Published in final edited form as:

Diabetes Res Clin Pract. 2011 March ; 91(3): 413–423. doi:10.1016/j.diabres.2010.12.003.

Diabetes-Related Change in Physical Disability from Midlife to Older Adulthood: Evidence from 1996-2003 Survey of Health and Living Status of the Elderly in Taiwan

Ching-Ju Chiu, PhD¹, Linda A. Wray, PhD¹, and Mary Beth Ofstedal, PhD²

¹Department of Biobehavioral Health, College of Health and Human Development, The Pennsylvania State University, University Park, PA

²Survey Research Center, University of Michigan, Ann Arbor, MI

Abstract

One in five older adults in Taiwan have been diagnosed with diabetes. This study drew on disability data for 5,121 nationally representative middle-aged and older adults from the 1996-2003 Survey of Health and Living Status of the Elderly in Taiwan (SHLSET). By employing cohort sequential design and multilevel models, it combined cross-sectional and longitudinal evidence to characterize the age trajectory of physical disability from midlife to older adulthood and to discern the extent to which diabetes contributes to the variation in that trajectory. The main effects of diabetes and diabetes $\times$ age interaction in the fully controlled model provide evidence that diabetes independently and consistently changes physical functioning over and above natural aging processes in Taiwanese adults. In addition, while adding diabetes in the age trajectory of physical disability explained 3.2% and 1.6% of the variance in levels of and linear changes in physical disability trajectory, respectively, further adding follow-up status, sociodemographic factors and comorbidities altogether explained 40.5% and 29.1% of the variance in levels of and linear changes in that trajectory. These results imply that preventing the incidence of diabetes-related comorbidities may reduce the deterioration in both levels of and rates of change in physical disability.

Keywords

Cohort-sequential design (accelerated longitudinal design); Multilevel modeling; Taiwan elders; Diabetes

Introduction

Diabetes is the fifth leading cause of death in Taiwan. Currently, adults with diabetes comprise approximately 20% of the population aged 65 and above in Taiwan [1,2]. Adults aged 65 and over currently represent 10.4% of the overall population in Taiwan, with that proportion projected to increase to over 20% by 2030 [3,4]. Because it is generally accepted

Correspondence to Ching-Ju Chiu, PhD, Department of Biobehavioral Health, 315 HHD East, The Pennsylvania State University, University Park, PA 16802. Telephone: 814-865-0773; Fax: 814-863-7525; cuc197@psu.edu.

Publisher's Disclaimer: This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final citable form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

Disclosure None of the authors has a conflict of interest associated with this study.

that the most important demographic change relating to future diabetes prevalence is the increase in the proportion of people >65 years of age [5], the growth in the number of older persons in Taiwan portends a considerable health care challenge in that country.

Diabetes has been linked to many serious complications, such as microvascular and macrovascular diseases, and thus it is presumable that a diagnosis of diabetes may be associated with a higher risk of physical disability. Although an increasing number of studies has supported this hypothesis [6-11], most of the existing evidence is based on Western data; it is less clear that the same relationship between diabetes and disability exists in non-Western countries. As an Asian country, Taiwan differs from Western countries in many biobehavioral (e.g., body fat composition, diet habit, leisure time activities) and social (e.g., health care system) dimensions that directly affect the health of older adults [12-15]. Thus, it is possible that the impact of diabetes on physical function may show differential pattern in Taiwan. For example, due to its universal health care system, Taiwanese adults with diabetes may have better access to earlier diagnoses and subsequent diabetes care and, thus, experience fewer and less severe adverse effects resulting from their diabetes.

In addition, it has long been supported in many U.S. and Western studies that women, as well as adults who are members of non-majority racial/ethnic minority groups and those with lower education tend to have poorer physical function [16-19] and worse diabetes management [20-26] than do their counterparts. Whether membership in these social groups further moderates the impact of diabetes on physical disability, however, remains unknown. Understanding the role that diabetes plays in physical disability from midlife to older age across sociodemographic backgrounds in Taiwan may provide important information in assessing the generalizability of commonly held diabetes management guidelines, and may also provide information for assessing needs in sub-groups within the country.

To provide detailed information on the effects of diabetes on disability in Taiwan, three main questions were addressed in the present study: (1) Does diabetes predict individual differences in levels of and rates of change in physical disability trajectories? (2) Does diabetes impose the same adverse effect from midlife to older age? (3) Can the disability trajectory differences in adults with and without diabetes be explained and/or moderated by sociodemographic background? These questions were answered by analyzing physical disability data over a 7-year period (1996-2003) in the Survey of Health and Living Status of the Elderly in Taiwan (SHLSET). The accelerated longitudinal nature (also called a cohort-sequential design) [27-30] of this dataset enables us to piece together the longer-term change patterns from shorter-term change in people who are at different ages at the beginning. Specifically, we are able to reasonably approximate age-related changes from age 51 to about 100 with data on changes in the broad age-range participants (eight five-year birth cohorts) during the seven-year observation period without having to follow a sample of persons age 51 for several decades. In addition, instead of arbitrarily assuming a common developmental trend across cohorts, we used a cohort convergence test to determine the best model for the trajectory. Our final model bringing age cohort heterogeneity to bear on the long-term trajectories enriches our research quality by providing both cross-sectional and longitudinal perspectives.

Methods

Sample and design

Our data are drawn from the Survey of Health and Living Status of the Elderly in Taiwan (SHLSET, 1996-2003). Fielded in 1989, this nationally representative survey aims to trace longitudinal changes in health, behavioral, financial, and emotional well-being of middle-aged and older adults in Taiwan. The survey was jointly conducted by the Taiwan National

Institute of Family Planning (now the Bureau of Health Promotion) and the Population Studies Center at the University of Michigan. The sampling frame for the SHLSET is the Taiwan Household Register, which includes people living in institutions as well as in the community. As a result, unlike many surveys of older adults that take their sample from only community-dwellers, the SHLSET is representative of the entire older population in Taiwan. At the first wave of data collection in 1989, a nationally representative sample of 4,412 adults aged 60 and older (born in 1929 or earlier) was selected, and 4,049 individuals were successfully interviewed (response rate=92%). Those who moved from the community to an institution were also traced during follow-ups [31]. In the second wave of data collection conducted in 1993, reinterviews were attempted with the 3,467 participants who survived from the 1989 interview. Among them, 3,155 completed the survey (response rate=91%). In the third wave, conducted in 1996, reinterviews were completed with 2,669 of the 3,002 survivors from the 1989 survey (response rate=89%). In addition, a nationally representative sample of individuals born in 1930-1945 were interviewed in 1996 to replenish the younger part of the age distribution of respondents ($N=2,462$, response rate 81%). As a result, the SHLSET sample in 1996 was representative of the entire Taiwan population aged 50 or over living in the community or in an institution ($N=5,131$). The response rates of follow-ups interviews were very high: Of the 4,646 survivors in 1996, 4,287 completed the follow-up interview (response rate among survivors= 92%), and of the 3911 survivors in 2003, 3650 completed their interview, with a 93% response rate among survivors.

Given that the focus in this study was to examine changes in physical functioning from midlife to older adulthood for adults with and without diabetes, this study utilized data on participants aged 50 or above who had answered questions on their diabetes status in the 1996 SHLSET, yielding an eligible sample size of 5,121. The responding sample sizes were 4,440 in 1999 and 3,778 in 2003. A detailed description of our sample is illustrated in Appendix A.

In order to draw on the advantages of the cohort-sequential design, which links adjacent and overlapping segments of available longitudinal data from different age cohorts, we categorized participants into eight cohorts based on their baseline age: 51-55, 56-60, 61-65, 66-70, 71-75, 76-80, 81-85, and 86 and above. Thus, with the seven-year follow-up, cohort 1 contributes to the estimation of longitudinal change from ages 51-62; cohort 2 contributes to the estimation from ages 56 to 67; and similarly, cohort 3, ages 61-73; cohort 4, ages 66-77; cohort 5, ages 71-82; cohort 6, ages 76-87; cohort 7, ages 81-92; and cohort 8, ages 86-104. The sample size for each cohort ranged from $n=101$ for cohort 1 to $n=1,092$ for cohort 5.

Measures

The independent variable of primary interest—diabetes—was obtained by self-report as measured in 1996. In 1996, there were 581 (11.4%) adults who reported having been diagnosed with diabetes, and 4,540 who reported no diabetes. We investigated physical disability trajectories, including levels of and rates of change, for the two groups based on their physical disability scores measured in 1996, 1999, and 2003. A total of 183 and 218 persons reported incident diabetes in 1999 and 2003, respectively. These respondents were treated as not having diabetes in our models and were retained in the analysis through the wave immediately prior to when they first reported diabetes. For example, data from the 1996 wave was used for those who first reported diabetes in 1999, and data from both 1996 and 1999 was used for those first reporting diabetes in 2003. We opted not to exclude these respondents because they contribute to the information on levels of physical disability for the non-diabetic adults.

The dependent variable, physical disability, was measured with the modified Katz Activities of Daily Living (ADL) scale [32], the Lawton Instrumental Activities of Daily Living

(IADL) scale [33], and Nagi strength and mobility activities [34]. In general, the Katz (ADL) scale concerns the most basic personal care tasks, whereas the Lawton (IADL) and Nagi (strength and mobility) items require greater physical activity. Participants in the SHLSET were asked at each wave if they had any difficulty performing each of a number of different tasks, including ADLs (bathing, dressing, eating, walking across a room, getting in/out of bed, and using a toilet independently), IADLs (preparing meals, shopping, managing money, using the telephone, and taking public transportations independently), and strength and mobility activities (walking several blocks, climbing several flights of stairs, stooping/kneeling/ or crouching, reaching above the head, and lifting or carrying weights over 10 pounds like a heavy bag of groceries). Respondents who reported that they had difficulty or were unable to do the task, or that they received help or used equipment when performing the task were coded as having difficulty with the task (1=yes, 0=no). Because the present study aims to identify the effect of diabetes on overall disability, summing the three scales into one score has the merits of capturing a broad range of physical disabilities and preventing any floor or ceiling effects [8,35]. This type of summary measure that combines the three domains has been widely used in previous studies [36-38] and has been shown to have good validity with regard to capturing hierarchical levels of physical disability [39]. The average internal consistency of the sixteen items across all waves was .89.

The variable for age measures the respondent's age at the time of each interview wave and is represented as a continuous variable, centering on the grand mean or median age in the analyses (depending on the model). Three time-invariant variables were also included in our models: gender, education and ethnicity. Gender is represented as a dummy variable in the models, with men serving as the reference group. Ethnicity was categorized into three groups (Fukienese, Mainlanders, Hakka and others) with Mainlanders, a social group that is not the majority in terms of numbers but tends to be more economically advantaged than are the Fukienese and Hakka [40-42], as the reference group. Education was categorized at three levels (low=0 years of formal education, medium=1-6 years of formal education, high=7 or above years of formal education) with high education as the reference group.

Six diabetes-related chronic conditions, suggested by their significant association with self-reported diabetes in chi-square tests, were included as time-varying covariates: high blood pressure, cancer, lung disease, heart disease, stroke, and arthritis. A dichotomous measure for each condition was obtained.

Statistical analyses

Two-level multilevel modeling (MLM) using the SAS Proc Mixed procedure was used. MLM has two major advantages in relation to the data being analyzed here. First, MLM is flexible in accommodating an unbalanced research design (i.e., the number and spacing of time points may differ across participants) [43]. Such flexibility ensures participants who missed one or more measurement points during the follow-up period to be included in the analyses. In addition, the flexibility enables us to bring multiple over-lapping cohorts into the model and to test the significance of cohort effects on the age trajectory [28]. Second, MLM can incorporate randomly varying effects of time-varying covariates. Such capability enables us to efficiently control for the time-varying covariates when studying the independent effect of diabetes on the levels of physical disability and on changes in the physical disability trajectory.

Our analyses proceeded in three stages. First, to describe the most accurate form (shape) of intra-individual change in physical disability from midlife to older adulthood, a two-level model with both age and cohort effects was employed (it will be called the *full* model in the next stage of analysis). In level 1 of the model, each person's observed physical disability score was conceived as a polynomial function of age (centering at the median age of each

cohort) plus random error. In level 2 of the model, these individual coefficients were assumed to vary as a function of the cohort plus person-specific random effects.

In the second stage, we tested if a parsimonious model (i.e., *reduced* model), which uses a common trajectory to describe change in all cohorts (i.e., ignoring the cohort effect), was tenable in describing physical disability trajectory from midlife to older adulthood. A cohort convergence test suggested by Miyazaki and Raudenbush [28] compared the reduced model to the best-shaped full model determined at the last stage of analysis, based on the likelihood-ratio test.

Finally, in the third stage, we tested the impact of diabetes on the average level of and change in physical disability. Five models were examined in this stage. Model 1 (the diabetes model) tested if the physical disability trajectories for adults with diabetes differed significantly from those without diabetes. This model was performed by adding baseline diabetes status in level 2 into either the full (1) or reduced model (2), depending on the results in stage two. Then in Models 2 to 4 (the diabetes and covariates models), we tested the moderating effects of gender, ethnicity, and education by adding interaction terms at the level 2 model. In Model 5, we tested if diabetes, net of mortality-related attrition, time-invariant demographics, and time-varying chronic health conditions, had a unique impact on the physical disability trajectory by adding the attrition variable and time-invariant demographic covariates in level 2, as well as time-varying chronic conditions at level 1.

The multilevel models were estimated with an unstructured covariance matrix for the random effects, and assumed a Gaussian distribution of the outcome. Although the composition of the sixteen items for assessing disability avoids a floor effect, the presence of skewness in the physical disability score can pose a threat to the estimation of standard errors. To assess the extent to which this is a problem, we estimated alternate models with square root transformations of the physical disability score. These alternate models yielded the same substantive results. Accordingly, the results presented below are from the model using the original summed score.

Results

Sample characteristics and association with physical disability

Table 1 presents the sample characteristics as well as their associations with baseline physical disability. The mean age of the sample was 66.2 years ($SD=9.5$); 46.2% were women; 67.2% were Fukienese, 15.1% were Hakka, and 17.8% were Mainlander. Diabetes was present in 11.4% of the sample. Baseline physical disability was higher in women than in men, in people with lower education than in those with higher educational levels, and in respondents who reported chronic conditions than in those free of chronic conditions. The age cohort provided the cross-sectional evidence that there is a trend toward increased disability as individuals age. For example, the average levels of physical disability in adults aged 51-55 (cohort 1) was 0.39, and was 1.16, 2.16, and 5.26 in adults aged 61-65 (cohort 3), 71-75 (cohort 5), and 81-85 (cohort 7), respectively.

Shape of physical disability trajectories from midlife to older adulthood

We examined the intercept only (unconditional), linear, quadratic, and cubic growth curve models to determine which best characterized the age trajectory of physical disability from midlife to older adulthood. Overall, fitting physical disability as a function of age (centered at the median age of each cohort), while controlling for cohort effects, accounts for a meaningful amount of variation across individuals. This was indicated by a substantial decrease in the deviance score ($-2LL$) from the unconditional model to the linear model ($X^2_{(19)}=3,303, p<.001$). The result that adding a cubic function of age did not significantly

improve the model fit ($X^2_{(9)}=7, p=.64$) suggests that a quadratic function may best characterize the physical disability trajectory from midlife to older adulthood. Figure 1 presents the sample raw mean versus age trajectory of physical disability based on our sample.

The best fitting model and variability in trajectories

The cohort convergence test [28] was employed in this stage to identify if a reduced (simpler) model without cohort effects fit the data as well as the model we tested in the last stage. The reduced model is a parsimonious model which enables us to use a single trajectory to approximate age-related changes over a long period of time without modeling the cohort effects. A corresponding quadratic reduced model was formed. We counted 34 parameters in the full model, with the deviance of 65,265. The number of parameters in the reduced model is 10, and the deviance is 65,488. By subtraction, we obtained $df=24$ for the likelihood ratio test ($\Delta X^2_{(24)}=223, p<.001$), suggesting that the more complex full model provides a significantly better fit than the reduced model. Figure 2 provides visual illustrations of the full and reduced models. We see that the overall mean trajectory estimated by the reduced model (dotted line) does not pass through the center of each of the eight cohort trajectories (solid lines) in the full model. Thus, both the statistical test and the configuration results suggest that it is not appropriate to use a single underlying change continuum to describe changes from midlife to older adulthood based on the present data. In the following section that tests the impact of diabetes, the full model (cohort-based age trajectory) was chosen to be the basic model. The growth parameter of age in this model provides the longitudinal evidence of change in physical disability; and on the other hand, by connecting the intercept (median age) of each cohort, physical disability score in each 5-year birth cohort can be understood with cross-sectional data.

How diabetes predicts physical disability trajectories

Having discerned the shape of the physical disability trajectories from midlife to older age and detected significant between-person variability, we turned to our main question: To what extent does diabetes change individual differences in the levels of and rates of change in the physical disability trajectory? Table 2 presents the results of models that answer this question.

Model 1, which adds diabetes and diabetes $\times$ age to age alone, significantly improved the model fit from model 0 ($\Delta X^2_{(4)} = 160, p<.001$), and accounted for 3.2% ($[10.202-9.880]/10.202$) and 1.6% ($[0.129-0.127]/0.129$) of the variance in the intercept and linear change of the physical disability trajectory, respectively. The main effect of diabetes was positive and significant ($\beta_{\text{diabetes}} = 1.984, p<.001$), meaning that the level of physical disability varied with diabetes status. Adults with diabetes had trajectories characterized by higher levels of limitations in physical functioning. The interaction of diabetes by linear age change was positive and significant ($\beta_{\text{diabetes*age}} = 0.127, p<.001$), indicating that number of limitations in physical functioning increases at a faster rate in adults with diabetes than in those without diabetes. For example, from age 57 (the medium age of cohort 1) to age 67, non-diabetic individuals increase their limitations in physical functioning by an average of 0.88 (0.088×10), but individuals with diabetes add an average of 2.15 ($[0.088+0.127] \times 10$) limitations in physical function over a ten-year period. The trajectories for adults with and without diabetes are shown in Figure 3. Note that adults with diabetes were characterized by trajectories that were higher in both levels of physical function and rates of change in physical function trajectories, and these patterns are evident from the beginning of midlife and throughout older adulthood. However, the difference between adults with and without diabetes appears to be less distinct in older adulthood.

Results in Model 2 provide estimates with the addition of the main effects of gender, gender $\times$ age, gender $\times$ diabetes, and gender $\times$ age $\times$ diabetes interaction terms. This model significantly improved the model fit from model 1 ($\Delta X^2_{(12)} = 159, p < .001$). As expected, the main effect of gender was significant. Being a woman was associated with higher levels of disability and faster rates of increases in disability over time. Results of the diabetes $\times$ gender and diabetes $\times$ gender $\times$ age interactions reveal that diabetes had similar impacts for men and women ($-0.089, ns$), and indicate that the dynamic version of diabetes effects did not differ by gender.

Similarly, estimates with the addition of ethnic- or educational-related effects are presented in Models 3 and 4, respectively. Results suggest that ethnicity and education were significant predictors for the inter-individual variation in disability trajectories. Compared to Fukienese, Mainlander and Hakka experienced lower levels of disability. In addition, Mainlanders had lower rates of increases in disability. Adults with low or medium levels of education not only had higher levels of disability, but also showed a greater increase in disability over time. No significant interactions between diabetes and ethnicity or diabetes and education were detected.

Model 5 includes all of the aforementioned predictors plus covariates of death/dropout as well as the six time-varying chronic health conditions. This model tested the independent effect of each predictor when controlling for all of the other predictors in the model. The addition of these variables accounted for a substantial amount of the variance in the age trajectory of physical function—40.5% (9.880-5.883/9.880) of the variance in the intercept, 29.1% (0.127-0.090/0.127) of the linear change, and 25.0% (0.002-0.0015/0.002) of the curvature variation. The effects of diabetes on the intercept and linear change were diminished after accounting for sociodemographic factors, follow-up status, and co-morbidity effects, suggesting that part of the overall effect of diabetes on physical function operates through these other factors (mainly the comorbidities). Nevertheless, diabetes remained a robust predictor for physical function in the fully controlled model. Furthermore, none of the interactions terms with diabetes were significant, suggesting the effect of diabetes on disability did not differ by gender, education, or ethnicity.

Discussion

To our knowledge, no previous studies have looked at the impacts of diabetes on physical disability, characterized by trajectory from midlife to older age. The present study used multilevel growth curve modeling and an accelerated longitudinal design to delineate the disability trajectory for Taiwanese from age 51 to 104. This technique is unique in that it facilitates the examination of the dynamic relationship between diabetes and physical disability over time. In addition, instead of arbitrarily assuming a common developmental trend across cohorts, we used a cohort convergence test to determine the best model for describing longitudinal change. Our final trajectory model, with age and age cohort effects included as major within-individual changes in physical disability over time, teased out effects that were confounded with natural aging processes and provided both cross-sectional and longitudinal evidence on the impact of diabetes on physical disability.

Our examination of the age trajectory of disability after age 50 identified that deterioration in physical functioning in Taiwanese adults began early, and even as early as the starting age of our examination. Physical disability kept accumulating with age; in addition, the quadratic function of age suggests that the rate of deterioration was more substantial in older adulthood than in midlife. For example, with the 16 physical disability items examined in the present study, Taiwanese adults experienced less than one physical disability at 51, and then about 1 at age 65, about 2 at age 70, and about 4 at 80.

The key research question addressed in this study was if diabetes changed the physical disability trajectory over and above the natural aging process. On the one hand, the fixed effect coefficients in the fully controlled covariate model, which showed that main effects of diabetes and diabetes $\times$ age interaction were highly positive and significant, suggest that diabetes, independent of the natural aging process, sociodemographic factors, and comorbidities, has an adverse effect on levels of and rates of change in physical function over time. These results support previous studies indicating an independent effect of diabetes on disability using different covariates and methodologies [8-10], and echo previous research suggesting that diabetes may independently lead to worsening muscle strength and quality through hyperglycemia [9,10], inflammatory cytokines [44,45], and neuropathic process [46,47]. This finding has clinical implications supporting the crucial role of glycemic control in adults with diabetes—simply managing blood glucose may avoid many debilitating health outcomes. On the other hand, based on changes in variance in the random effects model, while diabetes accounted for 3.2% ($[10.202-9.880]/10.202$) of the inter-individual variations in levels of physical disability and 1.6% ($[0.129-0.127]/0.129$) of linear changes in the trajectory from midlife to older adulthood, our fully controlled covariates model (which added comorbidities, gender, ethnicity, and education) accounted for 40.5% ($[9.880-5.883]/9.880$) and 29.1% ($[0.127-0.090]/0.127$) of the variance in the intercept and linear change of that trajectory, respectively. This finding further supports the importance of designing interventions that help adults with diabetes to achieve good glycemic control and to prevent the incidence of diabetes-related comorbidities to guard against premature or excessive decline in physical function.

We also observed differences in trajectories in overlapping age ranges as a result of the cohort sequential nature of our design, especially in those with diabetes. For example, at the age of 60, adults without diabetes had an average of about 0.5 physical disability, shown in both the younger and older age cohorts; in adults with diabetes, the estimation based on the older cohort suggested an average of 2 disabilities at age 60; however, it was about 3 based on the younger cohort data. Note that at any given age, physical disability was estimated with a longer follow-up period for younger cohort adults than that for older cohort adults, (e.g., age 63 is the median age 57 plus 6 years of follow-up in cohort 1, but is median age 62 plus 1 year of follow-up for cohort 2). In addition, because it is presumable that adults in different cohorts are not different on their duration of diabetes at baseline, the longer follow-up period may actually represent the accumulated years of living with diabetes. We thus infer that the effects of diabetes duration may lie beneath these cohort differences in adults with diabetes. Further studies are encouraged to discern the long-term effects of diabetes duration on disability levels and rates of change.

Does diabetes impose an adverse effect evenly from midlife to older age in Taiwan? When comparing the differences between adults with and without diabetes across different age cohorts (in the cross-sectional comparison), it seems that those differences are less distinct in older adulthood—a finding that is consistent with results from previous studies comparing physical disability between adults with and without diabetes with different age groups [48]. However, findings from our longitudinal data suggest that this cross-sectional observation may simply be due to differential survivorship: those who have diabetes and are more fragile are more likely to be lost to follow-up than are their healthier counterparts. By comparing within-individual change trajectories between the two equivalent age cohorts in adults with and without diabetes, a comparison based on longitudinal evidence and accounting for attrition, the data actually showed that differences between adults with and without diabetes increase with age. This finding highlights the need to identify risk factors that increase differences between adults with and without diabetes in older adulthood.

Although a wealth of literature suggests diabetes health outcomes may differ by gender, education, and ethnicity [49-53], the impact of diabetes on disability did not differ across these social groups in Taiwan. Because the main effects of gender, education and ethnicity on disability were still observed in our data, we suspect the universal health care in Taiwan may play a critical role in explaining this finding. Unlike in other countries where medical accessibility is greatly linked to socioeconomic background, Taiwanese adults have been covered by universal health care since 1995 [54]. This coverage, which includes as many as 97% of all the people in Taiwan [55], may have minimized many potential sociodemographic differences in physical disability outcomes by equalizing access to care and assistive technology for adults with diabetes. This is conjecture, of course; and further studies are needed to confirm the trivial effect of sociodemographic background on moderating the diabetes burden on disability by using other Taiwan data.

Limitations of this study should be noted. First, our results were based on 1996-2003 middle-aged and older adults who were born in 1898-1945. It is not clear if the results found here will generalize to other, more recently born middle-aged and older adults in Taiwan. For example, contemporary older adults in Taiwan experienced tremendous social changes during the early 1900s compared to more recently born adults, which may lead to differential relationships between sociodemographic backgrounds and diabetes-physical disability outcomes. Second, some important factors that might have a substantial impact on moderating the relationship between diabetes and physical disability, such as duration of diabetes, glycemic control, medication, psychological factors, and lifestyles, were not examined in the study. Future research with available data is encouraged to address their contribution to the diabetes-physical disability relationship.

In summary, this longitudinal examination of a nationally representative sample of middle-aged and older adults in Taiwan indicated that diabetes explained 3.2% and 1.6% of the variance in levels of and linear changes in physical disability, respectively. It also identified that controlling for the effects of follow-up status, sociodemographic factors and comorbidities, diabetes remains a robust predictor, and altogether explained 40.5% and 29.1% of those variances in the trajectory. These results provide evidence that diabetes may independently and consistently change physical functioning over and above the natural aging processes in Taiwanese adults. This finding also supports the importance to design interventions that help adults with diabetes to achieve good glycemic control and to prevent incidence of diabetes-related comorbidities to guard against excessive decline in physical function.

Acknowledgments

This work was supported by the Penn State Center on Population Health and Aging level 2 grant (parent grant, National Institute on Aging, P30-AG024395).

Appendix A

References

- [1]. Tseng CH, Chong CK, Heng LT, Tseng CP, Tai TY. The incidence of type 2 diabetes mellitus in Taiwan. *Diabetes research and clinical practice* 2000;50(Suppl 2):S61–4. [PubMed: 11024585]
- [2]. Chuang LM, Tsai ST, Huang BY, Tai TY. The current state of diabetes management in Taiwan. *Diabetes research and clinical practice* 2001;54(Suppl 1):S55–65. [PubMed: 11580970]
- [3]. Boyle JP, Honeycutt AA, Narayan KM, Hoerger TJ, Geiss LS, Chen H, Thompson TJ. Projection of diabetes burden through 2050: impact of changing demography and disease prevalence in the U.S. *Diabetes care* 2001;24:1936–40. [PubMed: 11679460]
- [4]. Robert L. The rapid increase of the aging population worldwide and especially in industrialized countries. *Biomedicine & pharmacotherapy = Biomedecine & pharmacotherapie* 2003;57:185–6.
- [5]. Wild S, Roglic G, Green A, Sicree R, King H. Global prevalence of diabetes: estimates for the year 2000 and projections for 2030. *Diabetes care* 2004;27:1047–53. [PubMed: 15111519]
- [6]. Songer, TJ. Harris, M.; Gowie, CC.; Stern, M.; Boyko, EJ.; G.E., R.; Bennett, PH., editors. *Diabetes in America*. Washington DC: U.S. Govt. Printing Office; 1995. Disability in Diabetes. p. 429-48. NIH publ. no. 95-1468
- [7]. Gregg EW, Beckles GL, Williamson DF, Leveille SG, Langlois JA, Engelgau MM, Narayan KM. Diabetes and physical disability among older U.S. adults. *Diabetes care* 2000;23:1272–7. [PubMed: 10977018]
- [8]. Wray LA, Ofstedal MB, Langa KM, Blaum CS. The effect of diabetes on disability in middle-aged and older adults. *The journals of gerontology* 2005;60:1206–11. [PubMed: 16183964]
- [9]. Park SW, Goodpaster BH, Strotmeyer ES, de Rekeneire N, Harris TB, Schwartz AV, Tylavsky FA, Newman AB. Decreased muscle strength and quality in older adults with type 2 diabetes: the health, aging, and body composition study. *Diabetes* 2006;55:1813–8. [PubMed: 16731847]
- [10]. De Rekeneire N, Resnick HE, Schwartz AV, Shorr RI, Kuller LH, Simonsick EM, Vellas B, Harris TB. Diabetes is associated with subclinical functional limitation in nondisabled older individuals: the Health, Aging, and Body Composition study. *Diabetes care* 2003;26:3257–63. [PubMed: 14633811]
- [11]. Chiu CJ, Wray LA. Physical Disability Trajectories in Older Americans with and without Diabetes: The Role of Age, Gender, Race/ethnicity and Education. *The Gerontologist*. 2010 In Press.
- [12]. Jenkins KR, Johnson NE, Ofstedal MB. Patterns and associations of body weight among older adults in two Asian societies. *J Cross Cult Gerontol* 2007;22:83–99. [PubMed: 17225191]
- [13]. Hu P, Wagle N, Goldman N, Weinstein M, Seeman TE. The associations between socioeconomic status, allostatic load and measures of health in older Taiwanese persons: Taiwan social environment and biomarkers of aging study. *J Biosoc Sci* 2007;39:545–56. [PubMed: 17052381]
- [14]. Chen MY, James K, Wang EK. Comparison of health-promoting behavior between Taiwanese and American adolescents: a cross-sectional questionnaire survey. *Int J Nurs Stud* 2007;44:59–69. [PubMed: 16386741]
- [15]. Collins AL, Goldman N. Perceived social position and health in older adults in Taiwan. *Soc Sci Med* 2008;66:536–44. [PubMed: 18037202]
- [16]. Chiu CJ, Wray LA. Gender Differences in Functional Limitations in Adults Living with Type 2 Diabetes: Biobehavioral and Psychosocial Mediators. *Ann Behav Med*. 2010 In press.
- [17]. Visser M, Kritchevsky SB, Goodpaster BH, Newman AB, Nevitt M, Stamm E, Harris TB. Leg muscle mass and composition in relation to lower extremity performance in men and women aged 70 to 79: the health, aging and body composition study. *Journal of the American Geriatrics Society* 2002;50:897–904. [PubMed: 12028178]
- [18]. Read JG, Gorman BK. Gender inequalities in US adult health: the interplay of race and ethnicity. *Soc Sci Med* 2006;62:1045–65. [PubMed: 16122860]
- [19]. Gorman BK, Read JG. Gender disparities in adult health: an examination of three measures of morbidity. *J Health Soc Behav* 2006;47:95–110. [PubMed: 16821505]
- [20]. Nilsson PM, Theobald H, Journath G, Fritz T. Gender differences in risk factor control and treatment profile in diabetes: a study in 229 swedish primary health care centres. *Scand J Prim Health Care* 2004;22:27–31. [PubMed: 15119517]

- [21]. McCollum M, Hansen LS, Lu L, Sullivan PW. Gender differences in diabetes mellitus and effects on self-care activity. *Gend Med* 2005;2:246–54. [PubMed: 16464736]
- [22]. Naar-King S, Idalski A, Ellis D, Frey M, Templin T, Cunningham PB, Cakan N. Gender differences in adherence and metabolic control in urban youth with poorly controlled type 1 diabetes: the mediating role of mental health symptoms. *J Pediatr Psychol* 2006;31:793–802. [PubMed: 16322274]
- [23]. Chou AF, Brown AF, Jensen RE, Shih S, Pawlson G, Scholle SH. Gender and racial disparities in the management of diabetes mellitus among Medicare patients. *Womens Health Issues* 2007;17:150–61. [PubMed: 17475506]
- [24]. Gucciardi E, Wang SC, DeMelo M, Amaral L, Stewart DE. Characteristics of men and women with diabetes: observations during patients' initial visit to a diabetes education centre. *Can Fam Physician* 2008;54:219–27. [PubMed: 18272638]
- [25]. Tang YH, Pang SM, Chan MF, Yeung GS, Yeung VT. Health literacy, complication awareness, and diabetic control in patients with type 2 diabetes mellitus. *J Adv Nurs* 2008;62:74–83. [PubMed: 18352966]
- [26]. Chiu CJ, Wray LA. Factors predicting glycemic control in middle-aged and older adults with type 2 diabetes. *Preventing Chronic Disease* 2010;7
- [27]. Schaie KW. A General Model for the Study of Developmental Problems. *Psychol Bull* 1965;64:92–107. [PubMed: 14320080]
- [28]. Miyazaki Y, Raudenbush SW. Tests for linkage of multiple cohorts in an accelerated longitudinal design. *Psychol Methods* 2000;5:44–63. [PubMed: 10937322]
- [29]. Tonry, M.; Ohlin, LE.; Farrington, DP. Human development and criminal behavior: New ways of advancing knowledge. Springer-Verlag; New York: 1991.
- [30]. Duncan SC, Duncan TE, Hops H. Analysis of longitudinal data within accelerated longitudinal designs. *Psychological Methods* 1996;1:236–48.
- [31]. TPIFP. Survey of health and living status of the elderly in Taiwan: questionnaire and survey design. Taiwan Provincial Institute of Family Planning, Population Studies Center and Institute of Gerontology, University of Michigan; 1989.
- [32]. Katz S, Ford AB, Moskowitz RW, Jackson BA, Jaffe MW. Studies of Illness in the Aged. The Index of Adl: A Standardized Measure of Biological and Psychosocial Function. *JAMA* 1963;185:914–9. [PubMed: 14044222]
- [33]. Lawton MP, Brody E. Assessment of Older People: Self-maintaining and Instrumental Activities of Daily Living. *The Gerontologist* 1969;9:179–86. [PubMed: 5349366]
- [34]. Nagi SZ. A Study in the Evaluation of Disability and Rehabilitation Potential: Concepts, Methods, and Procedures. *Am J Public Health Nations Health* 1964;54:1568–79. [PubMed: 14218194]
- [35]. de Leon, CF Mendes; Guralnik, JM.; Bandeen-Roche, K. Short-term change in physical function and disability: the Women's Health and Aging Study. *J Gerontol B Psychol Sci Soc Sci* 2002;57:S355–65. [PubMed: 12426444]
- [36]. Fried LP, Ettinger WH, Lind B, Newman AB, Gardin J. Physical disability in older adults: a physiological approach. Cardiovascular Health Study Research Group. *Journal of clinical epidemiology* 1994;47:747–60. [PubMed: 7722588]
- [37]. Langlois JA, Maggi S, Harris T, Simonsick EM, Ferrucci L, Pavan M, Sartori L, Enzi G. Self-report of difficulty in performing functional activities identifies a broad range of disability in old age. *Journal of the American Geriatrics Society* 1996;44:1421–8. [PubMed: 8951310]
- [38]. Siu AL, Reuben DB, Hays RD. Hierarchical measures of physical function in ambulatory geriatrics. *Journal of the American Geriatrics Society* 1990;38:1113–9. [PubMed: 2229865]
- [39]. Wang CY, Sheu CF, Protas E. Construct validity and physical performance of older adults in different hierarchical physical-disability level. *J Aging Phys Act* 2007;15:75–89. [PubMed: 17387230]
- [40]. Hermalin AI, Ofstedal MB, Sun C, Liu IW. Nativity differences in older age mortality in Taiwan: Do they exist and why? *Journal of Population Studies* 2009;39:1–55.
- [41]. Tung HJ, Mutran EJ. Ethnicity and health disparities among the elderly in Taiwan. *Research on Aging* 2005;27:327–54.

- [42]. Zimmer Z, Martin LG, Lin HS. Determinants of old-age mortality in Taiwan. *Social Science and Medicine* 2005;60:457–70. [PubMed: 15550295]
- [43]. Raudenbush, SW.; Bryk, AS. *Hierarchical Linear Models: Applications and Data Analysis Methods*. Sage; Newbury Park: 2002.
- [44]. Visser M, Pahor M, Taaffe DR, Goodpaster BH, Simonsick EM, Newman AB, Nevitt M, Harris TB. Relationship of interleukin-6 and tumor necrosis factor-alpha with muscle mass and muscle strength in elderly men and women: the Health ABC Study. *The journals of gerontology* 2002;57:M326–32. [PubMed: 11983728]
- [45]. Taaffe DR, Harris TB, Ferrucci L, Rowe J, Seeman TE. Cross-sectional and prospective relationships of interleukin-6 and C-reactive protein with physical performance in elderly persons: MacArthur studies of successful aging. *The journals of gerontology* 2000;55:M709–15. [PubMed: 11129392]
- [46]. Andersen H, Poulsen PL, Mogensen CE, Jakobsen J. Isokinetic muscle strength in long-term IDDM patients in relation to diabetic complications. *Diabetes* 1996;45:440–5. [PubMed: 8603765]
- [47]. Andersen H, Nielsen S, Mogensen CE, Jakobsen J. Muscle strength in type 2 diabetes. *Diabetes* 2004;53:1543–8. [PubMed: 15161759]
- [48]. Gregg EW, Mangione CM, Cauley JA, Thompson TJ, Schwartz AV, Ensrud KE, Nevitt MC. Diabetes and incidence of functional disability in older women. *Diabetes care* 2002;25:61–7. [PubMed: 11772902]
- [49]. Heisler M, Faul JD, Hayward RA, Langa KM, Blaum C, Weir D. Mechanisms for Racial and Ethnic Disparities in Glycemic Control in Middle-aged and Older Americans in the Health and Retirement Study. *Arch Intern Med* 2007;167:1853–60. [PubMed: 17893306]
- [50]. Hertz RP, Unger AN, Ferrario CM. Diabetes, hypertension, and dyslipidemia in Mexican Americans and non-Hispanic whites. *Am J Prev Med* 2006;30:103–10. [PubMed: 16459207]
- [51]. LeMaster JW, Chanetsa F, Kapp JM, Waterman BM. Racial disparities in diabetes-related preventive care: results from the Missouri Behavioral Risk Factor Surveillance System. *Prev Chronic Dis* 2006;3:A86. [PubMed: 16776887]
- [52]. Gary TL, McGuire M, McCauley J, Brancati FL. Racial comparisons of health care and glycemic control for African American and white diabetic adults in an urban managed care organization. *Dis Manag* 2004;7:25–34. [PubMed: 15035831]
- [53]. Quandt SA, Bell RA, Snively BM, Smith SL, Stafford JM, Wetmore LK, Arcury TA. Ethnic disparities in glycemic control among rural older adults with type 2 diabetes. *Ethn Dis* 2005;15:656–63. [PubMed: 16259490]
- [54]. Cheng SH, Chiang TL. The effect of universal health insurance on health care utilization in Taiwan: Results from a natural experiment. *Journal of the American Medical Association* 1997;278:89–93. [PubMed: 9214512]
- [55]. Lu JF, Hsiao WC. Does universal health insurance make health care unaffordable? Lessons from Taiwan. *Health Affairs* 2003;22:77–88. [PubMed: 12757274]

Figure 1.
Age Trajectory of Physical Disability and Plotted Sample Raw Mean Based on 5,121 Individual Trajectories
Notes: The solid line indicates quadratic trajectories over time in each cohort; the dashed line indicates mean limitations in physical function for each age.

Figure 2.

Age Trajectory of Physical Disability Estimated by Full Model versus Reduced Model

Notes: The full model considers both age and cohort effects. The reduced model considers only the age effect. The solid lines are estimated by full model; the dashed line is estimated by reduced model.

Figure 3.

Physical Disability Trajectories in Adults with and without Diabetes

Notes: The solid lines are estimated for adults with diabetes; the dashed lines are estimated for adults without diabetes.

Table 1**Baseline Characteristics and Association with Physical Disability**

	% ^a	Mean (SD)	P
Age		66.2 (9.5)	
(Age) Cohort			<.001
1	1.97	0.39(1.46)	
2	4.65	0.79(2.13)	
3	9.76	1.16(2.74)	
4	17.5	1.60(3.17)	
5	21.3	2.16(3.59)	
6	12.9	3.71(4.57)	
7	15.0	5.26(4.87)	
8	16.9	6.33(5.03)	
Gender			<.001
Women	46.2	2.33 (3.62)	
Men	53.8	1.33 (3.25)	
Education			<.001
Low	32.6	2.98 (4.03)	
Medium	39.2	1.28 (2.98)	
High	28.2	1.12 (2.98)	
Ethnicity			<.001
Fukienese	67.2	1.89 (3.55)	
Hakka	15.1	1.67 (3.32)	
Mainlander	17.8	1.38 (3.11)	
Diabetes Status			
Yes	11.4	3.09 (4.42)	
No	88.6	1.62 (3.27)	
High Blood Pressure			<.001
Yes	27.6	2.69 (4.17)	
No	72.4	1.44 (3.00)	
Cancer			<.001
Yes	1.4	3.81 (5.14)	
No	98.6	1.66 (3.42)	
Lung Disease			<.001
Yes	10.9	2.87 (4.22)	
No	89.1	1.65 (3.33)	
Heart Disease			<.001
Yes	15.9	2.96 (4.04)	
No	84.1	1.56 (3.22)	
Stroke			<.001
Yes	4.7	8.38 (6.35)	
No	95.3	1.47 (2.89)	

	% ^a	Mean (SD)	P
Arthritis			<.001
Yes	22.2	2.64 (3.65)	
No	77.8	1.54 (3.35)	

Table 2

Coefficient Estimates of Trajectory of Physical Function (SHLSET 1996-2003, N=5,121)

	Model 0 ^a	Model 1 ^b	Model 2 ^c	Model 3 ^d	Model 4 ^e	Model 5 ^f
<i>Fixed effects</i>						
Intercept	0.631***	0.509***	-0.071	0.584***	-0.008	-0.528
Age	0.097***	0.088***	0.060**	0.094***	0.045	0.003
Age ²	0.008	0.008	0.008	0.008	0.008*	0.008*
Cohort2	0.692***	0.584**	0.564**	0.629**	0.370*	0.319*
Cohort3	1.164***	1.066***	1.063***	1.189***	0.918***	0.791***
Cohort4	1.864***	1.727***	1.833***	2.018***	1.608***	1.293***
Cohort5	3.076***	2.941***	2.989***	3.227***	2.705***	2.179***
Cohort6	5.163***	5.055***	5.024***	5.243***	4.622***	3.624***
Cohort7	7.708***	7.593***	7.493***	7.704***	7.078***	5.880***
Cohort8	11.584***	11.626***	11.518***	11.726***	10.964***	9.327***
Age* Cohort2	0.039	0.035	0.033	0.038	0.029	0.025
Age* Cohort3	0.081**	0.076*	0.075*	0.084**	0.070*	0.053
Age* Cohort4	0.198***	0.191***	0.193***	0.206***	0.189***	0.168***
Age* Cohort5	0.335***	0.328***	0.325***	0.342***	0.322***	0.286***
Age* Cohort6	0.551***	0.542***	0.533***	0.552***	0.527***	0.481***
Age* Cohort7	0.695***	0.684***	0.674***	0.666***	0.667***	0.608***
Age* Cohort8	0.890***	0.889***	0.866***	0.888***	0.844***	0.765***
Age ² * Cohort2	-0.005	-0.005	-0.005	-0.005	-0.006	-0.006
Age ² * Cohort3	-0.002	-0.002	-0.002	-0.002	-0.002	-0.004
Age ² * Cohort4	0.007	0.008	0.008	0.008	0.008	0.010
Age ² * Cohort5	0.008	0.008	0.008	0.008	0.008	0.006
Age ² * Cohort6	0.025	0.024**	0.023**	0.024**	0.024**	0.023**
Age ² * Cohort7	0.011**	0.011	0.011	0.011	0.011	0.008
Age ² * Cohort8	0.028	0.027	0.026	0.027	0.025	0.020
Diabetes		1.984***	1.910***	2.024***	1.782***	1.166***
Diabetes* Age		0.127***	0.111**	0.132***	0.190***	0.142*
Women			1.210***			0.938***

	Model 0 ^d	Model 1 ^b	Model 2 ^c	Model 3 ^d	Model 4 ^e	Model 5 ^f
Women*Age			0.060***			0.043*
Women*Diabetes			-0.089			0.248
Women*Diabetes*Age			0.010			0.068
Mainlander				-1.235***		-0.570***
Hakka				-0.267*		-0.142
Mainlander*Age				-0.060*		-0.005
Hakka*Age				-0.028		-0.013
Mainlander*Diabetes				0.210		0.093
Hakka*Diabetes				-0.510		-0.227
Mainlander*Age*Diabetes				0.020		-0.055
Hakka*Age*Diabetes				-0.049		-0.037
Education_low					1.610***	0.899***
Education_med					0.476***	0.188
Education_low*Age					0.081***	0.032
Education_med*Age					0.055***	0.036
Edu_low*Diabetes					-0.059	-0.325
Edu_med*Diabetes					0.438	-0.147
Edu_low*Age*Diabetes					-0.121	-0.183*
Edu_med*Age*Diabetes					-0.066	-0.084
Deceased/dropout						1.558***
High blood pressure						0.127*
Cancer						-0.257**
Lung disease						0.364***
Heart disease						0.426***
Stroke						4.721***
Arthritis						0.131*
Random effects						
Variance						
Intercept (11)	10.202***	9.880***	9.391***	9.682***	9.366***	5.883***
Slope (22)	0.129***	0.127***	0.126***	0.127***	0.126***	0.090***
Curvature (33)	0.002***	0.002***	0.002***	0.002***	0.0016***	0.0015***

	Model 0 ^a	Model 1 ^b	Model 2 ^c	Model 3 ^d	Model 4 ^e	Model 5 ^f
Covariance						
Intercept, slope (12)	0.503	0.474***	0.436***	0.463***	0.453***	0.280***
Intercept, curvature (13)	-0.019	-0.022*	-0.024**	-0.022*	-0.022*	-0.019**
Slope, curvature (23)	0.009	0.008***	0.008***	0.008***	0.008***	0.007***
Residual	3.394***	3.383***	3.401***	3.391***	3.393***	3.464***
Goodness of fit						
AIC	65,327	65,171	65,020	64,998	64,992	62,557
BIC	65,530	65,387	65,262	65,266	65,260	62,949
-2LL	65,265	65,105	64,946	64,916	64,910	62,437
Parameters	34	38	50	56	56	100
LR Test						
$\Delta\chi^2$ (Degrees of freedom)	-	160(4)***	159(12)***	189(18)***	195(18)***	2,668(62)***

NOTE: AIC= Akaike's Information Criterion; BIC= Bayesian Information Criteria; LR=Likelihood Ratio; -2LL= -2 Log-Likelihood.

^aModel 0: Age & Cohort model.

^bModel 1: Diabetes model.

^cModel 2: Diabetes & Gender model.

^dModel 3: Diabetes & Ethnicity model.

^eModel 4: Diabetes & Education model.

^fModel 5: Diabetes & Covariates model.