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# Longitudinal Evidence of Social Influences on Cognitive Decline in South Korea: Focusing on the Joint Effects of Age, Gender, and Education*

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*A burgeoning research documented protective effects of education on later life cognitive health but available evidences of gender difference, or female disadvantage, in cognitive health have not been consistent --some supporting female disadvantage while others no meaningful difference between genders. This study, through examining the joint effect of gender, age and education on cognitive health, aims to test whether and to what extent portrayed gender difference depends on education. This study, utilizing Korean Longitudinal Survey of Aging (KLoSA), analyzed 5,772 persons aged 45 and over who have completed five times of biannual survey since 2006. The results from the random coefficient model indicate that female disadvantage in cognitive health is indeed observed and it increases as age advances. Furthermore, the growing gender difference with age depends on education. More specifically, no cognitive disadvantage observed among female with high education yet increasing cognitive disadvantage with age observed among female with low education. The findings suggest that the female disadvantage in cognitive decline observed frequently by previous research may be conditional on socio-environmental contexts such as age and education.*

**Keywords:** *social influences, gender difference, education, cognitive health*

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## Introduction

South Korea experiences one of rapid population aging in the world. The proportion aging over 60 year old is about 18.5% in 2015 yet is projected to be 41.5% in 2050. According to UN, Korean population composition is one of the youngest among the 34 OECD countries in 2015 but is projected to be one of the oldest in 2050(Would Population Prospects: The 2015 Revision). Aging population produces increasing number of age-related diseases such as Alzheimer Disease (AD), or diseases associated with cognitive decline (CD). Prevalence of AD, for example, is 9.18% in 2012 and is expected to be 15.06% in 2050. Even higher ratio of increases of AD prevalence relative to composition of elderly population over about 35 years may call for further attention to this issue. Furthermore, the care costs in the domains of finance and emotion, with respect to AD or CD are burdensome both for individuals and society, deserving careful and well-planned policies (Kurz et al. 2003; Toseland et al. 2002). Lastly, the fact that there is no medical cure available for individuals with severely impaired cognition may contribute to widespread notion of regarding AD as mysterious and unpredictable diseases and the ways in which to deal with uncertainty are indeed in high social demand, locally and globally.

Aforementioned daunting nature of CD does have received wide range of research interests or attentions investigating (a) genetic influences or biological processes of pathological CD and/or, (b) potential risk factors for such diseases processes. Although these lines of past research are important in many respects, we argue that dynamic social processes underlying such disease process have not been fully examined yet. First, previous research taking risk-factor approach has identified various risk-factors for cognitive decline, such as low education level, female, older age, but it has not been clear how these risk factors come to affect cognitive decline. For example, low level of education has been identified as significant risk factor but it remains to be learned whether such low educational risk even accelerates with advancing age. Second, relatedly, previous research documented inconsistent patterns with respect to female disadvantage in cognitive decline. Is it possible to attribute lack of consistent findings of female disadvantage to lack of considering relevant contexts that might have been responsible for the gender difference? Lastly, besides overall research trend of paying insufficient attention to socio-environmental processes, much of previous work examining social processes underlying cognitive decline relied on cross-sectional or short-term follow up data, rendering caution in the extent of statistical inferences or generalization of findings.

We address these shortcomings of previous research on cognitive decline by investigating whether or how multiple risk factors such as low level of education, older age, female come to have effects on cognitive decline. In particular, our investigation is centered on testing the extent of socio-environmental influences on cognitive decline by testing female disadvantage hypothesis. In essence, the process is to validate the existence of such disadvantage and, if so, is furthered assessed by more rigorous contingency of basic association such as age and education. To do this, we employ recent five waves of Korean Longitudinal Study of Ageing and follow respondents who have successfully completed all follow-up surveys up to 2014, and use random-intercept approach to appropriately examine long term change in the area of research interest. Lastly, Cognitive health score is measured via MMSE (i.e., Mini Mental State Examination).

## Background

### *1) Fundamental Causes of Health Inequality and Cognitive Decline*

Fundamental cause theory posits that one's location in hierarchical social position is a fundamental cause of population health disparities because one's social position affects a range of health outcomes through a host of risk factors. The consequences of differences in social standing cannot be reduced to proximate risk factors because differences of social standing in health outcomes reproduce themselves even though the operating mechanisms through which socioeconomic standing affects health outcomes change over time (Link and Phelan 1995). Hence, focusing only on proximal risk factors typically fails to address the role of fundamental cause of social conditions that produce "causes of causes" or "risk of risk" of social problems (Elo 2009; Herd, Goesling, and House 2007; Marmot 2005; Wilkinson 1997). Consistent with this prediction, available evidence generally supports strong linkage between socioeconomic standing and virtually every cause of morbidity and mortality (Elo 2009; Kaplan et al. 1996; Kitagawa and Hauser 1973; Marmot 2005; Wilkinson 1997). Under this general association, what might be the fundamental causes of cognitive health inequalities? Just like other health outcomes, fundamental cause theory would predict close ties between hierarchical social standings and varying cognitive status where those with higher social standings comprised by numerous indicators (e.g., high education, creative job, good income, male, etc.) would enjoy better cognitive health and lower social status suffers poorer cognitive health.

*2) Age, Gender, and Education, and Their Joint Effect Cognitive Decline*

Health researchers have been interested in understanding the dynamic relationships between socioeconomic standing in the context of age trajectory. For example, it has been a subject of debate whether health inequality by education grows or shrinks over the life course. These two views named as (a) age-as-leveler and (b) cumulative disadvantage (Dupre 2007) have their own merit and theoretical ground but the empirical supports for each prediction are not conclusive. We argue for the increasing cognitive health gap by social strata over the life course and provide relevant theories and empirical support for this prediction. Given the life course trajectory of cognitive health said to be maintained stably up to relatively late period of life and then slightly falls thereafter, the gaps between social groups are expected to follow the pattern. Therefore, the application of fundamental-causes may be tested by comparing the rate or the onset of cognitive decline among different social groups.

What might be theoretical prediction as to the gender difference in cognitive health according to fundamental-causes theory? First, there are differences in environmental conditions within which male and female are situated, and these different conditions may have significant implication for the performance of cognitive health. The key differences may include socioeconomic status and other stereotypes that favor one gender type over the other. Given observed and prevalent socioeconomic advantage of male and gender stereotypes favoring men in South Korea, males are expected to have greater cognitive advantage. Second, if framed on age trajectory, the gender difference in cognition may change over time to reflect change in social standing or gender norm. In other words, even though one observes significant female disadvantage in cognitive function at some point of time, the deficit may be reducing if social circumstances of gender equity improves significantly over time. In order to observe time dependency in female disadvantage, it is important to assess not only main effect of female but also female by time interaction to properly observe how the female disadvantage changes over time.

Available empirical evidence from South Korea strongly supports theoretical predictions of female disadvantage in cognitive (reserve) score

(Kim, Kim and Kim 2011; Woo 2014; Lee and Kahng 2011). Although majority of studies conducted in South Korea reported poorer cognitive score of female, it is not entirely clear whether female disadvantage increased with age. Improving social conditions for female predict gender gap may increase with age due to poorer socioeconomic status shared by female in earlier cohort but this theoretical prediction has not been examined empirically. Although it is based on a small cross-sectional sample of Korean elderly population, one recent study investigating the effect of gender and age on cognitive reserve does find increasing female disadvantage with age (Choi et al. 2016). Convincing evidences of gender difference in cognitive decline come from abroad where gender difference in cognition may change over time and across regions to reflect changes in socio-cultural environments (Mielke, Vemuri, and Rocca 2014; Musicco 2009). For example, gender difference in prevalence of AD is generally significant and robust in studies on European countries while tends to be non-significant in the research targeting US elderly population. Moreover, one study from abroad attributed pronounced female disadvantage in longitudinal age-related decline relative to that in cross-sectional setting to poorer educational opportunity shared by earlier cohorts (Singh-Manoux et al. 2012).

Relative to coherent evidence supporting why and how social environments affect cognitive decline of female and male differently, biological evidence supporting potential gender difference is more nuanced in nature. First, there is weak bio-genetic ground predicting gender difference in cognitive performance among young to mid-aged adult population. Although there is some evidence in gender difference in the domain of cognitive function such that there may be female advantage in verbal and male advantage in visuospatial areas, once believed significant sex differences in math have been shrinking, particularly among countries achieved gender equity, and many conclusions about sex differences in cognitive abilities need to be reexamined (Miller and Halpern 2014) Second, there may be male advantage in cognitive function due partly to postmenopausal reduction of estrogen that may point to explaining increasing female disadvantage among elderly population (Laws, Irvine, and Gale 2016), and it might be associated with male advantage in AD progression for the elderly population. Overall, if any, male advantage in AD among very old clinical population, but the weight of evidence is far from conclusive.

Comparing to the evidence assessing gender differences in cognition, protective role of education in CD has been well documented across places and time. First, the direct link of education and cognitive score has been documented where more years of education tend to be associated with higher cognitive scores (Matthews, Marioni, and Brayne 2012; Ye et al. 2013; Kim et al. 2011; Woo 2014) . Possible explanations include "cognitive reserve theory" where higher levels of cognitive reserve protect individuals from cognitive decline net of pathological progression of diseases process (Katzman et al. 1988; Stern 2002). Education level typically has been served as a proxy for cognitive reserve. While it is plausible to expect that the neuroplasticity of cognitive reserve within individual would fluctuate over the life course to reflect differing extent of cognitively stimulating environments one may have, available evidences during younger ages have not been widely available. Instead, current research seems to indicate that the highlight of cognitive reserve has more to do with moderating the pace of cognitive decline including pathological progression of disease process.

Next, the general role of education as a master tool for enhancing health outcomes has been better documented (Elo 2009; Herd et al. 2007; Mirowsky and Ross 2003a). Education is the leading component of SES that helps to build other components of SES, which may have sequential implications for how SES might relate to better cognitive functions. Moreover, the principle role of education is to build "human capital" via learned effectiveness, which stays with individual throughout their life (Mirowsky and Ross 2003a, 2003b). The enhanced human capital among high SES individuals in turn is likely to be used to cultivate other cognitively valuable health behaviors such as active social participation or regular physical exercise. On the other hand, individuals with poor education is likely to start off low level of human capital in early adulthood and would work under less cognitively stimulating environments and be exposed to stressful situation more frequently. Mirowsky and Ross explain "structural amplification" as a key process through which the health gap between differing education levels would grow over their life (Mirowsky and Ross 2003a, pp.154-58). The concept of "stress proliferation (Pearlin 1989)" and "Matthew effect (Merton 1968)" commonly describes observed gap would grow over time between those who have and have not.

In addition to formulating age by gender and age by education effect, joint effect of age, gender, and education on cognitive decline may be also drawn given Korean sociocultural contexts characterized by (a) decreasing educational inequality for female over time and (b) increasing gender equity for female over time (Park 2007). Social environmental contexts within which male and female are situated are different and these differences include not only disadvantage in educational opportunity but also in other cultural stereotypes that would lead individuals to treat male and female differently and these differences may have implication in cognitive health. For example, within the same lower education, there might be differing gender expectations that would lead male to form and develop certain level of cognitive stimulation but would lead female, instead, to just maintain or even slow down cognitive process. With having the same low education background, male may have engaged in more activities that are characterized by "cognitively complex and stimulating" whereas female are in charge of less-cognitively stimulating work such as housekeeping. Although global gender norm in Korea dictates specific gendered activity that may be on par overall, there may be weighted disadvantage for poorly educated women who are mostly engaged in less cognitively engaging social activities.

## Data and Method

The data used for these analyses come from the Korean Longitudinal Study of Ageing (KLoSA). The KLoSA is an ongoing panel survey covering family relationships, socioeconomic status, mental and physical health of non-institutionalized Koreans 45 year old or older. The sample was stratified by age and sex. The survey started in 2006, and conducted every 2 year thereafter.

Of 10,254 Wave 1 participants, 6,591 participants completed 5 times of surveys (source of non-response divides into 1964 cases of attrition, 1261 cases of mortality, and 438 cases of partial participation). Among them, 815 cases are dropped due to non-response in cognitive score (i.e., dependent variables), and additional 4 cases are removed due to non-response in covariates (i.e., 1 case in education, 1 case in self-rated health, and 2 cases in depression), making 5,772 cases of analytic sample who completed 5 times of follow-up survey.

Measurement description is provided here. First, dependent variable of cognitive score is measured using the K-MMSE, which is typically employed for evaluating global cognitive health status. The MMSE tests items such as orientation, recall, language, registration, attention, calculation, and the ability to follow simple command. Total scores range from 0 to 30, with higher scores indicating higher cognition status. Second, focal independent variables include age gender and education: Age is measured in years but centered at age 45. In addition, in order to capture curvilinear association of age and cognitive decline, squared & cubic terms of age are added to the models; Gender is a dummy variable with male equal to 0 and female equal to 1; Education is expressed with three dummy variables of elementary (reference), middle to high school graduation, and college or more. Third, we include a number of control variables included in each model. Such variables include: Household income is measured with three dummy variables of low (reference: 0-32 percentile), middle (33-66 percentile), and high (67-100 percentile). Employment status (1=currently employed, 0=not currently employed). Marital status (1=married, 0=not married). Region is measured with three dummy variables of metropolitan (reference), city, rural. Ordinal variable of number of contact (1 to 10), poor self-rated health (yes=1, no=0), depression (yes=1, no=0), Normal IADL (yes=1, no=0), disability (yes=1, no=0), sum of chronic diseases (self-reported diagnosis of hypertension, diabetes, cancer, lung disease, hepatic disease, heart disease, stroke disease, mental disease, and arthritis), regular exercise (yes=1, no=0). In addition, five waves of panel data will be classified with four dummy variables representing each wave.

Of these analyzed variables, only female and education are time-invariant and all others variables are measured in all five waves, thus serving as time-varying variables. Because there is possibility that cognitive function is associated with the risk of attrition, we adjusted for the hazard of attrition in all models. The Heckman selection attrition hazard is estimated to predict attrition based on entire KLoSA sample over the 8-year follow-up as a function of all the covariates employed in Model (1) in Table 2 including the covariates who coefficients are not shown.[1] We include the predicted hazard as a control variable in the model (Heckman, 1976).

To examine the cognitive health implications of age, gender, and education over time the data will be constructed as a long (or person-period) form where each respondent contributes evenly five cases to the data.[2] Random effects regression models will be used to account for the fact that the same individuals are measured more than once in this study design. Random-effect linear model is characterized as a two-level random-

[1] Controlling for non-selection-hazard does not seem to meaningfully affect significance of the key variables (age, female, education) but the coefficient of non-selection-hazard itself is negative and significant throughout indicating that on average non-selected reports lower cognitive score.

[2] The general patterns of observation between balanced and unbalanced data are not distinct. However, we choose the balanced data in part by the fact the balanced data would provide more "conservative" estimates because those who are not selected due to death or intermittent participation to survey are as a whole less healthy and less healthy in cognitive health as well. Hence, balanced data do select healthier sample, and consequently the magnitude of coefficients are less pronounced.

coefficient model with time measurement occasions (level-1 units) nested within individual (level-2 units) and is used to model continuous response variables (i.e., cognitive health), and other covariates.

The model for the continuous health outcome Yij of time (wave) i with respondent j is specified as:

$$Y_{ij} = \beta_1 + \beta_2 x_{1ij} + \beta_3 x_{2ij} + \ldots + \zeta_j + \varepsilon_{ij}, \quad (1)$$

where $\beta_1$ is a fixed intercept, $\beta_2$ and $\beta_3$ are coefficient for covariates, $\zeta_j$ is a random intercept (level 2) and $\varepsilon_{ij}$ is a level 1 error. This model assumes:

$$\varepsilon_{ij} \sim N(0, s^2)$$
$$\zeta_j \sim N(0, t^2)$$

All models were estimated as random intercept models using Stata 14 (Stata Corp).

## Results

First, we present weighted descriptive statistics of study participants at the baseline (Wave 1, 2006). On average, respondents are 57.76 year old and score 25.92 points in cognitive test. Slightly more than half of participants are female (54%). Education proportion splits into 39%, 50%, and 11% for elementary, middle to high school, and college and above, respectively. Descriptive statistics of other control variables are also reported in Table 1.

Each cell contains unstandardized regression coefficients with standard errors in parentheses. All models adjust for the hazard of attrition, multiple waves, marital status, region, employment, income, number of contact, poor self-rated health, depression, normal IADL, disability, sum of chronic diseases, regular exercise.

Next, we turn to report the results of multivariate relationships between dependent variable and other covariates in Table 2. As indicated in the note below Table 2, all Models controls for (a) potential attrition bias and wave clustering and (b) potential risk factors identified by previous research but the results are omitted intentionally. Model 1 exhibit that old age, female, and low education are associated with declining cognitive score. Notable is the curvilinear association between age and cognitive score captured by significant quadratic and cubic square age terms in addition to linear age

**TABLE 1**
**Weighted Descriptive Statistics of Study Participants: KLoSA2006 (N=5,772)**

| Variable | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|
| Cognitive score | 25.92 | 3.94 | 0 | 30 |
| Age at 2006 | 57.76 | 9.37 | 45 | 91 |
| Female (ref=male) | 0.54 | 0.50 | 0 | 1 |
| Education | | | | |
| elementary (E1, reference) | 0.39 | 0.49 | 0 | 1 |
| middle to high school (E2) | 0.50 | 0.50 | 0 | 1 |
| college (E3) | 0.11 | 0.32 | 0 | 1 |
| Married (ref=unmarried) | 0.85 | 0.36 | 0 | 1 |
| Income | | | | |
| low (reference) | 0.33 | 0.47 | 0 | 1 |
| middle | 0.34 | 0.47 | 0 | 1 |
| high | 0.33 | 0.47 | 0 | 1 |
| Employed status (ref=unemployed) | 0.49 | 0.50 | 0 | 1 |
| Region | | | | |
| metropolitan (reference) | 0.43 | 0.50 | 0 | 1 |
| city | 0.32 | 0.47 | 0 | 1 |
| rural | 0.25 | 0.43 | 0 | 1 |
| Number of Contact | 3.28 | 2.70 | 1 | 10 |
| Poor self-rated health (ref=non-poor SRH) | 0.24 | 0.43 | 0 | 1 |
| depression (ref=non-depressed) | 0.10 | 0.31 | 0 | 1 |
| Normal IADL (ref=non-normal IA이) | 0.91 | 0.29 | 0 | 1 |
| Disability (ref=non-disability) | 0.05 | 0.22 | 0 | 1 |
| Sum of Chronic Diseases | 0.70 | 1.05 | 0 | 8 |
| Regular exercise (ref=no regular exercise) | 0.40 | 0.49 | 0 | 1 |

term in the model. Cognitive function does not start to fall until very old age and the rate of decline is expected to considerably differ by various subgroup of population, and these variations are better captured by these polynomial age terms. Note also that age variable is centered at 45 to increase the literacy of constant term and to generate interaction terms with other variables in the subsequent models. Additional analysis, not shown but available upon request, indicates that adding each additional polynomial age term significantly increase model fit according to log-likelihood test, justifying the need of retaining those variables in the model. Each of net effect of gender and education is consist with previous evidence and theoretical expectation: female and low education disadvantage. Female on average report 1 cognitive

**TABLE 2**
**Unstandardized Regression Coefficients from the Random-intercept Models of the Association among Age, Gender, Education, and Cognitive Score: KLoSA, 2006-2014 (N=5,772)**

| VARIABLES | Model (1) | Model (2) | Model (3) | Model (4) | Model (5) |
|---|---|---|---|---|---|
| Fixed Part: | | | | | |
| Constant | 25.790*** | 26.552*** | 25.199*** | 26.115*** | 25.733*** |
| | (0.28) | (0.31) | (0.28) | (0.29) | (0.37) |
| (Age-45) | -0.061** | -0.116*** | -0.018 | -0.057** | -0.055* |
| | (0.02) | (0.02) | (0.02) | (0.02) | (0.02) |
| (Age-45)^2 | 0.003** | 0.004*** | 0.002* | 0.003* | 0.003** |
| | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) |
| (Age-45)^3 | -0.0001*** | -0.0001*** | -0.0001*** | -0.0001*** | -0.0001*** |
| | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) |
| Female | -0.986*** | -0.957*** | 0.218 | -1.545*** | 0.122 |
| | (0.08) | (0.08) | (0.14) | (0.12) | (0.29) |
| Education | | | | | |
| Elementary (E1, reference) | | | | | |
| Middle to high school (E2) | 1.480*** | 0.733*** | 1.408*** | 0.915*** | 1.057*** |
| | (0.09) | (0.17) | (0.09) | (0.13) | (0.29) |
| College (E3) | 1.972*** | 0.814** | 1.971*** | 1.432*** | 1.304*** |
| | (0.14) | (0.25) | (0.14) | (0.17) | (0.34) |
| Interactions: | | | | | |
| (Age-45) X Female | | -0.066*** | | | -0.070*** |
| | | (0.01) | | | (0.01) |
| (Age-45) X E2 | | | 0.038*** | | 0.003 |
| | | | (0.01) | | (0.01) |
| (Age-45) X E3 | | | 0.066*** | | 0.022 |
| | | | (0.01) | | (0.02) |
| Female X E2 | | | | 0.926*** | -0.237 |
| | | | | (0.15) | (0.34) |
| Female X E3 | | | | 1.198*** | -0.186 |
| | | | | (0.28) | (0.50) |
| (Age-45) X Female X E2 | | | | | 0.039** |
| | | | | | (0.01) |
| (Age-45) X Female X E3 | | | | | 0.063* |
| | | | | | (0.03) |

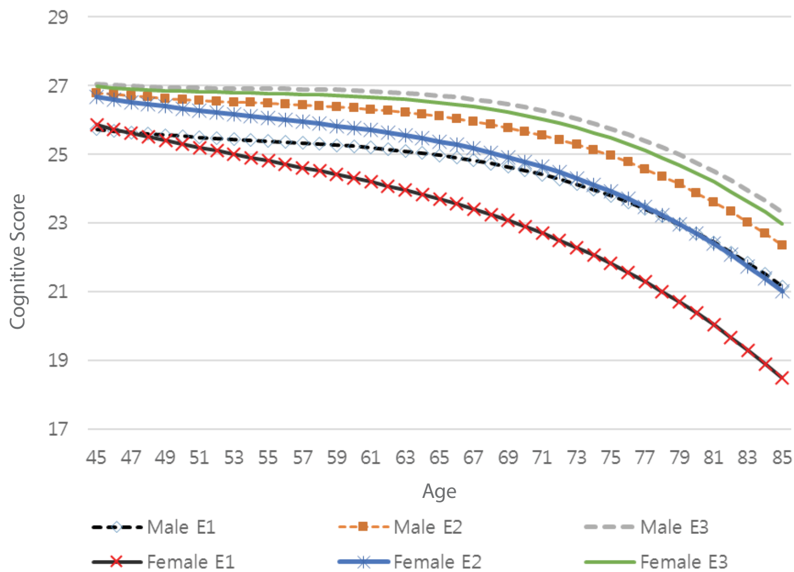
TABLE 2
(Continued)

| VARIABLES | Model (1) | Model (2) | Model (3) | Model (4) | Model (5) |
|---|---|---|---|---|---|
| Random Part: | | | | | |
| Level-two random intercept standard deviation (between-individual) | 2.257<br>(0.03) | 2.243<br>(0.03) | 2.223<br>(0.03) | 2.246<br>(0.03) | 2.212<br>(0.03) |
| Level-one random residual standard deviation (within-individual) | 2.755<br>(0.01) | 2.756<br>(0.01) | 2.757<br>(0.01) | 2.755<br>(0.01) | 2.757<br>(0.01) |
| Log Likelihood | -74,445 | -74,427 | -74,393 | -74,424 | -74,376 |
| AIC | 148,944 | 148,912 | 148,842 | 148,905 | 148,820 |
| Observations | 28,860 | 28,860 | 28,860 | 28,860 | 28,860 |
| Number of subject | 5,772 | 5,772 | 5,772 | 5,772 | 5,772 |

Notes.—***: $p$<0.001, **: $p$<0.01, *: $p$<0.05, +: $p$<0.01 (two tailed). Each cell contains unstandardized regression coefficients with standard errors in parentheses. All models adjust for the hazard of attrition, multiple waves, marital status, region, employment, income, number of contact, poor self-rated health, depression, normal IADL, disability, sum of chronic diseases, regular exercise.

score deficit (b=-0.986, SE=.08) relative to male. In the realm of education, compared to those who graduated elementary school, those with middle to high school graduates report about 1.5 point higher score (b=1.480, SE=.09), and those with more than college education report about 2 point higher cognitive score(b=1.972, SE=0.14).

Subsequent three Models, Model 2 to Model 4, add an unique combination of two-way interaction term among age, female, and education, to Model 1 to test whether observed associations in Model 1 is further shaped by their interactions. First, Model 2 indicates that female disadvantage reported in Model 1 increases with age by the factor of -0.066 points. At age 45, female on average report approximately 1 (b=-0.957, SE=.08) lower score than male, but at age 70, for example, the average gender gap increases to about 2.6 points ((-.066 x 25)+(-.957)=2.61). The result suggests that female disadvantage is not only present but escalates with age, indicating that more severe female cognitive deficit among elderly than among middle aged population. Model 3, testing age by education interaction, reports that declining cognitive trajectory with age are further tilted by educational level where the initial gap at earlier age between the groups of lower and higher




NOTES.— Figure 1 is based on Model (5) in Table 2. The slopes of the lines show predicted cognitive score of six groups (by gender and by education) with age. Female disadvantage in cognitive score grows with age for all three educational groups but the extent of disadvantage is largest among the lower educational group (E1) and smallest among the higher educational group (E3).

**FIG. 1.**— Cognitive Trajectories by Education and Gender: KLoSA, 2006-2014 (N=5,772).

education gets even larger with age, confirming that lower education disadvantage also grows with age as the case with female disadvantage. Model 4 gauges gender by education interaction to test whether the effect of education is differed by gender. The results show that there is gender difference in the effect of education where the significant female disadvantage in the lower education but no gender difference among middle to high education.

Model 5 serves as a full model including all possible combination of two-way interactions as well as a three-way interaction of age, gender, and education in predicting cognitive score. The combined result of Model 1 to Model 4 suggests that the effects of two-way interaction might be contingent upon the remaining third variable. Among numerous possible ways of interpretation (i.e., depending on research interests), this could indicate that observed growing female disadvantage with age examined in Model 2 might

**TABLE 3**
**Loglikelihood-ratio Test among Nested Models (The Row Models Are Nested in the Column Models)**

| | Model 5 | Model 4 | Model 3 | Model 2 |
|---|---|---|---|---|
| Model 4 | LR chi2(5) = 95.50 *** | | | |
| Model 3 | LR chi2(6) = 33.95 *** | NA | | |
| Model 2 | LR chi2(5) = 101.92*** | NA | NA | |
| Model 1 | LR chi2(7) = 138.44*** | LR chi2(2) = 42.94 *** | LR chi2(1) = 104.49*** | LR chi2(2) = 36.52*** |

Notes.—***: $p<0.001$. Degrees of freedom in parentheses.

hinge on the level of education. The significance of three-way interaction indeed supports the speculation and the results are visualized in Figure 1.

Figure 1, based on Model 5 in Table 2, displays six age trajectories by gender and education. Although all 6 trajectories eventually fall with advancing age, it seems clear that there are varying rates of decline by gender and education. First, among low educational group (i.e., elementary school graduate, E1), the gender gap grows wider with age. That is, between men and women sharing the poorest education, female disadvantage increases rapidly with age and highest among three educational group. Second, among mid educational group (i.e., middle to high school graduate, E2), the gender gap grows with age, yet, smaller scale than the low educational group. Between men and women with moderate level of education, female disadvantage with age observed but not as severe as the low educational group. Third, among high educational group (i.e., college or more), there is no or very little gender gap with age.

Table 3 reports a series of likelihood ratio tests among nested models in Table 1. The results confirm that considering interaction terms improves model fit significantly in terms of comparison between Model 1 and Model 2 to Model 5, respectively, and between each of Model 2 to Model 4 and Model 5. In addition, decreasing AIC (-2*LL-2k) magnitude with advancing Model in Table 2 indicates similar results as likelihood ration test that justifies considering higher order interaction terms.

## Conclusion and Discussion

Attention to cognitive decline has been escalated partly in response to the change or projected change of population composition characterized by increasing elderly population and well as even higher increase of AD relative to that of elderly population. Although previous studies has provided valuable insights and relevant observation in the understanding of CD, as a body of work, they are limited in revealing dynamic interactions among macro social factors come to influence the long-term process of CD. We address this issue by providing such evidence that female disadvantage varies with time, and even that pattern of association is also shaped by education level. We discuss several implications of this finding as well as limitations of this study.

First, the protective role of education in CD has been reaffirmed by longitudinal data. Participants with high education report high cognitive score and the gap from those with low education grow over their life-course, suggesting that cognition protecting function is not only present but increases with age. This pattern of increasing health gap with age by education have been observed with other health outcomes such as depression with respect to depression (Mirowsky 1996; Mirowsky and Ross, 2003b) and body mass index with female with low SES (Pudrovska et al 2014). The finding of education as a structural amplifier in the relationship with cognitive decline might also suggest more active role of education in CD because it boils down to the effect of education, or possible interaction of education with other factors that are responsible for widening distance in cognitive score between high and low education with age. Identifying potential interaction of education with other risk factors such as low level of social engagement, poor exercise/diet may be of use for understanding social processes of CD. Moreover, investigating the pathways through which these key variables come to affect CD would provide valuable insight in the context of South Korea facing ever-growing elderly population.

Second, female disadvantage of cognitive decline may be moderated by social contexts such as education. As mentioned earlier, it is not absolutely conclusive but there might be some female disadvantage in CD due possible to postmenopausal estrogen deprivation of female at older age that might operate through biological processes. Along with recent evidence supporting influential role of environment in gender difference in CD (Miller and Halpern 2014), finding of this study also echoes environmental influences of education in shaping female disadvantage in the contexts of South Korea. Structural disadvantage as well as poor health outcomes implicated from the poor education opportunity for female has been documented (Chun et al; Park 2007; Shin and Kong 2015). The results of this study add new evidence implicated in cognitive decline where initially observed female disadvantage that increases with age reduced among female with middle-level education and even nullified among female with high education. These patterns of association suggest that being female and high education might work as if chronic stressor and stress-buffer in stress process framework such that the effect of increasing female disadvantage with age is buffered by protective role of high education (Pearlin 1989; Pearlin et al. 1981). This account points to the possibility that South Korean women are exposed to additional stressors that are time-varying as well as education-specific, possibly, such as gender stereotypes. Indeed prevalence of such biased perception on female gender role has been dissipated significantly over time and that is exactly what data show.

Third, the results of this study may be pertinent to famous sex paradox observed in most societies: Female lives longer but also gets sick more. Woo (2014) reports that sex paradox is true in cognitive decline where female enjoys longer longevity yet suffers longer duration of cognitive disability. Moreover, in the same study, higher education not only increases quantity of longevity by extending life duration in absolute sense but quality of longevity by increasing the duration of healthy living portion (i.e., living without cognitive disability). The findings from our study using the same data reveal that female deficit in cognitive function at older age may be significantly prevented for women with higher education but may be more pronounced with poorer education. Combining these two sets of findings suggests that female sex paradox in cognitive health could be reduced with the improvement in gender equity in education.

Fourth, the finding of age differences in our study should be interpreted carefully in the context of the APC (Age-Period-Cohort) problem. Although we control for the effect of period in the study, the distinction between age and cohort has not been made due to the identification issue in APC model. Hence, it is possible to attribute the observed growing gender difference at older age in our study to shrinking gender gap from earlier cohort to recent cohort. Understanding exact source of variation would be invaluable and should be pursued in the future research. Recent debate as well as advancement on the APC processes might provide useful guidance in understanding how APC matters in cognitive health as well (Bell and Jones

2015; Reither et al. 2015).

Lastly, the key finding of this study suggests that female disadvantage in cognitive decline is not evitable. Instead, the results show achieving high education and develop high human capital may successfully fend off or minimize detrimental influence of female disadvantage in cognitive health. The active role of education observed for female disadvantage may be also useful for to be ever-growing elderly who have not recognize fully that what they do everyday matters in terms of health including cognitive function at older age.

Our study is characterized by following limitations. First, there are multiple measures of cognitive function and MMSE is just one of them. Although can be used as a global cognitive function, MMSE are known to have floor and ceiling effects and should be administered to serve as a screening instrument as opposed to be used for formal diagnosis of cognitive impairment such as dementia. Second, previous studies reported that there are normative level of cognitive score by age and education (Crum et al. 1993). However, it should not be misled to believe that the observed differences in score by education and age are given regardless of social circumstances that could have caused the differences in the first place. The results of our study show that they are deeply related in demonstrating strong environmental influences on cognitive score (Berkman 1986). Third, person-years sampling criteria include persistent participation of all five times of survey, thus selected sample composition is different from the one allowing partial participations of less than five times of survey. The resulting patterns of association from more flexible sample method are (not shown but available upon request) consistent with the one reported here but generally the relationships are more strong (i.e., steeper decline trajectories and wider distance between subgroups) with the flexible sample.

In spite of these limitations, the results of this study underscore the importance of social influences and interplays between age, gender, and education in shaping declining cognitive trajectories. The observed contingencies may be informative in explaining how cognitive function or decline has been keenly reflected by the processes of social stratification and cultural contexts such as gender norm. These complex social influences expressed through daily routines and accumulated over time may or may not interact with unobserved heterogeneity such as genetics or physiological processes in their effects on an array of health outcomes including cognitive health. Therefore, it will be important to look for and to secure interdisciplinary research opportunities to efficaciously deal with challenging face of cognitive decline.

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