical tests suggest that the link between physical demands on the job and knee pain is causal and not just correlational.

[24] Jobs that involve routine work are associated with more wrist and finger pain. Of the two measures that make up routine work, the relationship with pain is entirely through the manual component (finger dexterity) as opposed to the cognitive component (situations requiring the precise attainment of set limits, tolerances, or standards). This is consistent with pain resulting from repetitive use of those joints.

[25] This mean reversion might be due to people with severe knee pain retiring from their job. The appendix shows that knee pain leads to somewhat greater increases in people not-in-the-labor force for non-health reasons among the less educated, but the difference is not major.

V. Psychological Correlates of Pain

In this section, we examine whether a worse mental outlook influences the development of knee pain. Some evidence suggests that there may be factors other than obesity and physical demands that influence knee pain. Table 6 shows that pain in many joints and musculoskeletal areas is correlated with obesity and job demands. However, this variation does not fully define the differences across people. We estimated a seemingly unrelated regression model for the 10 joint and musculoskeletal areas including the same variables in Table 6, allowing for correlated errors. The average correlation of the errors is 0.48. One natural hypothesis is that psychological attributes of individuals affect the experience of pain.

Unfortunately, cross-sectional data such as NHIS and NHANES do not enable measurement of psychological variables prior to pain onset; thus, we need other data to test the theory. We utilize data from the Midlife in the United States (MIDUS). MIDUS is a survey of individuals conducted to understand the aging process. The original sample was 7,000 people in 1995-96, spanning adult ages. Follow ups were conducted approximately one decade and two decades later, referred to as MIDUS 2 (2004-06) and MIDUS 3 (2013-14).

The first round of the survey did not ask any questions about knee pain but rounds 2 and 3 did. People were asked "Do you have chronic pain, that is do you have pain that persists beyond the time of normal healing and has lasted from anywhere from a few months to many years?" If so, people were asked which joint. We select people without knee pain in wave 2 and predict the onset of pain by wave 3. To avoid selective mortality with greater age, we restrict the sample to people aged 45-74 in wave 3 of the survey. The sample size is 1,784 people.

Parts of the MIDUS sample are non-random,[26] so some questions exist about the external

[26] Some of the enrollees were nationally random, while others were not: siblings of those enrolled randomly, people from certain cities in the country, and twins. As a result, there are no national weights in the survey.

validity of the survey. We can examine this in part by looking at other measures such as survival and onset of drug use. Among the sample without knee pain in wave 2, death is 3 percentage points lower among college graduates than among people with a high school degree and taking prescription painkillers without a prescription is 4 percentage points lower, consistent with other evidence on education and its relationship to mortality and misuse of prescription painkillers.[27]

Physiological, economic, and psychological measures come from wave 2 of the survey. MIDUS asks about current weight but not maximum weight; we include BMI in the second wave as a measure of obesity.[28] Physical demands on the job come from the question "how often does your [current or most recent job in the past 10 years] require a lot of physical effort?" The possible answers were all of the time, some of the time, most of the time, little of the time, never. We include the response as a series of dummy variables.

MIDUS contains a number of questions about psychological well-being, which we group into several areas. We describe the variables briefly here; the appendix has more detail along with summary statistics by education. The first measure is overall life satisfaction, scored on a 1 to 10 scale. People with more years of education report greater life satisfaction than people with fewer years of education. Positive and negative affect are based on a series of questions of the form, "During the past 30 days, how much of the time did you feel…" Among the domains are "cheerful" (positive aspect) and "so sad that nothing could cheer you up" (negative affect). People with more

[27] The finding about death controls for five-year age-sex interactions in the second wave, race, and being US born. The finding about opioid abuse controls for five-year age-sex interactions in the second wave, race, and being US born. The exact question is "The next questions are about the use of drugs or medications on your own. By "on your own" we mean either without a doctor's prescription, in larger amounts than prescribed, or for a longer period than prescribed. During the past 12 months did you ever use any of the following substances on your own?" The answer we analyze is "Analgesics or other prescription painkillers on your own (NOTE: this does not include normal use of aspirin, Tylenol without codeine, etc., but does include use of Tylenol with codeine and other prescribed painkillers like Demerol, Darvon, and Percodan)."

[28] We have also estimated models including as an independent variable weight in the first wave of the survey. This did not materially affect the results.

years of education report higher levels of positive affect and lower levels of negative affect.

There are several measures of a person's sense of control. A general control scale is formed from questions about personal mastery (e.g., "I can do just about anything I really set my mind to") and perceived constraints ("There is little I can do to change the important things in my life"). We also form a control scale for health care, using questions such as "Keeping healthy depends on things that I can do". Both general and health-related control are higher for people with more years of education.

The final variables measure psychological well-being in six dimensions: personal autonomy ("I have confidence in my opinions, even if they are contrary to the general consensus"), environmental mastery ("In general, I feel I am in charge of the situation in which I live"), personal growth ("For me, life has been a continuous process of learning, changing, and growth"), positive relations with others ("Maintaining close relationships has been difficult and frustrating for me"), purpose in life ("I live life one day at a time and don't really think about the future"), and self-acceptance ("When I look at the story of my life, I am pleased with how things have turned out"). All of these measures are higher for people with more years of education.

Table 8 shows the impact of obesity, physical requirements on the job, and psychosocial factors on the onset of knee pain. The first column includes education dummies and standard demographics: five-year age-sex dummy variables, dummy variables for race and ethnicity, and a dummy variable for being US born. Among people without knee pain at baseline, respondents with a college degree are 3.8 percentage points less likely to develop chronic knee pain in the next decade than are people with a high school degree or less. The second column includes physical demands on the job and wave 2 obesity categories. The coefficients of each are reported in the appendix. As the last rows of the table show, roughly 1/3 of the onset of knee pain is explained by physical demands on the job and another 1/3 by obesity. This is very similar to the estimates in the NHANES, even with a very different sample and estimation strategy.

The next columns add the psychological variables noted above, first individually (columns 3-6) and then as a group (column 7). Very few of these variables have a significant effect on the onset of knee pain, and when they do, the effect is modest. The strongest relationship is between negative affect and the onset of the pain. People who score one standard deviation higher on the negative affect scale are 3.9 percentage points more likely to report knee pain a decade after the affect was measured. However, differences in negative affect explain only 14% of the education gap in the onset of knee pain. Indeed, including all the psychological variables together explains only 11% of the education gradient in knee pain. Thus, a battery of psychosocial measures accounts for only a small share of the onset of knee pain.

Somatic Sensitivity

An alternative psychological hypothesis is that education is associated with pain because people with fewer years of education are more sensitive to painful stimuli than are people with more years of education. The response to painful stimuli differs across individuals. For example, when a person puts their hand into a bucket of ice water, their blood pressure rises. The extent to which blood pressure rises differs across individuals. It is possible that worse mental health, lack of sleep, or other challenges make stimuli more consequential for the less educated.

The MIDUS data provides one test of this hypothesis. In wave 2, people are asked several questions about their sensitivity to stimuli, including questions such as "I have a low tolerance for pain."[29] We combine a series of such variables into a somatic amplification scale. People with more years of education report less somatic amplification than do people with fewer years of education: for example, 32% of people with a high school degree or less agree that they have extremely or moderately low pain tolerance, compared to 27% of people with a college degree. The results of relating somatic amplification to the onset of knee pain is shown in column (8) of Table 8. There is no significant relationship between the two.

Other surveys have more objective measures of somatic sensitivity. We examine one such measure from the Coronary Artery Risk Development in Young Adults (CARDIA) study. CARDIA enrolled about 5,000 young adults at four sites in the mid-1980s. In the second wave of the study, enrollees were given three stressful tests: star tracing with a mirror image; playing the ATARI breakout game; and hand immersion in ice water for 45 seconds. Blood pressure was measured before, during, and after each test. The increase in blood pressure during the test is a measure of immediate response to stress and the degree to which blood pressure remains high after the test is a measure of prolonged response.[30]

Figure 9 shows the change in systolic blood pressure by education during and after each of the tests.[31] Even at young ages, people with more years of education have lower blood pressure than people with fewer years of education. However, the response to stressful tests is similar by education and if anything, slightly larger for the college graduates.[32] We thus find no evidence that physiological responses to stimuli differ by education.

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[29] The questions are: a) "I am often aware of various things happening within my body"; b) "Sudden loud noises really bother me"; c. "I hate to be too hot or too cold"; d) "I am quick to sense hunger contractions in my stomach"; e. "I have a low tolerance for pain". The somatic amplification scale is similar to a factor analysis of these questions.
[30] Blood pressure reactivity on these tests has been shown to correlate with the later development of hypertension (Matthews et al., 2004).
[31] The people were relatively young when given the test, between 20 and 32 years old. Thus, we relate reactivity to final education, which may have been realized after the test was administered. The results are similar examining diastolic blood pressure.
[32] These findings are also true controlling for age, race, and baseline blood pressure.

VI. Treatment of Musculoskeletal Pain

The final hypothesis we consider is that education is related to access to medical care, and differential access to care leads to differences in pain control. While differential access to medical care is an important consideration in many studies of socioeconomic status and health, pain treatment is likely an exception, as there are few effective treatments for pain. Still, it is worth considering the hypothesis in more detail.

To examine education differences in treatment empirically, we need an exogenous measure of access to treatment. We follow the methodology of McWilliams et al. (2007) and Card, Dobkin, and Maestas (2009) and use Medicare eligibility at age 65 as an instrument for access to care. Less educated people benefit more from reaching age 65 since they are less likely to be insured prior to age 65 and their pre-Medicare insurance is less generous on average. Thus, if differential access to medical care explains the education gradient in knee pain, the gap in treatment differences should narrow after age 65.

We test this using data from the Health and Retirement Study (HRS). Starting with the 1995 wave, respondents have been asked whether arthritis "sometimes limit[s] your usual activity."[33] Follow-up questions are then asked about what treatments people receive. For the population that reports limitations due to arthritis in any wave of the survey,[34] we consider what treatments people report receiving in the next wave, roughly two years in the future. We examine how these treatments change when people reach age 65, differentially for those with more and fewer years of education.

[33] Unfortunately, the HRS does not ask which joints are affected by arthritis. However, Figure 1 shows that the joints associated with pain are similar by education. Thus, one would not expect optimal treatments to vary greatly by education.
[34] People with a high school degree or less are 12 percentage points more likely to report being limited by arthritis than are higher SES people (controlling for age-sex, race, and Hispanic ethnicity, and year).

Figure 10 plots rates of arthritis treatment by education and age; the appendix shows regression discontinuity estimates. Outcomes for people with a high school degree or less are in the left column and outcomes for people with a college degree are in the right column. Panel (a) reports the share of people with health insurance by age. At age 65, insurance coverage rises more for the less educated (10 percentages points) than for the more educated (5 percentage points).

Panels (b)-(d) show the medical care outcomes for seeing a doctor, taking medication, and having joint surgery. In general, these rates are reasonably similar for the two education groups. Further, there is no jump in treatment for either group at age 65. Substantively, the change at age 65 is small, and statistically the estimates are indistinguishable from zero. Thus, we find no evidence that treatment for arthritis differentially increases for people with fewer years of education when they reach age 65.

One issue we cannot address with the HRS data is whether treatment quality varies by education. For example, the rate of knee replacement surgery may be similar for more and less educated people, but the quality of the surgeon may vary. However, other data suggest this is not likely to be materially important. Complication rates for hip and knee replacements are similar across hospitals with different rates of low income patients, with the exception that the quintile of hospitals with the fewest low income patients has lower complication rates than the remaining 80% (Thirukumaran et al., 2019). Overall, therefore, this evidence does not suggest that differential access to medical care explains the difference in knee pain by education.

VIII. Conclusion

Chronic knee pain differs greatly by education. Along with the chronic pain comes functional limitations, labor force withdrawal, and enrollment in disability insurance.

Understanding why education is so strongly related to pain is thus a key issue. We test four theories for the difference in pain by education. We find strong support for the idea that obesity and working in a physically demanding job explain differential rates of knee pain. Each of these are quantitatively important. Further, the two interact. Being in a physically demanding job matters more for knee pain when one has a history of obesity. In contrast, we find very little evidence that psychosocial factors or differential access to medical care explain the education gradient in knee pain.

We can use our results to make guesses about the future of knee pain and its associated disability. The most recent BLS forecasts of employment by occupation use data through 2016 and forecast through 2026. Matching employment forecasts with our measure of physical demands on the job, the data suggest that work-related physical demands are likely to rise modestly over the next decade.[35] While this seems surprising at first, the reason is the large projected growth in home health aides, personal care workers, janitors and cleaners, and construction laborers. All of these are physically intensive jobs.[36] Further, employment in many occupations that have relatively low physical demands—secretaries, for example—is expected to decline.

Obesity is more difficult to forecast. However, we have some information on obesity from the NHANES surveys. The share of people obese at their maximum weight has been rising over time. Among the population aged 45-74, the share of the population obese at maximum weight was 41% in 1988-94, 45% in 1999-2004, 48% in 2009-10, and 55% in 2015-16. The share is also higher for the less educated. Based on these trends, knee pain and associated impairments will likely continue to increase. Designing social policies to meet these needs is a key social priority.

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[35] The physical demands measure for the 2016 data is -0.162; the forecast for 2026 is -0.154.
[36] The demands of jobs requiring help to transfer people also increase with the obesity of patients.

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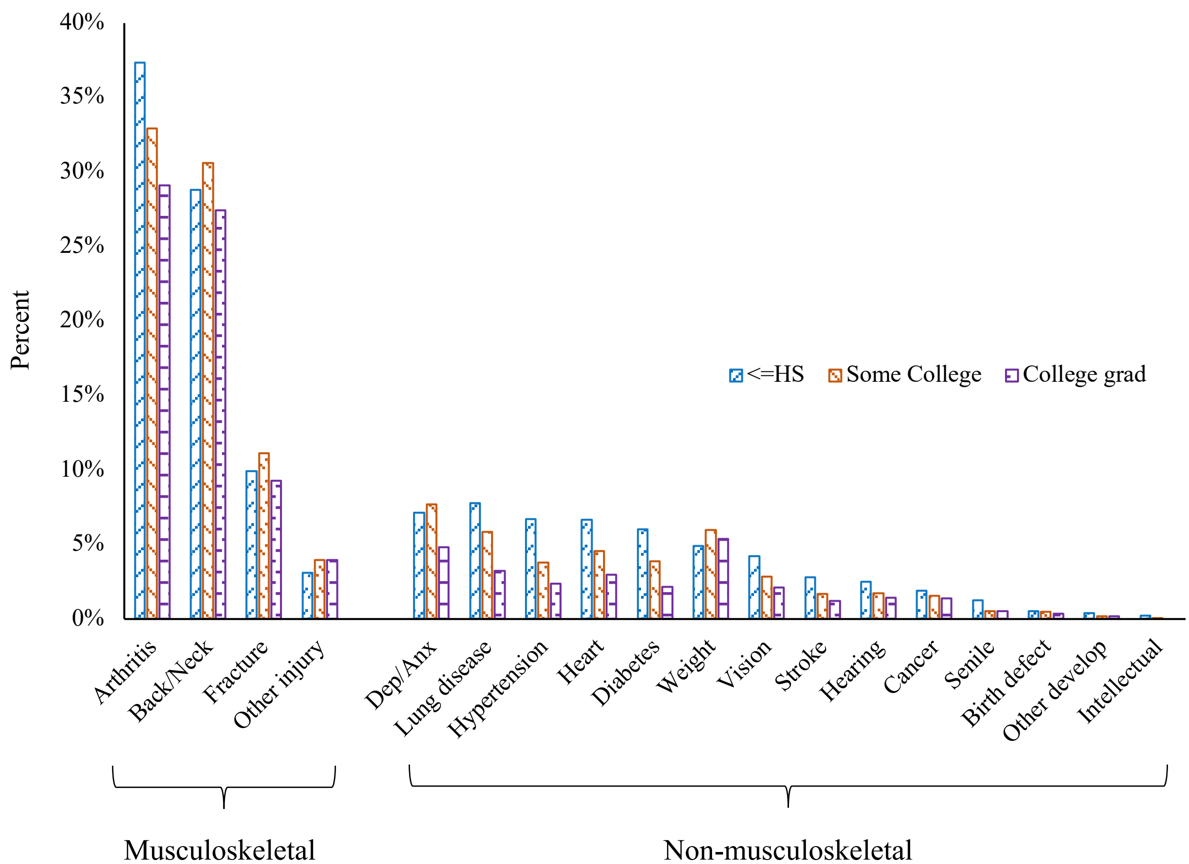
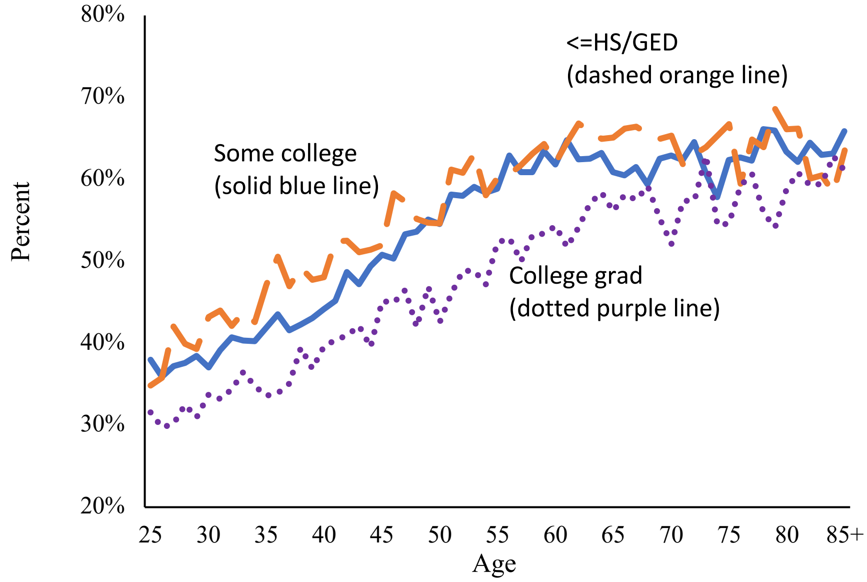
Figure 1: Reported Cause of Functional Limitations



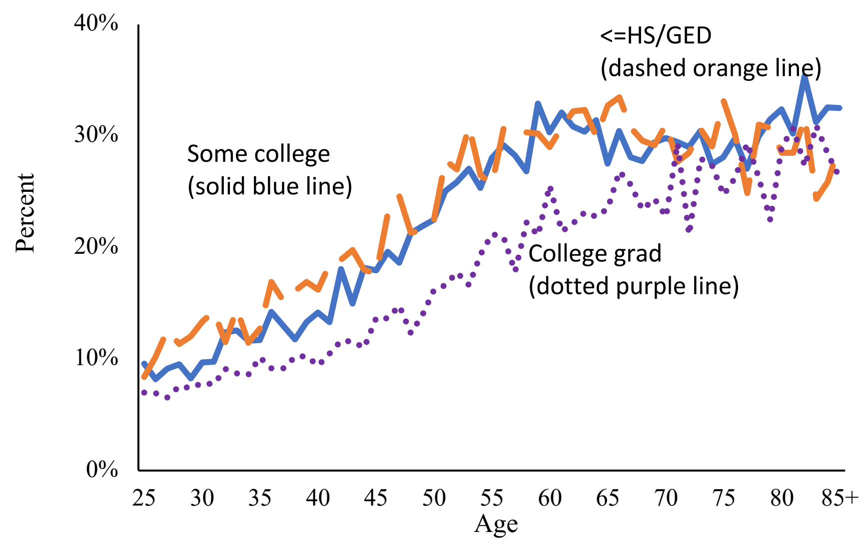
Note: Data are from the National Health Interview Survey, 2009-2016, and are weighted to be representative of the US population. The sample is people who report at least one functional limitation. People can select more than one cause. “Dep/Anx” stands for depression/anxiety. “Other develop” stands for other developmental difficulty, and Intellectual stands for intellectual disability.

Figure 2: Components of Pain by Education and Age

(a) Percent with Back, Neck, or Joint Pain

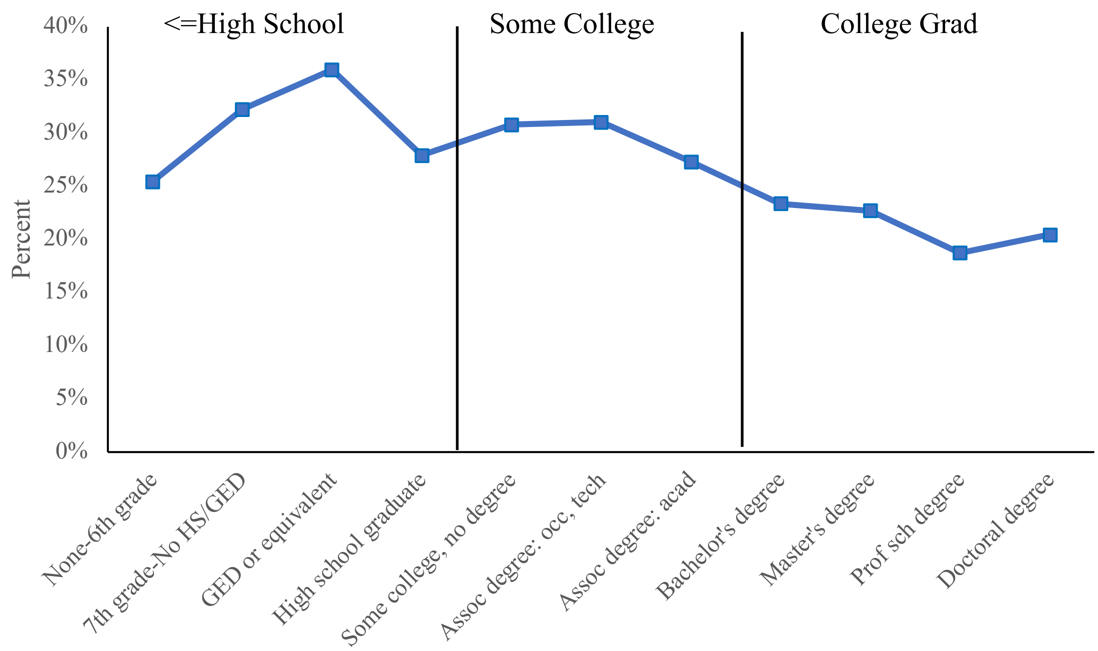


(b) Percent with Chronic Knee Pain



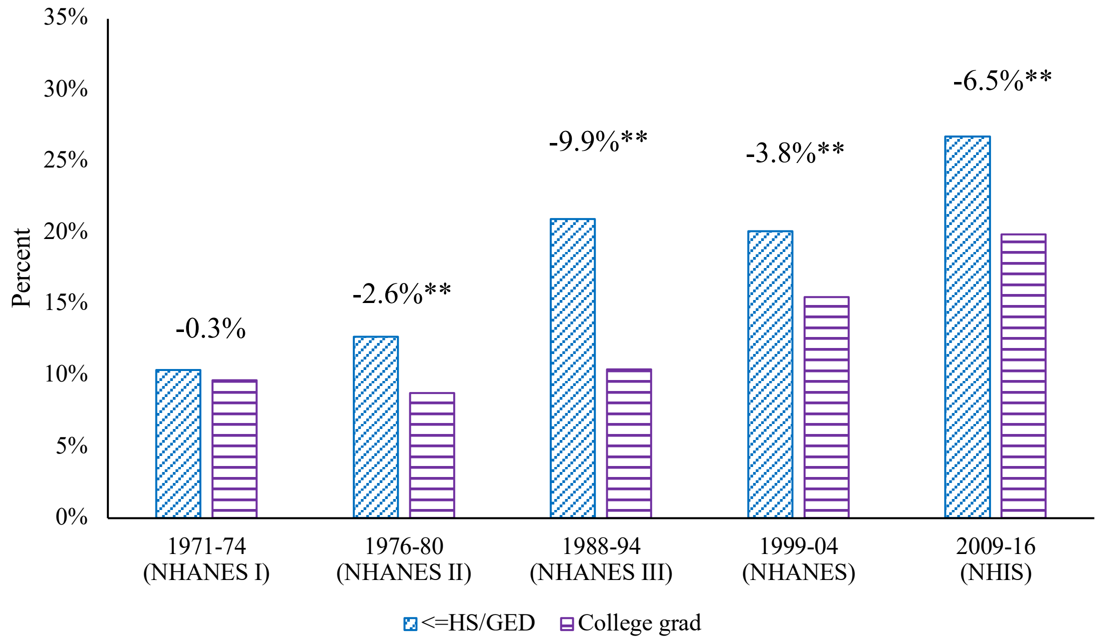
Note: Data are from the National Health Interview Survey, 2009-2016 and are weighted to be representative of the US population. Panel (a) shows symptoms of joint pain, aching, or stiffness in the past 30 days in either hip or knee, or neck or low back pain in the past three months. Panel (b) shows symptoms of joint pain, aching, or stiffness in the past 30 days that began at least three months prior.

Figure 3: Prevalence of Chronic Knee Pain by More Detailed Education Levels



Note: Data are from the National Health Interview Survey, 2009-2016, aged 45 and older, and are weighted to be representative of the US population. Education effects are adjusted for age and sex differences. Knee pain includes symptoms of joint pain, aching, or stiffness in the past 30 days in either knee, with an onset at least three months prior.

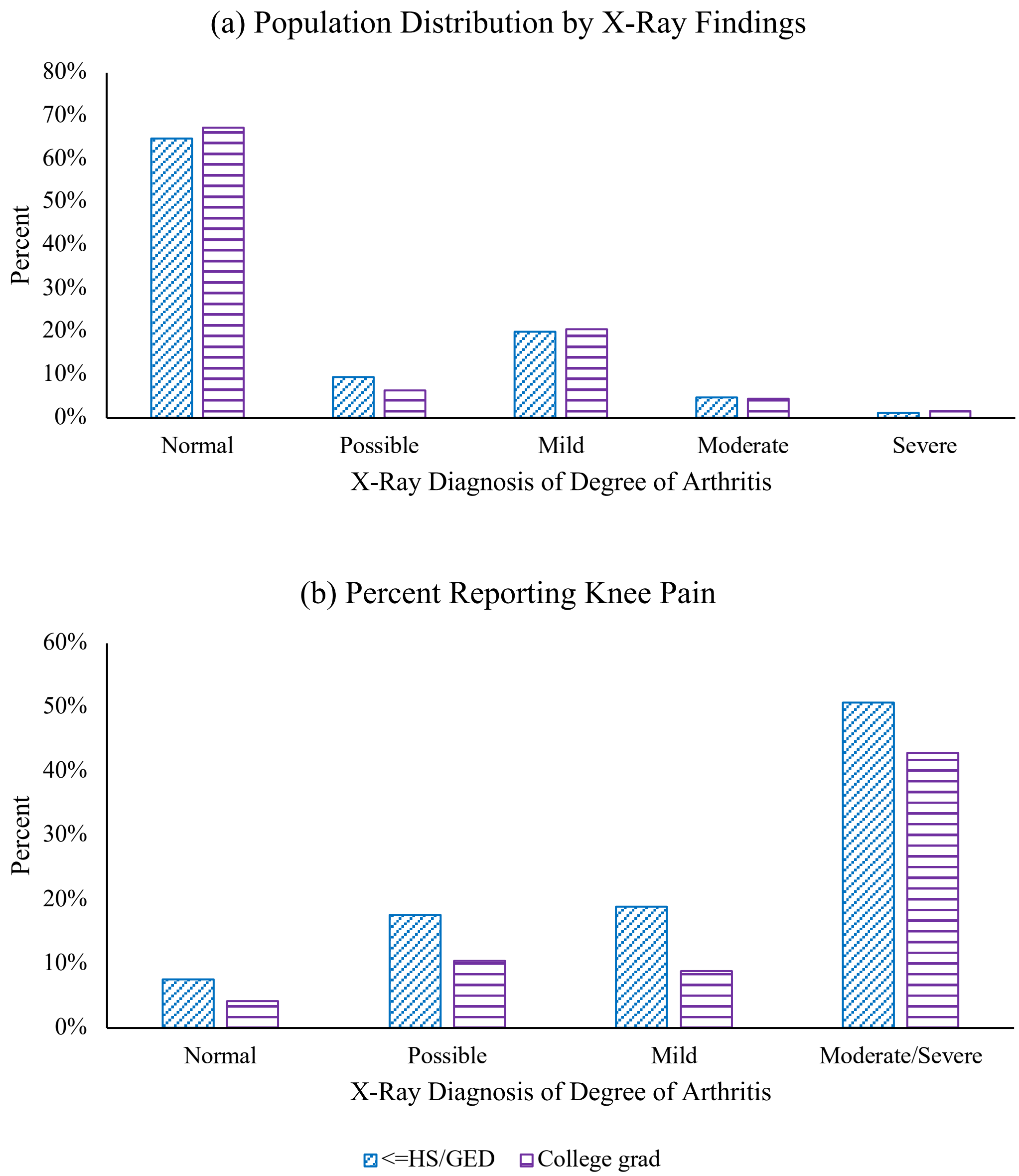
Figure 4: Percent of People Reporting Knee Pain, by Education and Time



Note: Data are from the NHANES I, NHANES II, NHANES III, continuous NHANES, and NHIS. Analyses are weighted to be representative of the US population. The sample is people aged 45-74 with the exception of NHANES III, where the sample is ages 60-74. Description of the data and question about knee pain are in Table 1. Data in each survey are weighted to reflect the age and sex distribution of the population in the 2009-16 NHANES. To account for missing data on younger ages in NHANES III, we assume that knee pain at ages 45-60 in NHANES III bears the same relationship to knee pain at ages 60-74 as in the NHIS.

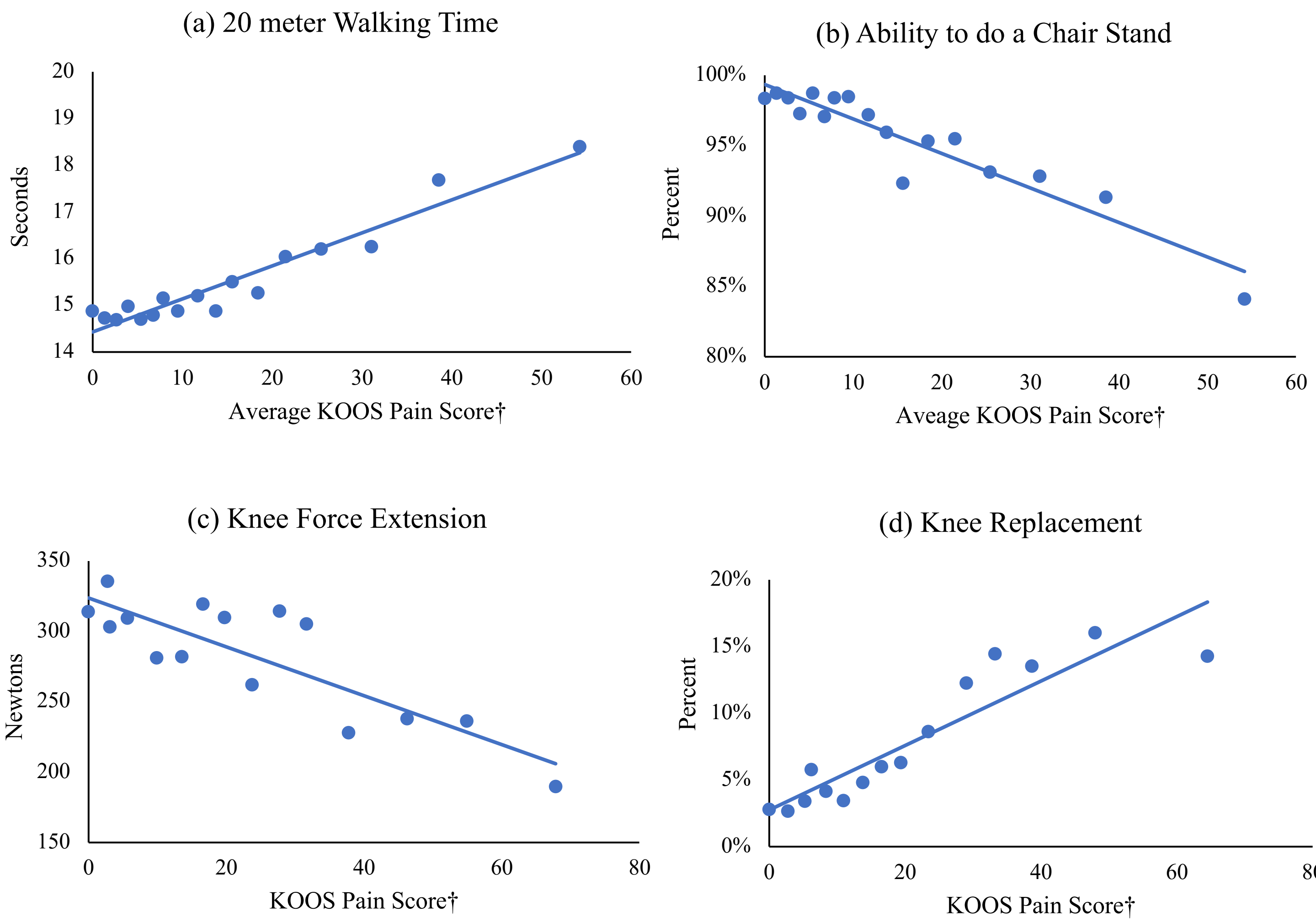
**(*) indicates that difference for between the <=HS/GED group and the college graduates is statistically significant at the 5% (10%) level.

Figure 5: Severity of Knee Arthritis and Pain Conditional on Arthritis



Note: Data are from the second phase of NHANES III, 1992-94, and are weighted to be representative of the US population. The sample is people aged 60-74 with both reports of knee pain and x-ray readings. Each observation is a knee.

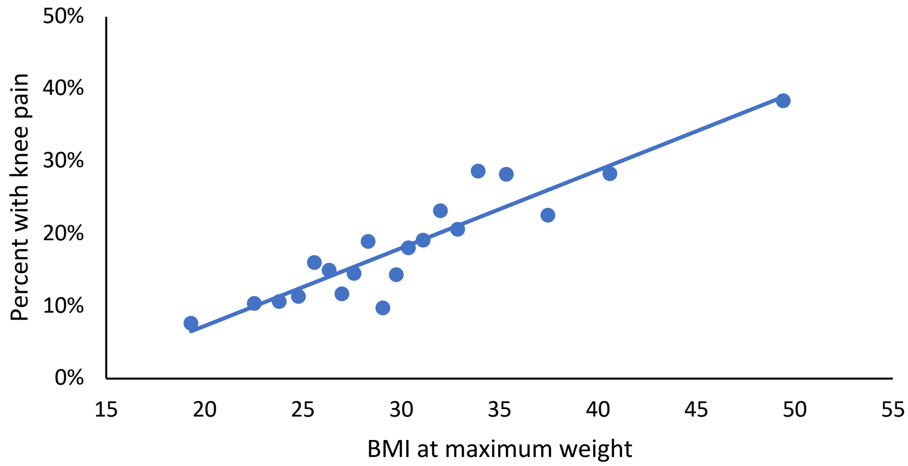
Figure 6: Relationship Between Knee Pain, Physical Performance, and Subsequent Medical Care



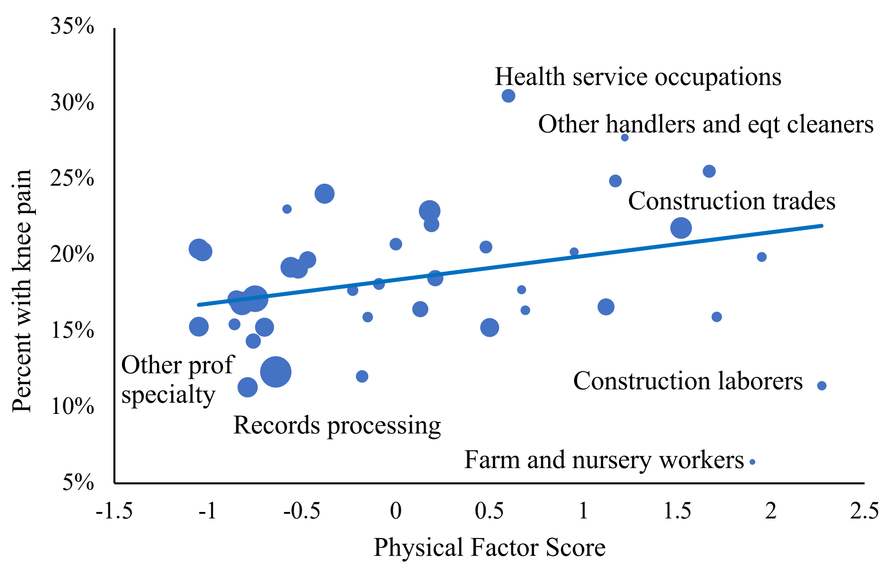
Note: Data are from the OsteoArthritis Initiative (OAI). In panels (a)-(c), performance measures and pain are taken from the second wave of the survey. Walking time is in seconds. Ability to do a chair stand is the percent of people who can stand from a chair with their arms crossed. Both are related to the average level of pain in the two knees. Maximum force at exertion is specific to the knee. In panel (d), knee replacement is at any time over the course of the survey and is related to pain score at enrollment.
† The KOOS score is subtracted from 100 so that 0 is no pain, and higher values correspond to more pain. The KOOS, the Knee Injury and Osteoarthritis Outcome Score, grades knee pain based on a 9-item questionnaire.

Figure 7: Relationship Between Knee Pain, Obesity, and Job Requirements

(a) BMI at Maximum Weight

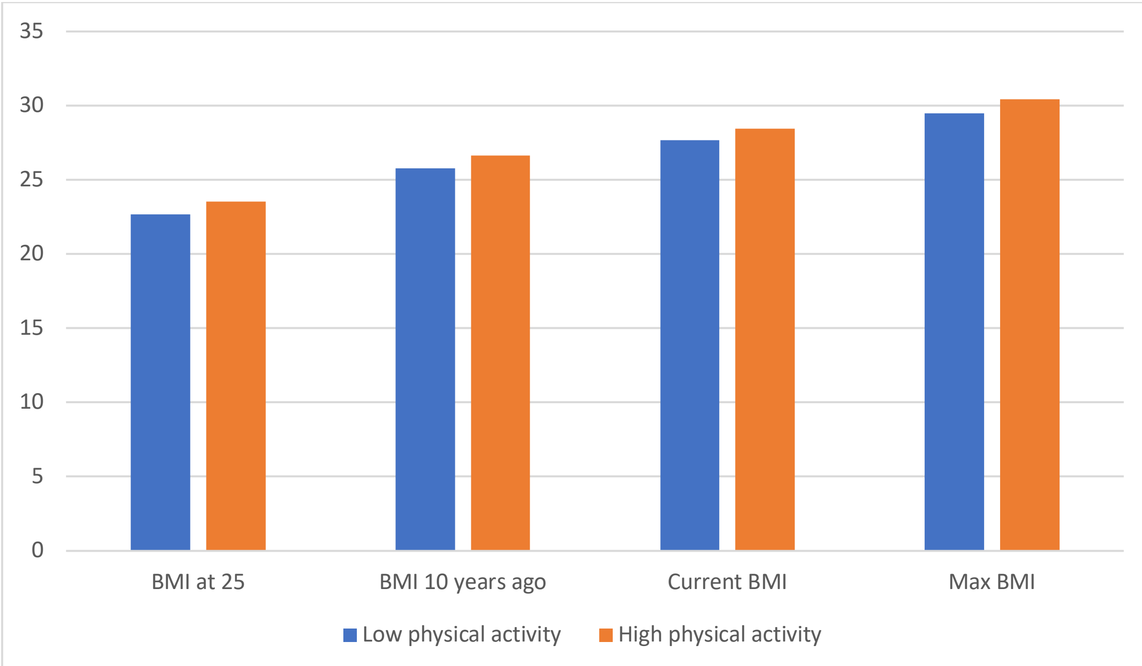


(b) Physical Requirements on Longest Job



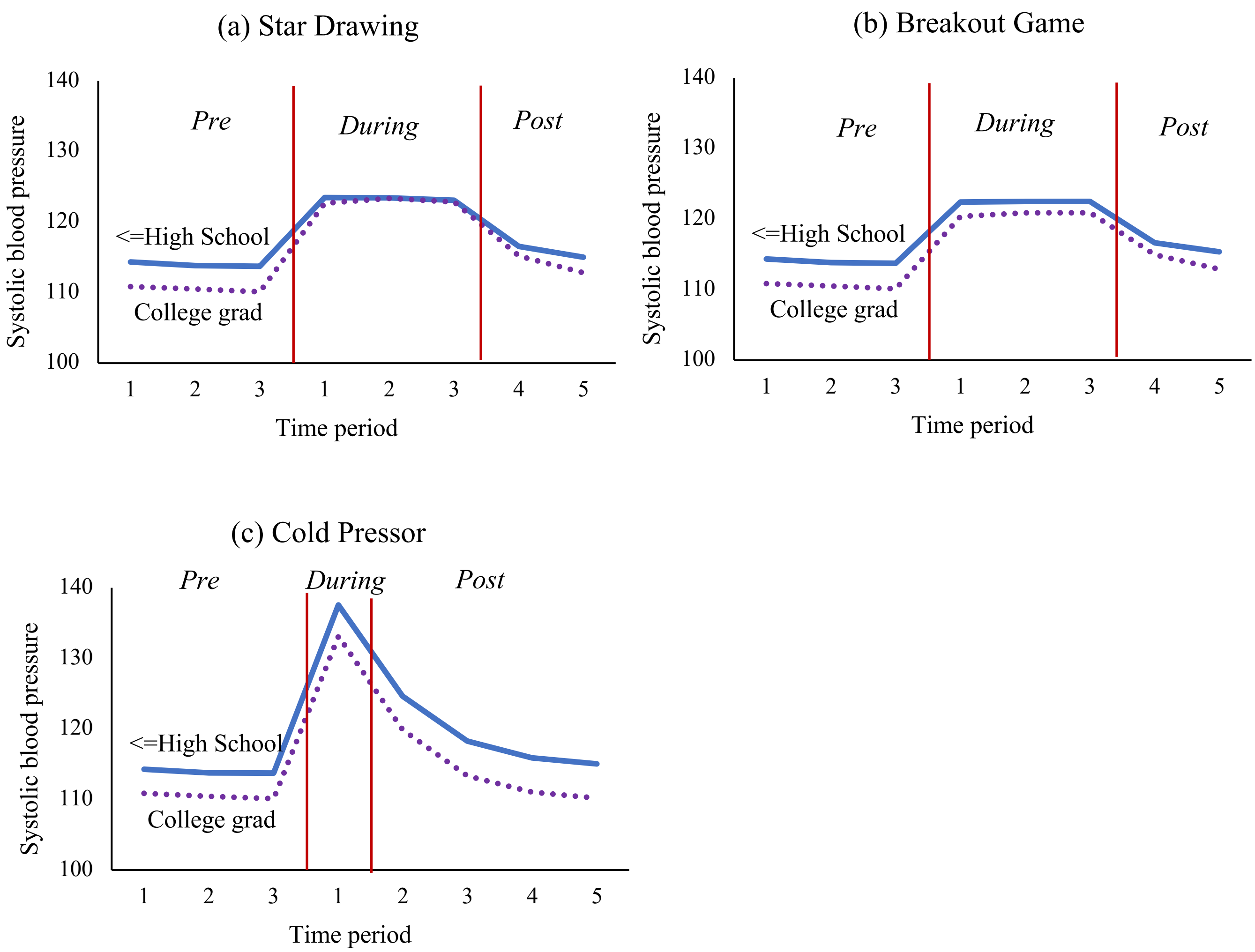
Note: Data are from the NHANES, 1999-2004, and are weighted to be representative of the US population. The sample is people aged 45-74. In panel (b), the physical factor is the first factor from a principal component model including strength requirements, reaching, climbing, and The four physical measures are: (1) a five point strength scale (sedentary, light, medium, heavy, very heavy); (2) the percent of workers engaged in climbing and/or balancing; (3) the percent engaged in stooping, kneeling, crouching, and or crawling; and (4) the percent engaged in reaching, handling, fingering, and/or feeling. Each circle is weighted by the population in the occupation.

Figure 8: Evolution of BMI by Age and Physical Activity on the Job



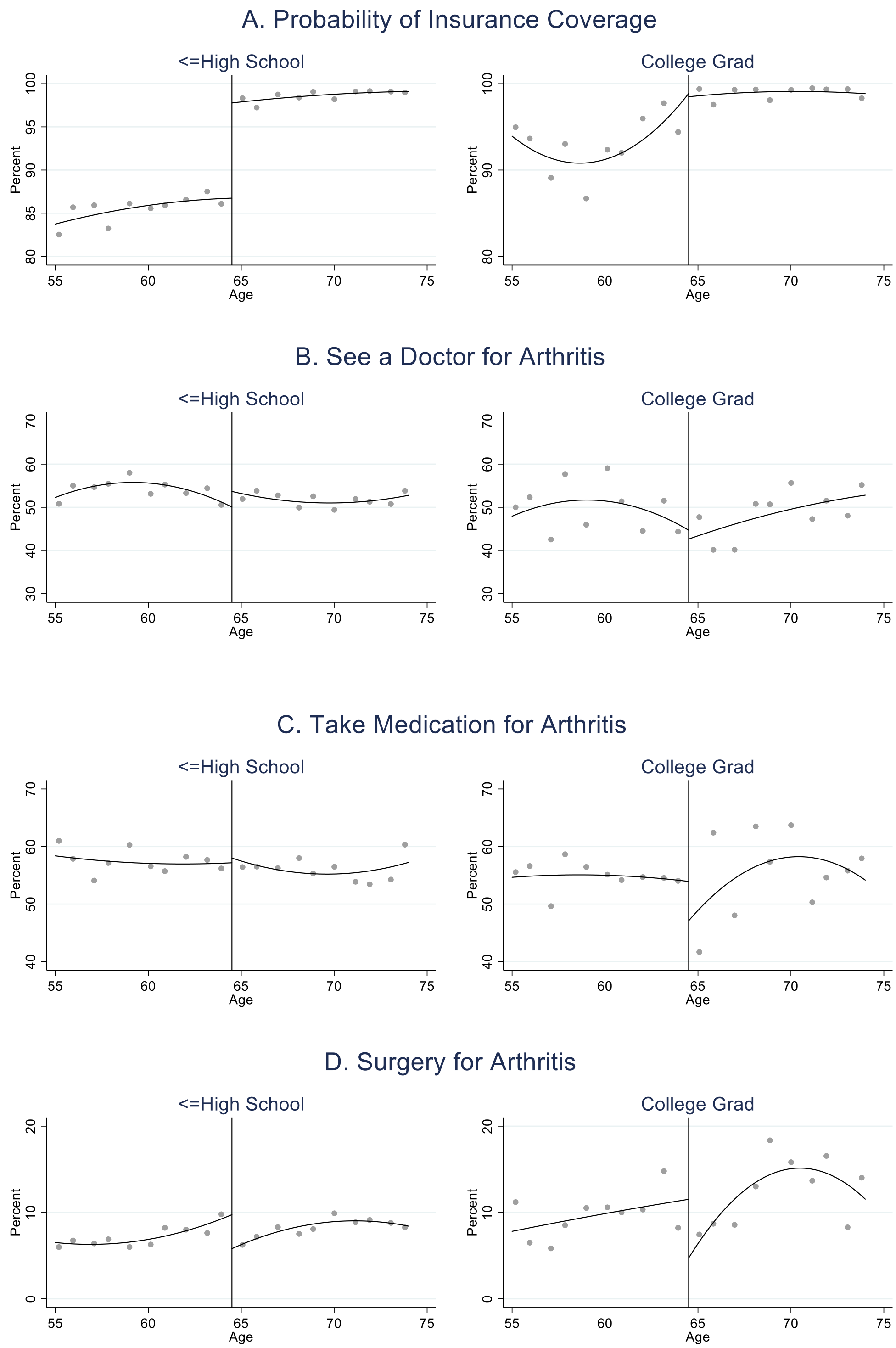
Note: Data are from the continuous NHANES, 1999-2004, and are weighted to be representative of the US population. Physical activity is based on factor score of physical demands on the job (split at median).

Figure 9: Blood Pressure Response to Stressor by Education



Note: Data are from the Coronary Artery Risk Development in Young Adults (CARDIA) study. Each observation is a blood pressure reading. The first values of 1-3 are before the test. The remaining values are during and after the test. All readings are systolic blood pressure.

Figure 10: Impact of Turning 65 on Arthritis Treatment



Note: The sample is people in the Health and Retirement Study, 1995-2014. Analyses are weighted to be representative of the US population. People are aged 51-74 and report that arthritis limited their activity in the prior wave. The line is a second order polynomial.

Table 1: Population Samples with Knee Pain Data

	NHANES I (1971-74)	NHANES II (1976-80)	NHANES III (1988-94)	NHANES (1999-04)	NHIS (2009-16)
Sample size (45-74)	4,104	6,549	6,227	6,371	106,999
Knee pain question	Pain most days in for at least 6 weeks	Pain or aching most days for at least 6 weeks	Pain, aching, or stiffness most days for at least 6 weeks	Pain, aching, stiffness, or swelling in past 12 months	Pain, aching, or stiffness in past 30 days, began at least 3 months ago
Percent with knee pain (ages 45-74)					
Unadjusted	10.1%	11.9%	---	18.3%	24.9%
Age-sex adjusted	10.1%	11.7%	---	18.8%	24.9%
Percent with knee pain (ages 60-74)					
Unadjusted	11.9%	13.5%	19.1%	20.8%	28.3%
Age-sex adjusted	11.7%	13.4%	19.0%	20.8%	28.3%
Percent obese (45-74) (age-sex adjusted)	18.6%	14.1%	28.0%	31.3%	33.0%
X-rays	Yes	---	1992-94	---	---
Occupation in longest job	---	---	40 categories	40 categories	93 categories

Note: The exact questions on knee pain are as follows. NHANES I: Yes to both of "Have you had pain in or around knee most days for at least one month?" and "Has the pain in knee area been present on any one occasion for at least six weeks?" NHANES II: "Have you had pain or aching in any joint other than the back or neck on most days for at least six weeks?" NHANES III: "Have you ever had pain in your knees on most days for at least 6 weeks? This also includes aching and stiffness." Continuous NHANES: "During the past 12 months, {have you/has SP} had pain, aching, stiffness or swelling in or around a joint?" NHIS: Yes to both of "Please do NOT include the back or neck. During the past 30 days, have you had any symptoms of pain, aching, or stiffness in or around a joint?" and "Did the joint symptoms begin more than 3 months ago?" Data are weighted to be representative of the US population.

Table 2: Impact of Imaging on Education Gradient in Knee Pain

	NHANES III (1992-94)		OsteoArthritis Initiative (2005)			
	Knee Pain (binary)		Knee Pain (Binary)		KOOS Pain Scale†	
Independent Variable	(1)	(2)	(3)	(4)	(5)	(6)
Education						
Some college	.042	.046	.012	.016	-2.10	-2.09
	(.036)	(.033)	(.035)	(.033)	(1.42)	(1.28)
College grad	-.073**	-.063**	-.067**	-.044*	-6.21**	-5.31**
	(.023)	(.021)	(.031)	(.029)	(1.23)	(1.09)
Imaging / observation controls	---	KL grade, crepitus, swelling, range of motion	---	KL grade, crepitus, cartilage, meniscus, bone marrow lesion	---	KL grade, crepitus, cartilage, meniscus, bone marrow lesion
Other controls	Age-sex, race, US born, veteran, side	Age-sex, race, US born, veteran, side	Age-sex, race, Hispanic, hear about survey, site, side	Age-sex, race, Hispanic, hear about survey, site, side	Age-sex, race, Hispanic, hear about survey, site, side	Age-sex, race, Hispanic, hear about survey, site, side
N	3,126	3,126	2,494	2,494	2,497	2,497
R^2	.024	.163	.035	.145	.068	.234
Change in coefficient on college grad	---	14%	---	34%	---	14%

Note: Each observation is a knee. Standard errors are clustered at the individual level. Columns (1) and (2) are from NHANES III, 1992-94, weighted to be representative of the US population. Columns (3)-(6) are from wave 1 of the Osteoarthritis initiative (the wave after enrollment). **(*) indicates that difference for between the <=HS/GED group and the college graduates is statistically significant at the 5% (10%) level.
† The KOOS score is subtracted from 100 so that 0 is no pain and a higher value corresponds to more pain. The KOOS, the Knee Injury and Osteoarthritis Outcome Score, grades knee pain based on a 9-item questionnaire. The average person reports a pain score of 13.5 with a standard deviation of 16.2.

Table 3: Correlation Among Job Attributes

	Measure			
	Physical demands	Abstract work	Routine work	Manual work
Physical demands	1.000			
Abstract work	-.440	1.000		
Routine work	.229	-.176	1.000	
Manual work	.613	-.241	.070	1.000

Note: Data are from the NHANES, 1999-2004. Analyses are weighted to be representative of the US population. The correlations are based on job characteristics from the 1977 Dictionary of Occupation Titles (DOT). The sample size is 495 occupations. Physical demands is the first principle component from a factor model using four measures of physical demands: a five-point strength scale; the share of workers engaged in climbing; the share engaged in reaching; and the share engaged in stooping. Abstract work, routine work, and manual work are as defined in Autor, Katz, and Kearney (2006) and Autor and Dorn (2013).

Table 4: Impact of Obesity and Job Attributes on Knee Pain

	Dependent variable: Pain in either knee				
Independent Variable	(1)	(2)	(3)	(4)	(5)
Education					
Some college	-0.008	0.003	-0.001	-0.005	0.001
	(0.012)	(0.012)	(0.012)	(0.012)	(0.012)
College graduate	-0.045**	-0.023*	-0.028*	-0.029**	-0.014
	(0.012)	(0.014)	(0.015)	(0.012)	(0.014)
Job attributes on longest job					
Physical demands	---	0.026**	0.023**	---	0.022**
		(0.007)	(0.009)		(0.009)
Abstract work	---	---	0.012	---	0.013*
			(0.008)		(0.008)
Routine work	---	---	0.012*	---	0.014**
			(0.006)		(0.006)
Manual work	---	---	0.010	---	0.008
			(0.008)		(0.008)
Current BMI					
Underweight	---	---	---	0.089	0.092*
				(0.055)	(0.055)
Overweight	---	---	---	-0.004	-0.003
				(0.016)	(0.016)
Obese	---	---	---	0.032	0.035
				(0.022)	(0.022)
Morbidly obese	---	---	---	0.132**	0.137**
				(0.029)	(0.029)
Maximum BMI					
Underweight	---	---	---	-0.106	-0.107
				(0.082)	(0.082)
Overweight	---	---	---	0.055**	0.055**
				(0.018)	(0.018)
Obese	---	---	---	0.117**	0.115**
				(0.022)	(0.022)
Morbidly obese	---	---	---	0.100**	0.095**
				(0.028)	(0.028)
N	6,366	6,366	6,366	6,366	6,366
R^2	.018	.021	.022	.049	.053
Change in coefficient on college grad	**---**	**49%**	**38%**	**36%**	**70%**
From physical demands	**---**	**48%**	**42%**	**---**	**40%**
From obesity	**---**	**---**	**---**	**36%**	**36%**

Note: Data are from the NHANES, 1999-2004. The sample is people aged 45-74. Analyses are weighted to be representative of the US population. Physical effort is the first principle component from a factor model using four measures of physical demands: a five-point strength scale; the share of workers engaged in climbing; the share engaged in reaching; and the share engaged in stooping. Abstract work, routine work, and manual work are as defined in Autor, Katz, and Kearney (2006) and Autor and Dorn (2013). All regressions control for five-year age-sex cells, race and ethnicity dummy variables, a dummy variable for veteran status, and a dummy variable for being US born. In columns 2, 3, and 5, dummy variables are included for whether the person's longest job was in the armed forces, was missing, and whether the person never worked. In columns 4-5, dummy variables are included for missing current BMI and missing maximum BMI. **(*) indicates statistically significant at the 5% (10%) level.

Table 5: Impact of Obesity and Job Attributes Interactions

Independent Variable	Dependent variable: Pain in either knee				
	Table 4 column (5)	(2)	(3)	(4)	(5)
Job attributes on longest job					
Physical demands	0.022**	0.011	0.018**	0.022**	0.022**
	(0.009)	(0.010)	(0.010)	(0.009)	(0.009)
Current BMI					
Obese	0.035	0.036	0.035	0.035	0.036
	(0.022)	(0.022)	(0.022)	(0.022)	(0.022)
Morbidly obese	0.137**	0.139**	0.137**	0.139**	0.137**
	(0.029)	(0.029)	(0.029)	(0.029)	(0.030)
Maximum BMI					
Obese	0.115**	0.117**	0.115**	0.121**	0.116**
	(0.022)	(0.022)	(0.022)	(0.023)	(0.023)
Morbidly obese	0.095**	0.096**	0.096**	0.101**	0.094**
	(0.028)	(0.028)	(0.028)	(0.029)	(0.031)
BMI at 25					
Obese	---	---	---	-.063**	---
				(.028)	
Morbidly obese	---	---	---	.074*	---
				(.041)	
BMI 10 years ago					
Obese	---	---	---	---	-.003
					(.021)
Morbidly obese	---	---	---	---	.005
					(.028)
Interactions of physical demands &					
Maximum BMI ≥ obese	---	.024**	---	---	---
		(.012)			
Current BMI ≥ obese	---	---	.012	---	---
			(.012)		
BMI at age 25 ≥ obese	---	---	---	-.002	---
				(.003)	
BMI 10 years ago ≥ obese	---	---	---	---	-.001
					(.015)
N	6,366	6,366	6,366	6,366	6,366
R^2	.053	.053	.053	.055	.053

Models and data are same as in Table 4 adding interactions for physical demands on the job with BMI. Dummies for underweight and overweight are included but not reported. In the interaction rows, physical demands is interacted with a dummy variable for being either obese or morbidly obese, using the definition of obesity indicated in the appropriate row. **(*) indicates statistically significant at the 5% (10%) level.

Table 6: Impact of Job Attributes and Obesity on Musculoskeletal Pain

	Joint Pain								Muscle Pain	
Independent variable	Knees	Hips	Ankles	Toes	Shoulders	Elbows	Wrists	Fingers	Lower back	Neck
Prevalence	18%	8%	10%	4%	13%	8%	8%	12%	40%	23%
					A. Demographics only					
College graduate	-0.045**	-0.024**	-0.059**	-0.006	-0.072**	-0.066**	-0.056**	-0.039**	-0.149**	-0.093**
	(0.012)	(0.009)	(0.010)	(0.006)	(0.011)	(0.009)	(0.008)	(0.010)	(0.016)	(0.013)
N	6,366	6,366	6,366	6,366	6,366	6,366	6,366	6,366	6,368	6,367
					B. Adding jobs and obesity					
College graduate	-0.014	-0.007	-0.039**	-0.004	-0.041**	-0.050**	-0.040**	-0.025**	-0.115**	-0.082**
	(0.014)	(0.010)	(0.011)	(0.007)	(0.013)	(0.010)	(0.010)	(0.012)	(0.018)	(0.016)
Job attributes										
Physical demands	0.022**	0.016**	0.007	-0.002	0.022**	0.020**	0.008	0.009	0.028**	0.006
	(0.009)	(0.006)	(0.007)	(0.004)	(0.008)	(0.006)	(0.006)	(0.007)	(0.011)	(0.009)
Abstract work	0.013*	0.001	0.001	0.002	-0.006	-0.004	-0.005	0.003	-0.003	-0.004
	(0.008)	(0.006)	(0.006)	(0.004)	(0.007)	(0.006)	(0.006)	(0.007)	(0.010)	(0.009)
Routine work	0.014**	0.006	-0.001	0.001	0.003	-0.008*	0.008*	0.011**	-0.005	-0.007
	(0.006)	(0.004)	(0.005)	(0.003)	(0.005)	(0.004)	(0.004)	(0.005)	(0.008)	(0.007)
Manual work	0.008	-0.012*	0.012*	0.010**	0.007	-0.009	-0.002	0.005	0.007	0.006
	(0.008)	(0.006)	(0.006)	(0.004)	(0.007)	(0.006)	(0.006)	(0.007)	(0.011)	(0.009)
N	6,366	6,366	6,366	6,366	6,366	6,366	6,366	6,366	6,368	6,367
Ch in coef on college grad	**70%**	**72%**	**34%**	**---**	**43%**	**24%**	**29%**	**38%**	**23%**	**12%**
From physical demands	**40%**	**57%**	**9%**	**---**	**26%**	**26%**	**12%**	**18%**	**16%**	**5%**
From obesity	**36%**	**25%**	**19%**	**---**	**7%**	**2%**	**6%**	**10%**	**6%**	**4%**

Note: Data are from the NHANES, 1999-2004. Analyses are weighted to be representative of the US population. The sample size is 6,366 for joint pain, 6,368 for lower back pain, and 6,367 for neck pain. Regressions include dummy variables for armed forces, no work, and missing work. **(*) indicates statistically significant at the 5% (10%) level. "Physical demands" is the first principle component from a factor model using four measures of physical demands: a five-point strength scale; the share of workers engaged in climbing; the share engaged in reaching; and the share engaged in stooping. Abstract work, routine work, and manual work are as defined in Autor, Katz, and Kearney (2006) and Autor and Dorn (2013).

Table 7: Impact of Labor Force Status on Knee Pain
[Dependent Variable: KOOS Pain Score†]

Independent Variable	Interaction with Education <=HS	Some college	College grad
Labor force status (relative to working)			
Not working due to health	5.25**	6.60**	3.52**
	(1.10)	(0.99)	(0.72)
Not working due to other reasons	-2.11**	0.23	0.22
	(0.86)	(0.48)	(0.27)
N		22,947	
R^2		.512	

Note: The sample is people in the OAI, all waves after the enrollment wave. Regressions also include education dummy variables, lagged knee pain in the relevant knee and its square, each interacted with education, age x sex dummy variables, and dummy variables for race and ethnicity, left/right knee, site, and wave. Standard errors are clustered by knee.

† The KOOS score is subtracted from 100 so that 0 is no pain and a higher value corresponds to more pain. The KOOS, the Knee Injury and Osteoarthritis Outcome Score, grades knee pain based on a 9-item questionnaire. The average person reports a pain score of 13.5 with a standard deviation of 16.2.

Table 8: Impact of Psychological Factors on Knee Pain

	Dependent variable: Onset of Knee Pain							
Independent Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Education								
Some college	-0.015	0.000	0.000	0.004	0.001	0.001	0.004	0.000
	(0.019)	(0.019)	(0.019)	(0.019)	(0.019)	(0.019)	(0.019)	(0.019)
College graduate	-0.038**	-0.009	-0.007	-0.005	-0.006	-0.006	-0.005	-0.008
	(0.017)	(0.018)	(0.018)	(0.018)	(0.018)	(0.018)	(0.018)	(0.018)
Physical effort on job	---	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Current BMI	---	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Psychosocial variables								
Life satisfaction	---	---	-0.009*	---	---	---	-0.004	---
			(0.005)				(0.006)	
Affect								
Positive affect	---	---	---	-0.003	---	---	-0.006	---
				(0.012)			(0.014)	
Negative affect	---	---	---	0.039**	---	---	0.043**	---
				(0.017)			(0.018)	
Sense of control								
Overall	---	---	---	---	-0.014*	---	-0.008	---
					(0.008)		(0.011)	
Health – self	---	---	---	---	0.004	---	0.005	---
					(0.009)		(0.009)	
Psychological well-being[a]	---	---	---	---	---	[.899]	[.914]	---
Somatic amplification	---	---	---	---	---	---	---	0.014
								(0.013)
N	1,784	1,784	1,784	1,784	1,784	1,784	1,784	1,784
R^2	.016	.050	.053	.056	.052	.051	.059	.051
Change in coefficient on college grad	**---**	**77%**	**81%**	**88%**	**83%**	**84%**	**87%**	**79%**
From phys. demands	**---**	**39%**	**37%**	**35%**	**36%**	**37%**	**35%**	**38%**
From obesity	**---**	**38%**	**37%**	**37%**	**37%**	**37%**	**37%**	**38%**
From psych. var(s)	**---**	**---**	**3%**	**14%**	**10%**	**8%**	**11%**	**4%**

Note: Data are from MIDUS. The sample is people aged 45-74 in the third wave who reported no knee pain in the second wave. All regressions control for five-year age-sex cells, race and ethnicity dummy variables, a dummy variable for being US born, and dummy variables for missing or refused answers.

[a] The psychological well-being variables include measures of autonomy, environmental mastery, personal growth, positive relations with others, purpose in life, and self-acceptance. Somatic amplification is the average of five question, for example agreement that the person has a low tolerance for pain. Tables A6 and A7 have definitions and means for all of the variables. The value in [.] in the psychological well-being row is the p-value for the hypothesis test that the psychological well-being variables are jointly zero.

**(*) indicates statistically significant at the 5% (10%) level.