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Social network and health behaviors among Japanese older adults: A three-wave longitudinal study

Abstract

Identifying modifiable determinants of behavior is essential for developing effective strategies to promote health behaviors among older adults. Although social networks are potentially modifiable determinants of health behaviors, their longitudinal associations have not been established in previous studies. The present study examined whether a larger social network is associated with higher dietary variety, longer time spent exercising, and shorter time spent viewing TV among older adults. This is a longitudinal study. The data of 908 Japanese older adults were obtained through a three-wave questionnaire survey (Wave 1, December 2017 to January 2018; Wave 2, after one year; Wave 3, after three years) and analyzed. In each wave of the survey, dietary variety (dietary variety score), exercise time (hours per day), TV viewing time (hours per day), and social network (family and friend subscales of the Japanese version of the abbreviated Lubben Social Network Scale) were measured. The present study used latent growth, cross-lagged, and simultaneous effect models to investigate the longitudinal associations of family and friend social networks with dietary variety, exercise time, and TV viewing time. However, these models did not show clear and robust associations. Whether social networks are determinants of health behaviors among older adults remains inconclusive.

Keywords: Determinants; Health Behavior: Older People; Social Networks

Lay Summary

The importance of promoting health behaviors among older adults is obvious. Identifying the

modifiable determinants of health behaviors is essential for developing effective strategies to promote health behaviors. Although social networks are potentially modifiable determinants of health behaviors, their longitudinal associations have not been established in previous studies. This study examined the longitudinal associations between social networks and health behaviors among older adults. To address this issue, we conducted a three-wave questionnaire. However, we failed to find clear and robust associations between social networks and health behaviors. Whether social networks are determinants of health behaviors among older adults remains inconclusive.

Introduction

The importance of health behaviors such as a high-quality diet, exercising well, and reducing TV time for health promotion among older adults is obvious. One essential aspect of diet quality among older adults is dietary variety. Dietary variety is associated with various geriatric health problems (Motokawa et al., 2018; Otsuka et al., 2017; Yokoyama et al., 2017). The health benefits of incorporating physical activity are evident (Ministry of Health, Labour, and Welfare, 2013; World Health Organization, 2020). Exercise is a major component of physical activity performed during leisure time (Ministry of Health, Labour, and Welfare, 2013; World Health Organization, 2020). Since older adults tend to lose the opportunity to accumulate physical activity in occupational and transportation settings due to retirement (Barnett et al., 2014), leisure time is a relatively more important setting for incorporating physical activity among them. The Japanese government recommends engaging in exercise for at least 30 minutes per day, twice a week or more, regardless of its intensity (Ministry of Health, Labour, and Welfare, 2013). As recommended by the World Health Organization (2020), the health impacts of sedentary behavior are widely accepted. The major domain of sedentary behavior among older adults is TV viewing (Shibata et al., 2019). Meta-analyses

confirmed that longer TV viewing time is associated with higher mortality risks (Grøntved & Hu 2011; Sun et al., 2015). Identifying modifiable determinants of behavior is essential for developing effective strategies to promote health behaviors (Sallis et al., 2000). Since behavior-specific approaches are recommended when examining the determinants of health behavior (Sallis & Owen, 2015), examining the determinants specified for dietary variety, exercising behavior, and TV viewing behavior is meaningful apart from determinants of overall indices of dietary habits, physical activity, and sedentary behavior.

Social networks are modifiable determinants of dietary variety, exercise behavior, and TV viewing behavior among older adults. Social networks refer to connections and ties between individuals and represent the structural aspect of social relationships (Holt-Lunstad & Uchino, 2015). Umberson et al. (2010) proposed a conceptual model to theoretically explain the link between social networks and health behaviors. This model (Umberson et al., 2010) assumes that social networks influence healing behaviors mediated by multiple pathways, such as social support, social and personal control, social norms, stress, and mental health. The ecological model of health behavior (Sallis & Owen, 2015) proposes that health behaviors are determined by multilevel factors, such as individual, social, and environmental factors. Social networks can be categorized as one factor at the social level. While various social-level factors have been investigated as determinants of health behaviors, one potential advantage of examining social networks is that a desirable social network could connect with health outcomes not only through health behaviors (Xiao et al., 2019) but also through other mediating processes such as stress (Ellwardt et al., 2020) and well-being (Harada et al., 2021), as conceptually proposed (Thoits, 2011). Another potential advantage is that previous studies have developed intervention strategies to enhance social network among older adults (Fujiwara et al., 2009; Harada et al., 2021; Jones et al., 2015; Rook & Sorkin, 2003). By employing such strategies, it is possible to modify social networks among older adults.

Although previous studies have examined this, it remains unclear whether social networks are determinants of health behaviors among older adults. Some cross-sectional studies have reported that desirable social networks are associated with greater consumption of fruits and vegetables (Choi et al., 2020; Sahyoun et al., 2005), higher levels of physical activity (Shiovitz-Ezra & Litwin, 2012), and lower levels of sedentary behavior (Asiamah et al., 2021; Tully et al., 2020). However, other cross-sectional studies have reported null results regarding its association with fruit and vegetable consumption (Doubova et al., 2016), exercise behavior (Doubova et al., 2016), physical activity (Chen et al., 2021; Harada et al., 2019; Tully et al., 2020), sedentary behavior (Chen et al., 2021; Loprinzi & Crush, 2018), and TV viewing time (Russell & Chase, 2019; Van Cauwenberg et al., 2014). While one potential reason for inconsistencies in their associations would be the cross-sectional study design, only a few studies have examined their longitudinal associations among older adults. Moreover, the findings from longitudinal studies are also inconsistent. Shatenstein et al. (2016) reported that, while the cross-sectional association between a higher social network and dietary quality was null, a higher social network was longitudinally associated with lower dietary quality among older adults. Bloom et al. (2017) showed that higher social networks were cross-sectionally associated with higher diet quality among older women but not among older men and not longitudinally associated among both older women and men. Nemoto et al. (2021) revealed a cross-sectional association between social contact and physical activity but failed to show significant longitudinal associations among older adults. Therefore, more longitudinal studies are necessary to confirm whether social networks are the determinants of health behaviors.

The present study examined whether a larger social network is associated with higher dietary variety (Hypothesis 1), longer time spent exercising (Hypothesis 2), and shorter time spent viewing TV (Hypothesis 3) among older adults.

Methods

Participants and Procedures (Figure 1)

This study had a longitudinal design. The present study analyzed data obtained from a three-wave questionnaire survey targeting older adults living in Nada Ward of Kobe City, Hyogo Prefecture, Japan. The survey was conducted via mail. From the official register of residents of Nada Ward, the survey extracted all men aged 64, 69, and 74 years on the first day of April 2017 (n = 2204) and all their wives aged within ten years of men (n = 1516). We asked 3720 individuals to complete the baseline questionnaire from December 2017 to January 2018 (Wave 1). Among them, 1784 individuals (48.0%) answered the questionnaire. Among the 1784 individuals, 1079 agreed to provide further contact with our research group. We conducted a one-year follow-up survey of 1079 individuals, of which 919 individuals answered (December 2018 to January 2019: Wave 2). We also conducted a three-year follow-up survey of 1079 individuals and 854 individuals who answered (December 2020 to January 2021: Wave 3).

[insert - Figure 1. Flowchart of the participants and procedure - here]

Among the 1784 respondents of Wave 1, the present study excluded 876 individuals because 1) they did not answer both Wave 2 and Wave 3 surveys (n=807) and 2) they had certification of long-term care, support, or missing values of the certification at any wave (n=69). Thus, the remaining data from 908 individuals were analyzed in the present study.

The survey was conducted as a large-scale research project. Using the data from this survey, the authors of this study have already published two papers (Harada, Masumoto, & Okada, 2021; Harada et al. 2022), and submitted several other papers. None of these studies treated the association between social networks and health behavior as the primary research question.

Written informed consent was obtained from all participants. Approval was obtained from the Ethical Committee of the Graduate School of Human Development and

Environment, Kobe University (No. 549-2). All the procedures were conducted in accordance with the principles of the Declaration of Helsinki.

Measures

Health Behaviors

The survey at each wave measured dietary variety using the Dietary Variety Score (Kumagai et al., 2003). This is one of the most used scales with older Japanese adults (Motokawa et al., 2018; Uemura et al., 2018; Yokoyama et al., 2017). This score evaluates frequencies of consuming ten components (meat, fish, eggs, milk, soy products, green and yellow vegetables, potatoes, fruit, seaweed, and fats and oils) in a usual week by four choices: "almost every day," "3 or 4 days a week," "1 or 2 days a week," and "almost never." The present study calculated the sum of the number of components to which a respondent answered "almost every day" as the dietary variability score (range, 0–10) (Kumagai et al., 2003). Higher scores represent greater dietary variety.

Following research trends in Japan (Chen et al., 2013; Harada, in press; Ministry of Health, Labour, and Welfare, 2020; Sugisawa et al., 2020), at each wave the survey asked individuals to indicate how many days they engaged in exercise in a usual week (0 to 7 days). If they answered one to seven days, the survey also asked them to indicate the average exercise time (hours and minutes) for days when they engaged in exercise. The present study calculated weekly exercise time (hours per day) by multiplying the frequency by time.

For TV viewing time among nonworkers, the survey, at each wave, was asked to report the average TV viewing time (hours per day) on a typical day. For workers, the survey asked to answer the weekly frequencies of working, the time spent viewing TV on typical non-working days, and the time spent viewing TV on typical working days. From these responses, the TV viewing time (hours per day) among the workers was calculated.

Social Network

The survey in each wave employed the Japanese version of the abbreviated Lubben Social Network Scale (Lubben et al., 2006; Kurimoto et al., 2011). For the reliability of the Japanese version, Cronbach's alpha was 0.82, and Pearson's correlation coefficient for test-retest was 0.92 (Kurimoto et al., 2011). For validity, significant associations of this scale with the risk of suicide, depression, and social support have been confirmed (Kurimoto et al., 2011). This scale consists of family and friend subscales: the family subscale has three items, and the friend subscale has three items. Each item asks about the number of qualified persons from "none (0)," one (1)," two (2)," three or four (3)," "five through eight (4)," or "nine or more (5)." Several studies have reported that the relationships between social networks and health behaviors differ according to social network sources (Choi et al., 2020; Nemoto et al., 2021; Shiovitz-Ezra et al., 2012). Thus, instead of calculating total scores by combining the family and friends subscales, the present study summed the scores of the items for the family (range, 0 to 15) and friend (range, 0 to 15) social networks separately. Higher scores represent larger social networks.

Basic Factors

The present study analyzed the data on age, gender (men, women), educational background (junior high or high school, more than high school), living alone (no, yes), current employment (no, yes), and frailty (no, yes) in Wave 1 as basic factors. The survey evaluated frailty by the Kihon Checklist (Ministry of Health, L. and Welfare, 2009; Satake et al., 2016). This scale has 25 items, and the sensitivity and specificity to detect frailty status by its cut-off point (7/8) were 89.5% and 80.7%, respectively (Satake et al., 2016).

Analysis

Overall Plan

This study investigated the associations between social networks and health behaviors using three models: a latent growth model, a cross-lagged model, and a

simultaneous effect model. As the conceptual model (Umberson et al., 2010) proposes that various factors would mediate the associations among them, the present study examined both time-lagged and simultaneous associations. Such models have several advantages. While the latent growth model cannot examine bidirectional associations directly, it can examine time-lagged and simultaneous associations together:1) whether the initial status of the social networks is associated with the initial status of health behaviors (i.e., simultaneous associations); 2) whether the initial status of the social networks predicts further changes in health behaviors (i.e., time-lagged associations); and 3) whether changes in social networks over time accompany changes in health behaviors (i.e., simultaneous associations). While a cross-lagged model and simultaneous effect model cannot examine both time-lagged and simultaneous associations in one model, they can directly examine bidirectional associations. Concordance of the results for their associations from different models strengthens the robustness of the findings.

The present study employed the comparative fit index (CFI), the Tucker–Lewis index (TLI), and root-mean-square error of approximation (RMSEA) as model fit indices. The cut-off for CFI and TLI was 0.95 and 0.06 for RMSEA (Hu & Bentler, 1999). The present study handled missing data using a full information maximum likelihood estimation (FIML). IBM SPSS AMOS 25.0 was utilized to conduct both models. Statistical significance was set at $P < 0.05$.

Latent Growth Model

As shown in Supplementary Figure 1, the latent growth model estimated the intercept (initial level) and slopes (longitudinal change over time) of social networks with family, social networks with friends, and health behaviors from the observed data at each wave. The factor loadings for the intercept were set at 1 for all waves, and the slope was set at 0, 1, and 3 for Wave 1, Wave 2, and Wave 3, respectively. The present study investigated three types of

paths: 1) the paths from the intercepts of social networks with family and friends to the intercepts of health behavior, 2) the paths from the intercepts of social networks with family and friends to the slope of health behavior, and 3) the path from the slopes of social networks with family and friends to the slope of health behavior. The correlations between the intercept of social network with family, the intercept of social network with friends, the slope of social network with family, and the slope of social network with friends, and the correlation between the intercept and slope of health behavior were included. The present study did not include paths from basic factors to the intercepts and slopes of the social network variables and health behavior because improper solutions were obtained if such paths were included. If the paths from the intercepts of the family and friends social networks to the intercepts of health behaviors were significant, this would support the existence of simultaneous associations between them. If the paths from the intercepts of the family and friends social networks to the slopes of health behaviors were significant, then the existence of time-lagged associations would be supported. Furthermore, if the slopes of family and friends social networks to the slopes of health behaviors were significant, then the existence of simultaneous associations would be supported.

Cross-lagged Model

As shown in Supplementary Figure 2, the cross-lagged model specified six types of paths: 1) autoregressive paths within social networks with family, social networks with friends, and health behaviors; 2) paths from the social network with family and friends at prior waves to health behaviors at posterior waves; 3) paths from health behaviors at prior waves to social network with family and friends at posterior waves; 4) paths from the social network with family at prior waves to social network with friends at posterior waves; 5) paths from the social network with friends at prior waves to social network with friends at posterior waves; and 6) paths from basic factors at Wave 1 to social network with family, the social

network with friends, and health behaviors at Wave 1. The cross-sectional correlations among social networks with family, social networks with friends, and health behaviors at each wave, and the cross-sectional correlations among basic factors were included in the model. If the paths from the prior-wave family and friends social networks to posterior-wave health behaviors were significant, the existence of time-lagged associations would be supported.

Simultaneous Effect Model

As shown in Supplementary Figure 3, the simultaneous model specified six types of paths:1) autoregressive paths within family and friends social networks with family and health behaviors; 2) paths from family and friends social networks to health behaviors within the same wave; 3) paths from health behaviors to family and friends social networks within the same wave; 4) paths from family social networks to those of friends within the same wave; 5) paths from the friends social networks to the same within the same wave; and 6) paths from Wave 1 basic factors to family and friends social networks and health behaviors in Wave 1. The cross-sectional correlations among family and friends social networks and health behaviors in Wave 1 and the cross-sectional correlations among the basic factors were included in the model. If the paths from the family and friends social networks to health behaviors within the same wave were significant, simultaneous associations were supported.

Additional Analyses

To examine the potential influences of excluding 807 individuals who did not respond to both Wave 2 and 3 surveys, the present study included their data with FIML to conduct latent growth, cross-lagged, and simultaneous effect models. While weight-adjustment approaches such as the response propensity model (Little, 1986) have also been used in such cases (e.g. Neumark-Sztainer et al., 2006), Lee et al. (2019) recommends FIML or multiple imputation to reduce non-response bias in the longitudinal studies. Previous longitudinal studies have also employed FIML to handle non-respondents' data (e.g., Mallory

et al., 2021).

Results

Characteristics of Participants

Table 1 shows the baseline characteristics of the participants. Compared to those excluded from the analyses, those included in the analyses were likely to have a higher educational background, not have frailty, consume varied diets, spend more time exercising, spend less time watching TV, and have a higher social network with family and friends.

[insert - Table 1. Baseline characteristics of participants - here]

Supplementary Table 1 shows longitudinal changes in health behaviors and social network variables. Compared with Wave 1, the respondent spent longer time exercising and viewing TV and reduced their social network with friends at Wave 3. Dietary variety and social network with family did not significantly change from Wave 1 to Wave 2 and Wave 3.

Supplementary Table 2 shows Pearson's correlation coefficients among basic factors, health behaviors, and social network variables at Wave 1. At Wave 1, social network with family was positively and significantly correlated with dietary variety. Social network with friends was positively and significantly correlated with dietary variety and exercise time, and was negatively and significantly correlated with TV viewing time.

Latent growth model for Associations of Social Network with Health Behaviors

Figure 2 shows the results of the latent growth model for the associations between social networks and health behaviors. As shown in Figure 2, the paths from the intercepts of social networks with family and friends to the intercept of dietary variety and the path from the intercept of social networks with friends to the intercept of exercise time were positive and significant. The path from the intercept of social networks with friends to the intercept of TV time was negative and significant. However, all paths from the slopes and intercepts of social networks with family and friends to the slopes of dietary variety, exercise time, and TV

viewing time were not significant.

[insert - Figure 2. Results of latent growth model for associations of social network with dietary variety (A), exercise time (B), and TV viewing time (C) - here]

Cross-lagged model for Associations of Social Network with Health Behaviors

Figure 3 shows the results of the cross-lagged models for the associations of social networks with health behaviors. The path from the friends social network in Wave 1 to dietary variety in Wave 2 and the path from the friends social network in Wave 2 to exercise time in Wave 3 were significant and positive. However, other cross-lagged paths from social networks with family or friends to health behaviors were not significant.

[insert - Figure 3. Results of cross-lagged model for associations of social network with dietary variety (A), exercise time (B), and TV viewing time (C) - here]

Simultaneous effect model for Associations of Social Network with Health Behaviors

Figure 4 shows the results of the simultaneous effect models for the associations between social networks and health behaviors. The path from the friends social network to dietary variety was significant and positive within Wave 2. However, other simultaneous paths from family or friends social networks to health behaviors were not significant.

[insert — Figure 4. Results of simultaneous effect model for associations of social network with dietary variety (A), exercise time (B), and TV viewing time (C) - here]

Additional Analyses for Associations of Social Network with Health Behaviors

The additional analyses for the latent growth model (Supplementary Figure 4), cross-lagged model (Supplementary Figure 5), and the simultaneous effect model (Supplementary Figure 6), showed the same results as the corresponding main analyses reported in Figures 2 to 4.

Discussions

The present study did not obtain clear and robust findings regarding the cross-lagged

and simultaneous associations of social networks with dietary variety, exercise time, and TV viewing time. In particular, significant and positive associations of friends social network with dietary variety were observed for the intercepts in the latent growth model, Waves 1 to 2 in the cross-lagged model, and Wave 2 in the simultaneous effect model. Moreover, a significant and positive association of family social network with dietary variety was observed for the intercepts in the latent growth model. However, regarding other time frames and other analyses, the associations of social networks with dietary variety were null. Regarding exercise behavior, while significant and positive associations of friends social network with exercise time were revealed in the intercept in the latent growth model and Waves 2 to 3 in the cross-lagged model, the other associations were null. Regarding TV viewing behavior, only one significant and negative association of friends social network with TV viewing time was observed for the intercept in the latent growth model. Because eating with others is associated with higher dietary variety (Kimura et al., 2012), sufficient social networks may provide more opportunities for eating with others. Regarding the association of friends social network with exercise behavior, many prefer to exercise with people of the same age (Beauchamp et al., 2007) and gender (Dunlop & Beauchamp, 2011); therefore, friends might be a good source of group exercise. For the significant association of friends' social network with TV viewing, having a social network is a predictor of spending more time outside the home (Harada et al., 2019). Therefore, insufficient friend networks might lead to older adults staying at home more and watching more TV. However, null results were also revealed for their associations in the different time frames and models. From these equivocal and inconsistent findings, the present study failed to show robust results. It remains inconclusive whether social networks are determinants of health behaviors among older adults. Only a few previous studies have examined longitudinal associations between social networks and health behaviors (Bloom et al., 2017; Nemoto et al., 2021; Shatenstein et al., 2016), and they have failed to show clear

and desirable associations. Similarly, inconsistent findings on the associations among older adults have been reported in previous cross-sectional studies (Asiamah et al., 2021; Chen et al., 2021; Choi et al., 2020; Doubova et al., 2016; Harada et al., 2019; Loprinzi & Crush, 2018; Russell & Chase, 2019; Sahyoun et al., 2005; Shiovitz-Ezra & Litwin, 2012; Tully et al., 2020; Van Cauwenberg et al., 2014). One potential reason for their inconsistencies might be that the pathways from social networks to health behaviors are distal and indirect. A conceptual model (Umberson et al., 2010) proposes that social networks influence healing behaviors mediated by various factors, such as social support, social and personal control, social norms, stress, and mental health. It should be noted that this study did not measure these potential mediators. However, from this model, it is reasonable to assume the associations between social networks and health behaviors may not be proximal or direct. While several previous studies have supported the mediating role of social support (Thanakwang & Soonthorndhada, 2011; Wu & Sheng, 2019), the mediating role of these factors has not been comprehensively established. Further well-organized studies are necessary to clarify the mechanisms underlying the link between social networks and health behaviors among older adults.

The present study contributes to establishing determinants of health behaviors among older adults. The strength of the present study is its three-wave longitudinal study design. However, the present study has some limitations. First, it had a selection bias. As shown in Figure 1, only 908 of the 3720 individuals were analyzed in the present study. Moreover, Table 1 indicates that the individuals included in the present study tended to have better frailty status, health behavior, social network, and higher educational backgrounds than those excluded from the analyses. Since the additional analyses showed the same results as the main analyses, the influences of the non-response bias might not be critical. Nevertheless, selection bias is the most serious limitation of the present study and possibly weakens

the generalizability of the findings. Second, this study did not employ objective methods to measure health behaviors. Third, the latent growth model did not statically adjust for the potential influences of basic factors because an improper solution was obtained when including them. Fourth, it is unclear whether the intervals of each wave are appropriate for capturing the time-lagged association between social networks and health behaviors. Fifth, this study conducted a Wave 3 survey during the COVID-19 pandemic. The pandemic might have confounded the associations between social networks and health behaviors. Finally, measures of dietary variety and exercise time were based on domestic research trends in Japan. They are inconsistent with global research trends.

Regarding the practical implications of the findings from the present study, the effectiveness of providing social network interventions for promoting health behaviors among older adults remains unclear. Previous studies have reported that various types of programs such as event-based programs (Harada et al., 2021), intergenerational volunteer programs (Fujiwara et al., 2009; Rook & Sorkin, 2003), and online programs (Jones et al., 2015), are effective in promoting social networks among older adults. However, from the findings of the present study, the desirable translating effects of such programs on changes in health behaviors may be equivocal.

Conclusions

The present study examined whether a larger social network is associated with higher dietary variety, longer time spent exercising, and shorter time spent viewing TV among older adults. From the three-wave longitudinal survey, the present study failed to demonstrate clear and robust findings regarding the associations of social networks with dietary variety, exercise time, and TV viewing time among older adults. Given this, it remains unclear whether social networks are determinants of health behaviors.

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Figure and Table Captions

Figure 1. Flowchart of the participants and procedure

Table 1. Baseline characteristics of participants

Figure 2. Results of latent growth model for associations of social network with dietary variety (A), exercise time (B), and TV viewing time (C). The values represent unstandardized path coefficients and standard errors. Bold lines represent significant paths and dashed lines represent insignificant paths. For clarity, observed variables at each wave were not displayed. Model fit indices were $\chi^2(20)=63.70(p<0.001)$, CFI = 0.988, TLI = 0.974, and RMSEA = 0.049 for dietary variety; $\chi^2(20)=64.55(p<0.01)$, CFI = 0.987, TLI = 0.971, and RMSEA = 0.050 for exercise time; and $\chi^2(20)=64.32(p<0.001)$, CFI = 0.988, TLI = 0.974, and RMSEA = 0.049 for TV viewing time. *p<0.05, **p<0.01, ***p<0.001.

Figure 3. Results of cross-lagged model for associations of social network with dietary variety (A), exercise time (B), and TV viewing time (C). The values represent unstandardized path coefficients and standard errors. Bold lines represent significant paths and dashed lines represent insignificant paths. For clarity, autoregressive paths within social network variables and health behaviors, paths from basic factors, cross-sectional correlations among social network variables and health behaviors, and cross-sectional correlations among basic factors were not displayed. Model fit indices were $\chi2(42)=81.00(p<0.001)$, CFI=0.991, TFI=0.974, and RMSEA=0.032 for dietary variety; $\chi2(42)=95.66(p<0.001)$, CFI=0.987, TFI=0.962, and RMSEA=0.038 for exercise time; and $\chi2(42)=61.90(p=0.024)$, CFI=0.995, TFI=0.987, and RMSEA=0.023 for TV viewing time. *p<0.05, **p<0.01, ***p<0.001.

Figure 4. Results of simultaneous model for associations of social network with dietary variety (A), exercise time (B), and TV viewing time (C). The values represent unstandardized path coefficients and standard errors. Bold lines represent significant paths, and dashed lines represent insignificant paths. For clarity, autoregressive paths within social network variables and health behaviors, paths from basic factors, cross-sectional correlations among social network variables and health behaviors, and cross-sectional correlations among basic factors were not displayed. Model fit indices were $\chi 2(48)=84.65(p=0.001)$, CFI=0.991, TFI=0.979, and RMSEA=0.029 for dietary variety; $\chi 2(48)=105.23(p<0.001)$, CFI=0.986, TFI=0.964, and RMSEA=0.036 for exercise time; and $\chi 2(48)=67.63(p=0.032)$, CFI=0.995, TFI=0.989, and RMSEA=0.021 for TV viewing time. *p<0.05, **p<0.01, ***p<0.001.

Online supplementary material.

Supplementary Figure 1. Conceptual diagram of latent growth model for associations of social network with health behaviors.

Supplementary Figure 2. Conceptual diagram of the cross-lagged model for associations of social network with health behaviors. Basic factors were age, gender (men=0, women=1), educational background (junior high or high school=0, more than high school=1), living alone (no=0, yes=1), current employment (no=0, yes=1), and frailty (no=1, yes=1). Cross-sectional correlations among basic factors were included in the model.

Supplementary Figure 3. Conceptual diagram of the simultaneous effect model for associations of social network with health behaviors. Basic factors were age, gender (men=0, women=1), educational background (junior high or high school=0, more than high school=1), living alone (no=0, yes=1), current employment (no=0, yes=1), and frailty (no=1, yes=1). Cross-sectional correlations among basic factors were included in the model.

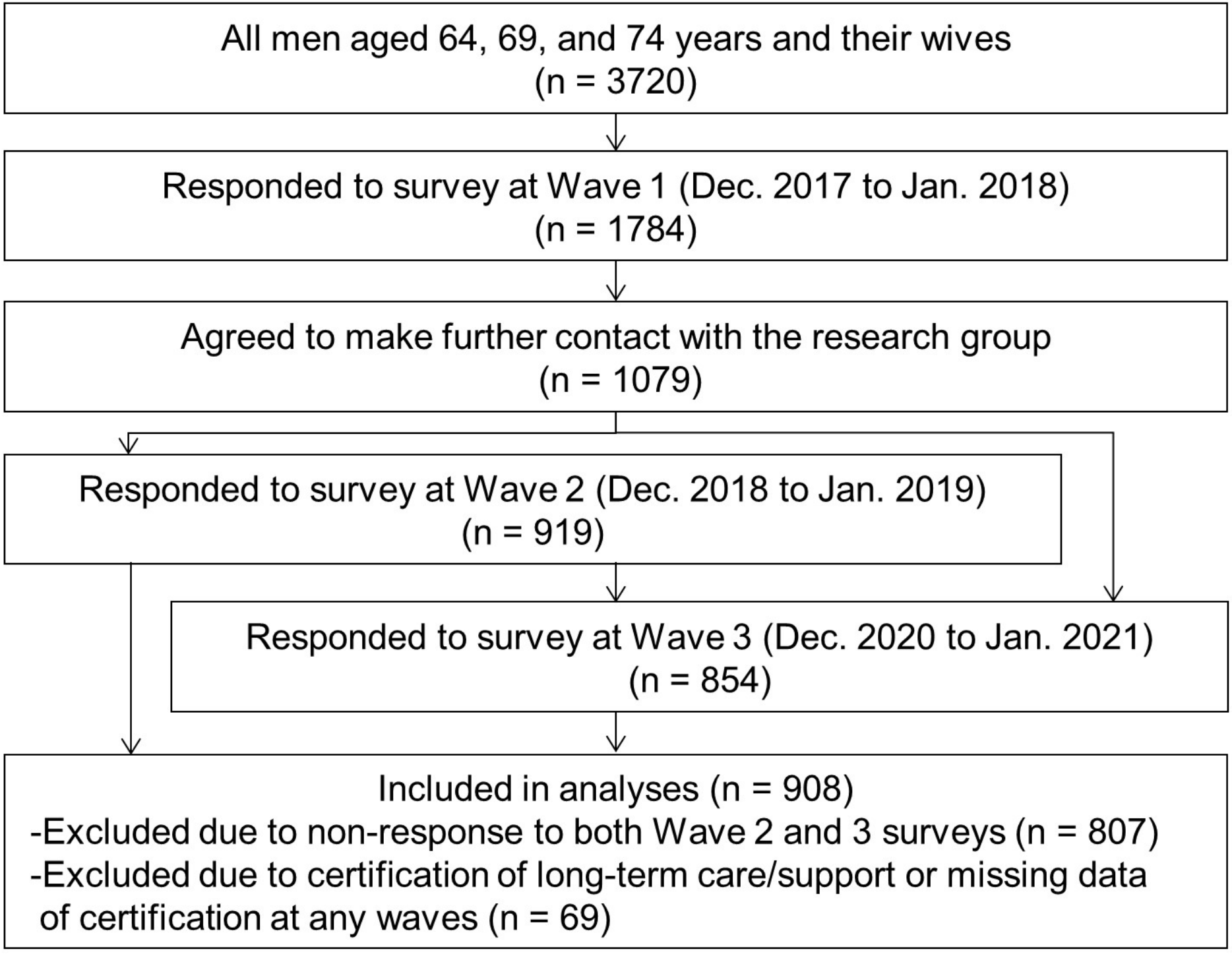
Supplementary Table 1. Longitudinal changes in health behavior and social network at each wave

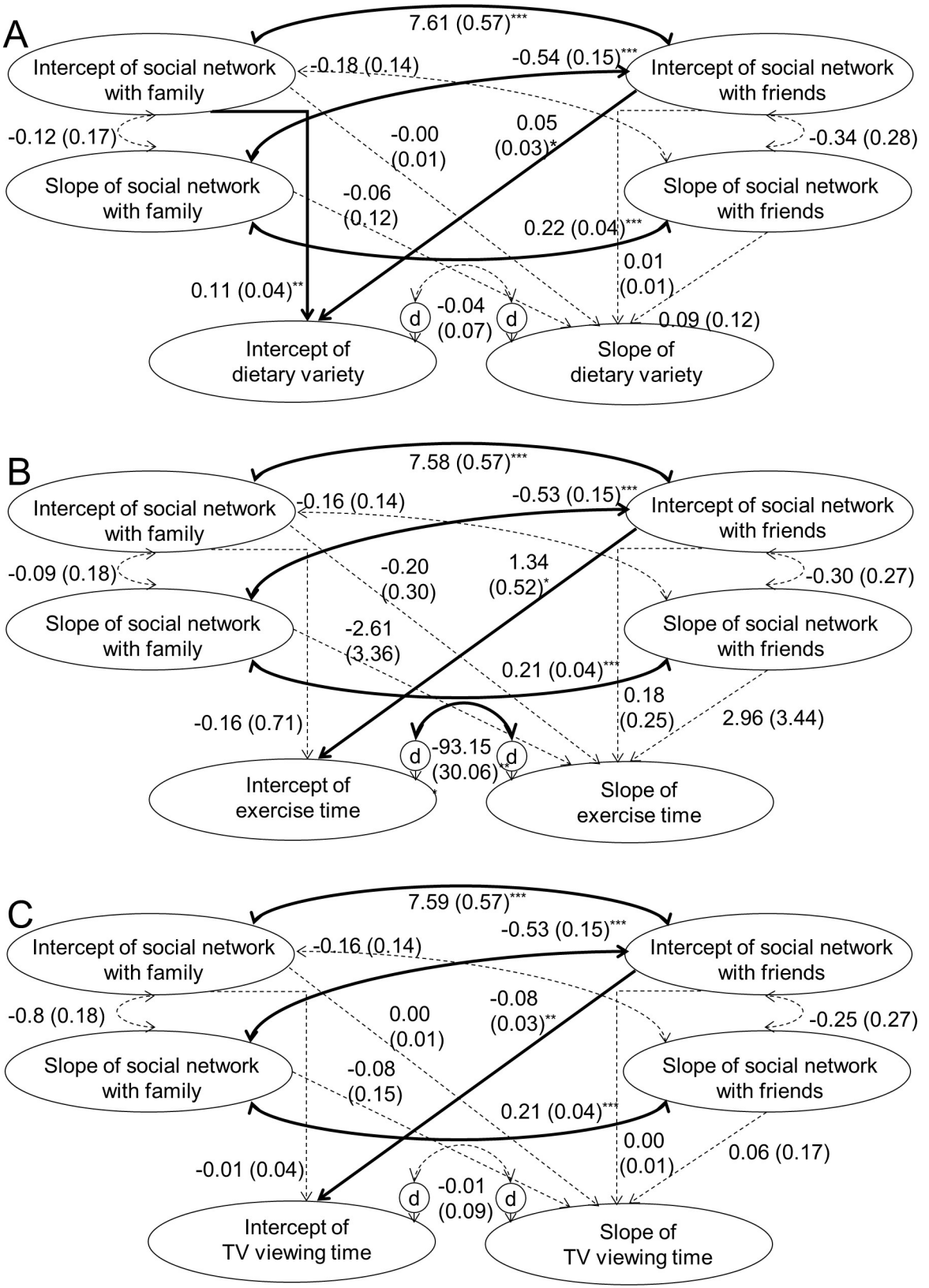
Supplementary Table 2. Pearson's correlation coefficients among basic factors, health behaviors, and social network variables at Wave 1

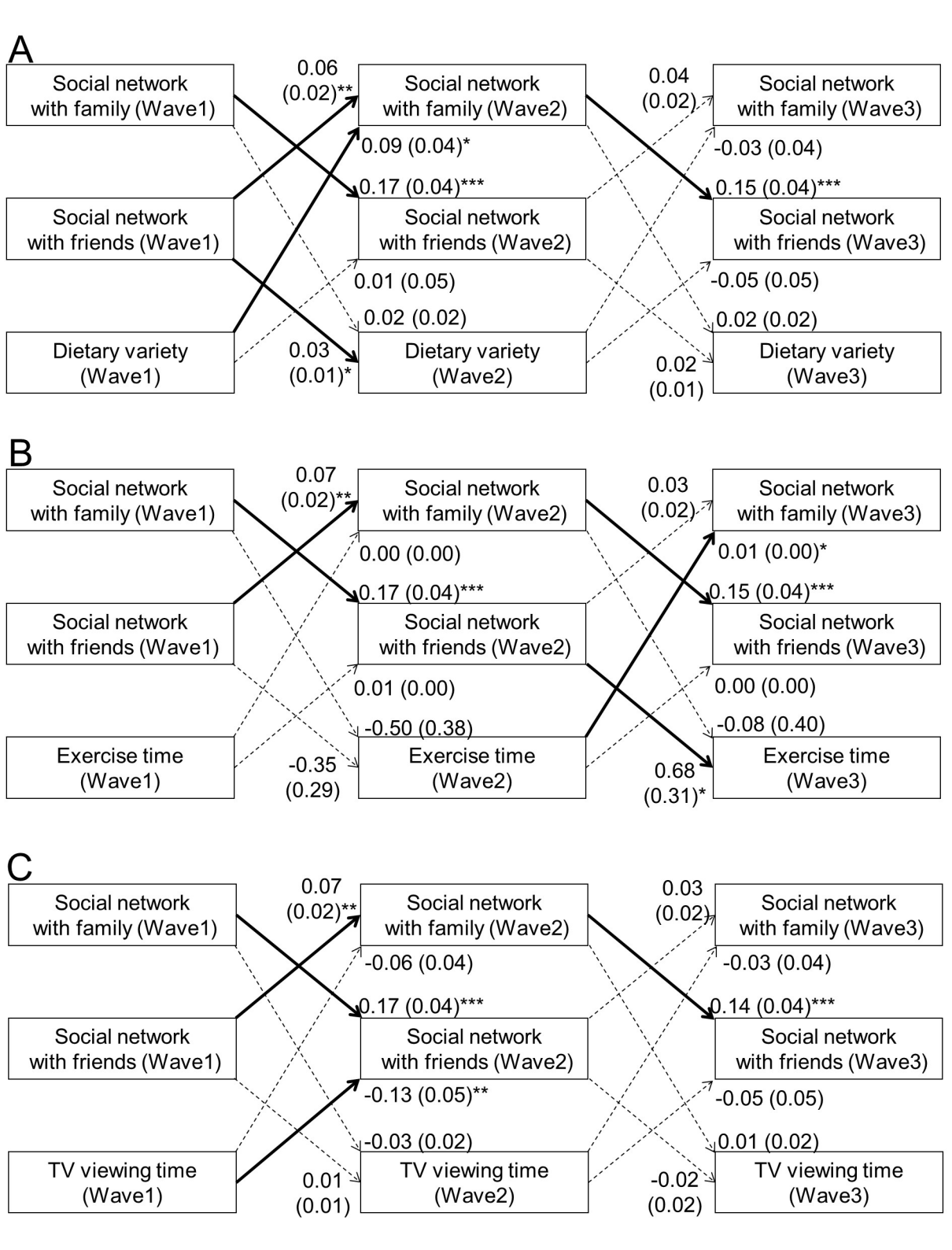
Supplementary Figure 4. Results of latent growth model for associations of social network with dietary variety (A), exercise time (B), and TV viewing time (C), including the non-respondents of both Waves 2 and 3. The present study handled the data of non-respondents

653 through full information maximum likelihood. The values represent unstandardized path
654 coefficients and standard errors. Bold lines represent significant paths and dashed lines
655 represent insignificant paths. For clarity, observed variables at each wave were not displayed.
656 Model fit indices were $\chi^2(20)=65.43(p<0.001)$, CFI = 0.988, TLI = 0.974, and RMSEA =
657 0.037 for dietary variety; $\chi^2(20)=63.67(p<0.01)$, CFI = 0.988, TLI = 0.973, and RMSEA =
658 0.036 for exercise time; and $\chi^2(20)=64.46(p<0.001)$, CFI = 0.988, TLI = 0.974, and RMSEA
659 = 0.037 for TV viewing time. *p<0.05, **p<0.01, ***p<0.001.
660
661 *Supplementary Figure 5*. Results of cross-lagged model for associations of social network
662 with dietary variety (A), exercise time (B), and TV viewing time (C), including the non-
663 respondents of both Waves 2 and 3. The present study handled the data of non-respondents
664 through full information maximum likelihood. The values represent unstandardized path
665 coefficients and standard errors. Bold lines represent significant paths and dashed lines
666 represent insignificant paths. For clarity, autoregressive paths within social network variables
667 and health behaviors, paths from basic factors, cross-sectional correlations among social
668 network variables and health behaviors, and cross-sectional correlations among basic factors
669 were not displayed. Model fit indices were $\chi2(42)=80.99(p<0.001)$, CFI=0.992, TFI=0.977,
670 and RMSEA=0.024 for dietary variety; $\chi2(42)=97.46(p<0.001)$, CFI=0.988, TFI=0.965, and
671 RMSEA=0.028 for exercise time; and $\chi2(42)=61.79(p=0.024)$, CFI=0.996, TFI=0.988, and
672 RMSEA=0.017 for TV viewing time. *p<0.05, **p<0.01, ***p<0.001.
673
674 *Supplementary Figure 6*. Results of simultaneous model for associations of social network
675 with dietary variety (A), exercise time (B), and TV viewing time (C), including the non-
676 respondents of both Waves 2 and 3. The present study handled the data of non-respondents
677 through full information maximum likelihood. The values represent unstandardized path

coefficients and standard errors. Bold lines represent significant paths, and dashed lines represent insignificant paths. For clarity, autoregressive paths within social network variables and health behaviors, paths from basic factors, cross-sectional correlations among social network variables and health behaviors, and cross-sectional correlations among basic factors were not displayed. Model fit indices were $\chi 2(48)=84.65(p=0.001)$, CFI=0.992, TFI=0.981, and RMSEA=0.021 for dietary variety; $\chi 2(48)=107.14(p<0.001)$, CFI=0.987, TFI=0.967, and RMSEA=0.027 for exercise time; and $\chi 2(48)=61.77(p=0.025)$, CFI=0.996, TFI=0.988, and RMSEA=0.017 for TV viewing time. *p<0.05, **p<0.01, ***p<0.001.


All men aged 64, 69, and 74 years and their wives
(n = 3720)
Responded to survey at Wave 1 (Dec. 2017 to Jan. 2018)
(n = 1784)
Agreed to make further contact with the research group
(n = 1079)
Responded to survey at Wave 2 (Dec. 2018 to Jan. 2019)
(n = 919)
Responded to survey at Wave 3 (Dec. 2020 to Jan. 2021)
(n = 854)
Included in analyses (n = 908)
-Excluded due to non-response to both Wave 2 and 3 surveys (n = 807)
-Excluded due to certification of long-term care/support or missing data
of certification at any waves (n = 69)


A
7.61 (0.57)***
Intercept of social network with family
-0.18 (0.14)
-0.54 (0.15)***
Intercept of social network with friends
-0.12 (0.17)
-0.00 (0.01)
0.05 (0.03)*
-0.34 (0.28)
Slope of social network with family
-0.06 (0.12)
Slope of social network with friends
0.22 (0.04)***
0.01 (0.01)
0.11 (0.04)**
d
-0.04 (0.07)
d
0.09 (0.12)
Intercept of dietary variety
Slope of dietary variety
B
7.58 (0.57)***
Intercept of social network with family
-0.16 (0.14)
-0.53 (0.15)***
Intercept of social network with friends
-0.09 (0.18)
-0.20 (0.30)
1.34 (0.52)*
-0.30 (0.27)
Slope of social network with family
-2.61 (3.36)
Slope of social network with friends
0.21 (0.04)***
0.18 (0.25)
-0.16 (0.71)
2.96 (3.44)
d
-93.15 (30.06)**
d
Intercept of exercise time
Slope of exercise time
C
7.59 (0.57)***
Intercept of social network with family
-0.16 (0.14)
-0.53 (0.15)***
Intercept of social network with friends
-0.8 (0.18)
0.00 (0.01)
-0.08 (0.03)**
-0.25 (0.27)
Slope of social network with family
-0.08 (0.15)
Slope of social network with friends
0.21 (0.04)***
0.00 (0.01)
-0.01 (0.04)
0.06 (0.17)
d
-0.01 (0.09)
d
Intercept of TV viewing time
Slope of TV viewing time


A
Social network with family (Wave1)
Social network with friends (Wave1)
Dietary variety (Wave1)
Social network with family (Wave2)
Social network with friends (Wave2)
Dietary variety (Wave2)
Social network with family (Wave3)
Social network with friends (Wave3)
Dietary variety (Wave3)
0.06 (0.02)**
0.09 (0.04)*
0.17 (0.04)***
0.01 (0.05)
0.02 (0.02)
0.03 (0.01)*
0.04 (0.02)
-0.03 (0.04)
0.15 (0.04)***
-0.05 (0.05)
0.02 (0.02)
0.02 (0.01)
B
Social network with family (Wave1)
Social network with friends (Wave1)
Exercise time (Wave1)
Social network with family (Wave2)
Social network with friends (Wave2)
Exercise time (Wave2)
Social network with family (Wave3)
Social network with friends (Wave3)
Exercise time (Wave3)
0.07 (0.02)**
0.00 (0.00)
0.17 (0.04)***
0.01 (0.00)
-0.50 (0.38)
-0.35 (0.29)
0.03 (0.02)
0.01 (0.00)*
0.15 (0.04)***
0.00 (0.00)
-0.08 (0.40)
0.68 (0.31)*
C
Social network with family (Wave1)
Social network with friends (Wave1)
TV viewing time (Wave1)
Social network with family (Wave2)
Social network with friends (Wave2)
TV viewing time (Wave2)
Social network with family (Wave3)
Social network with friends (Wave3)
TV viewing time (Wave3)
0.07 (0.02)**
-0.06 (0.04)
0.17 (0.04)***
-0.13 (0.05)**
-0.03 (0.02)
0.01 (0.01)
0.03 (0.02)
-0.03 (0.04)
0.14 (0.04)***
-0.05 (0.05)
0.01 (0.02)
-0.02 (0.02)

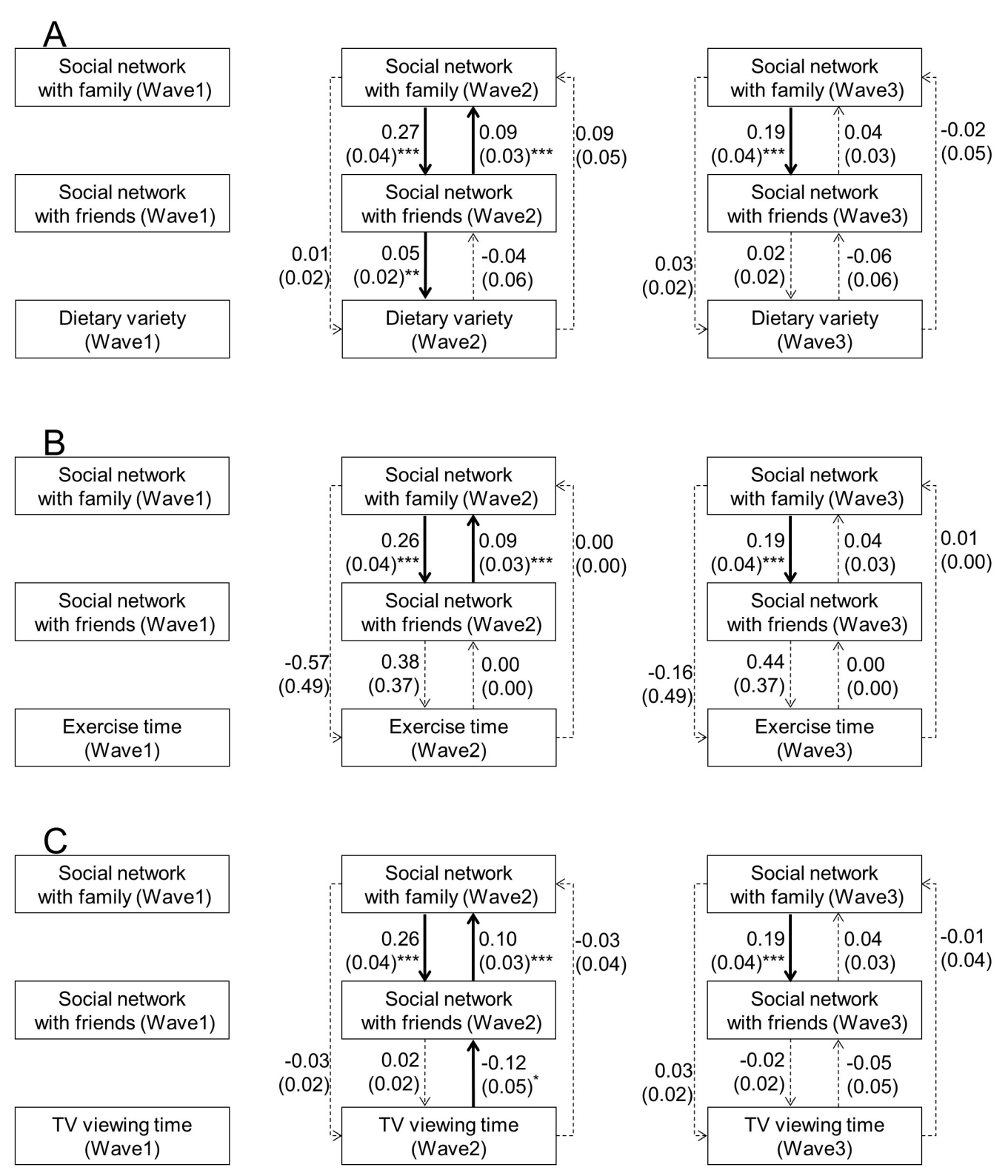
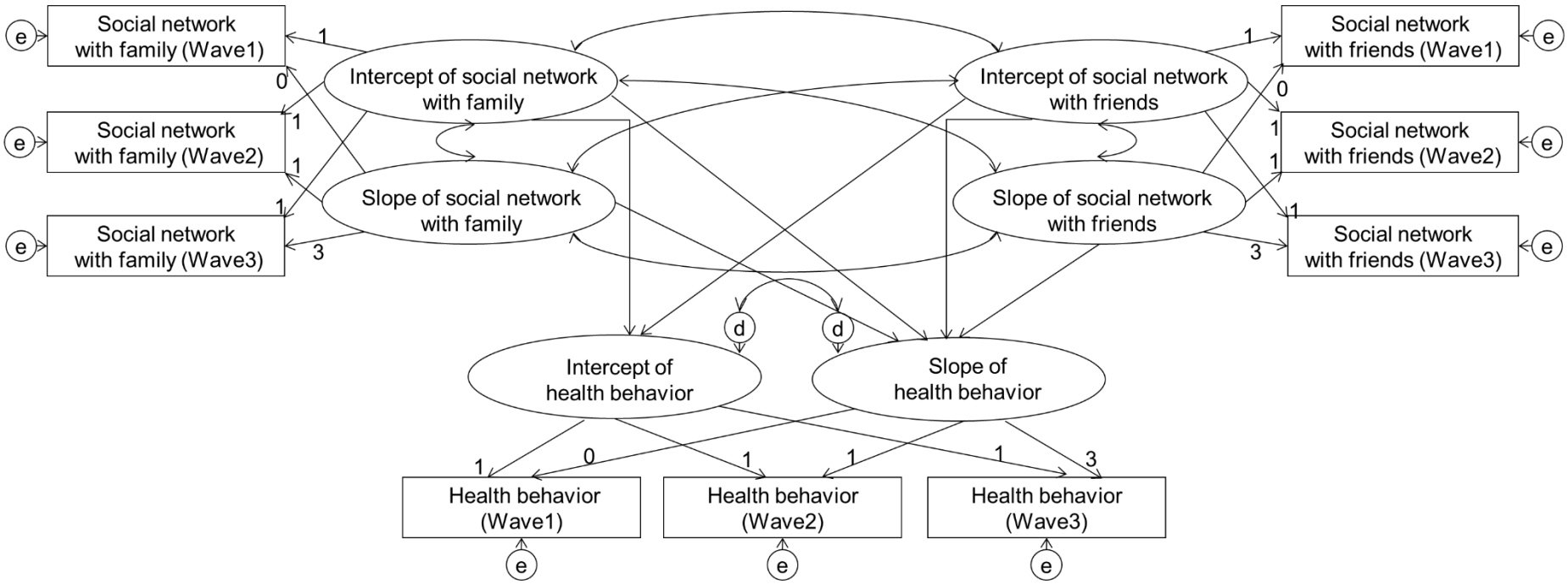

A
Social network with family (Wave1)
Social network with friends (Wave1)
Dietary variety (Wave1)
Social network with family (Wave2)
Social network with friends (Wave2)
Dietary variety (Wave2)
0.27 (0.04)***
0.09 (0.03)***
0.09 (0.05)
0.01 (0.02)
0.05 (0.02)**
-0.04 (0.06)
Social network with family (Wave3)
Social network with friends (Wave3)
Dietary variety (Wave3)
0.19 (0.04)***
0.04 (0.03)
-0.02 (0.05)
0.03 (0.02)
0.02 (0.02)
-0.06 (0.06)
B
Social network with family (Wave1)
Social network with friends (Wave1)
Exercise time (Wave1)
Social network with family (Wave2)
Social network with friends (Wave2)
Exercise time (Wave2)
0.26 (0.04)***
0.09 (0.03)***
0.00 (0.00)
-0.57 (0.49)
0.38 (0.37)
0.00 (0.00)
Social network with family (Wave3)
Social network with friends (Wave3)
Exercise time (Wave3)
0.19 (0.04)***
0.04 (0.03)
0.01 (0.00)
-0.16 (0.49)
0.44 (0.37)
0.00 (0.00)
C
Social network with family (Wave1)
Social network with friends (Wave1)
TV viewing time (Wave1)
Social network with family (Wave2)
Social network with friends (Wave2)
TV viewing time (Wave2)
0.26 (0.04)***
0.10 (0.03)***
-0.03 (0.04)
-0.03 (0.02)
0.02 (0.02)
-0.12 (0.05)*
Social network with family (Wave3)
Social network with friends (Wave3)
TV viewing time (Wave3)
0.19 (0.04)***
0.04 (0.03)
-0.01 (0.04)
0.03 (0.02)
-0.02 (0.02)
-0.05 (0.05)

Table 1. Baseline characteristics of participants

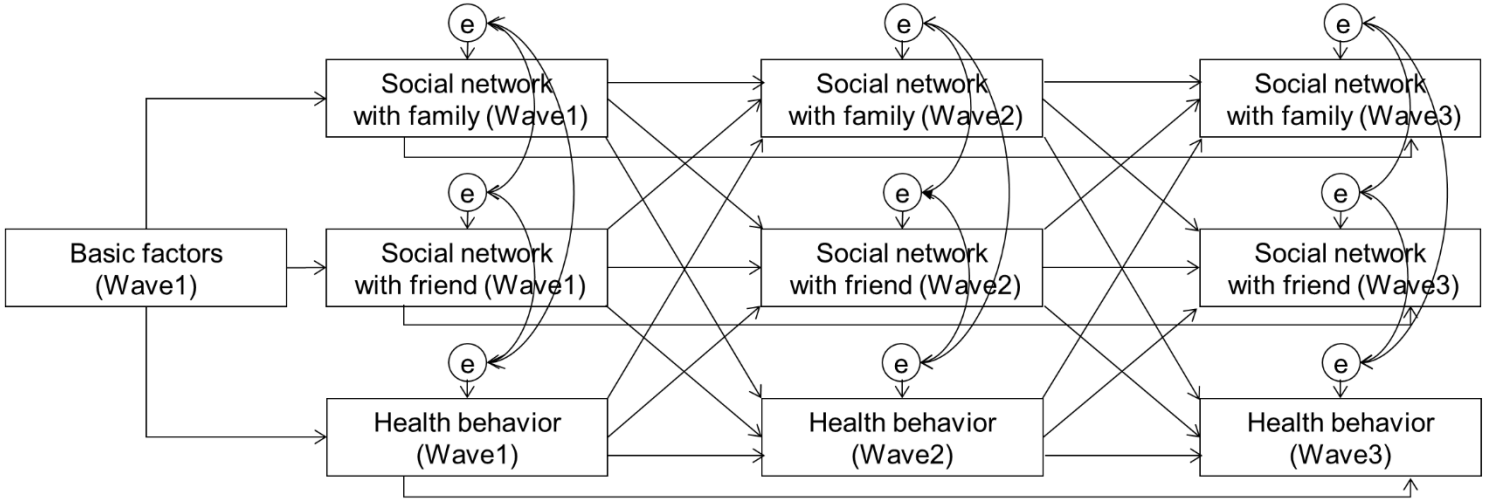
	Excluded from analyses		Included in analyses		
	n	M (SD) or %	n	M (SD) or %	p-value
Age (years), M (SD)	876	68.3 (4.1)	908	67.9 (4.3)	0.058
Gender (women), %	876	39.6%	908	40.0%	0.875
Educational background (beyond high school), %	852	**43.2%**	904	**56.8%**	**<0.001**
Living alone (yes), %	864	8.1%	902	7.1%	0.425
Current employment (yes), %	817	44.8%	872	49.2%	0.070
Frailty (yes), %	834	**14.4%**	897	**8.4%**	**<0.001**
Dietary variety (score), M (SD)	849	**3.1 (2.3)**	892	**3.6 (2.2)**	**<0.001**
Exercise time (minutes per day), M (SD)	713	**32.1 (43.3)**	746	**36.6 (41.4)**	**0.046**
TV viewing time (hours per day), M (SD)	749	**4.3 (2.6)**	826	**3.9 (2.4)**	**0.003**
Social network with family, M (SD)	843	**7.6 (3.6)**	897	**8.2 (3.5)**	**0.001**
Social network with friends, M (SD)	840	**6.6 (4.8)**	897	**7.9 (4.6)**	**<0.001**

[a]t-test, [b]chi-squared test

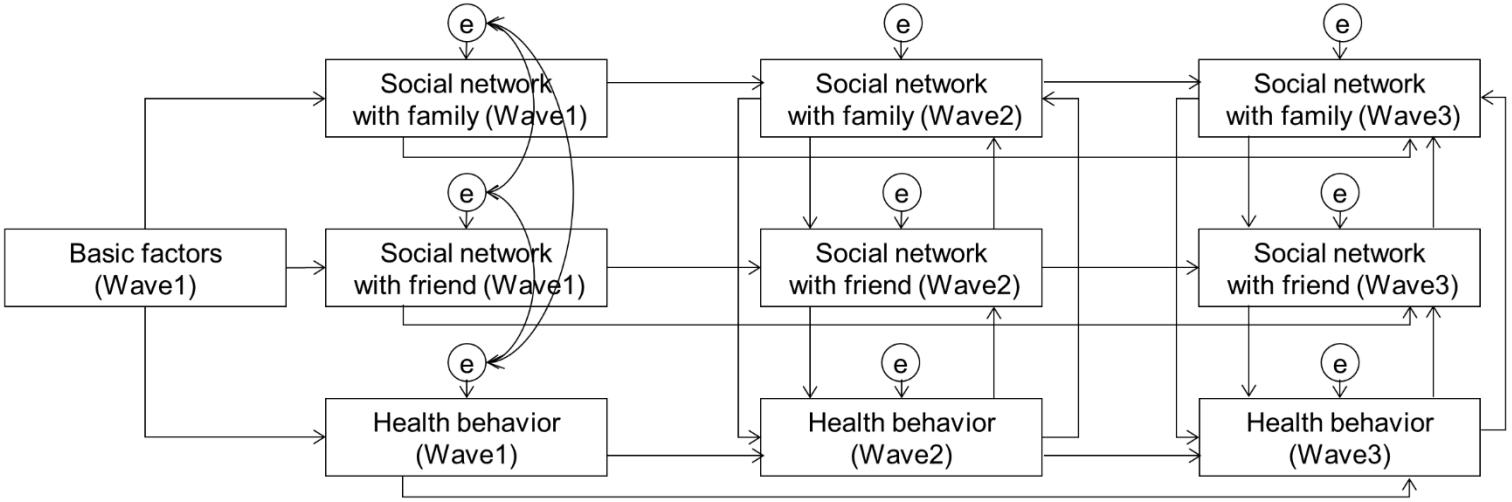
Sample size of each variable varies due to missing values.



Supplementary Figure 1. Conceptual diagram of latent growth model for associations of social network with health behaviors.



Supplementary Figure 2. Conceptual diagram of the cross-lagged model for associations of social network with health behaviors. Basic factors were age, gender (men=0, women=1), educational background (junior high or high school=0, more than high school=1), living alone (no=0, yes=1), current employment (no=0, yes=1), and frailty (no=1, yes=1). Cross-sectional correlations among basic factors were included in the model.



Supplementary Figure 3. Conceptual diagram of the simultaneous effect model for associations of social network with health behaviors. Basic factors were age, gender (men=0, women=1), educational background (junior high or high school=0, more than high school=1), living alone (no=0, yes=1), current employment (no=0, yes=1), and frailty (no=1, yes=1). Cross-sectional correlations among basic factors were included in the model.

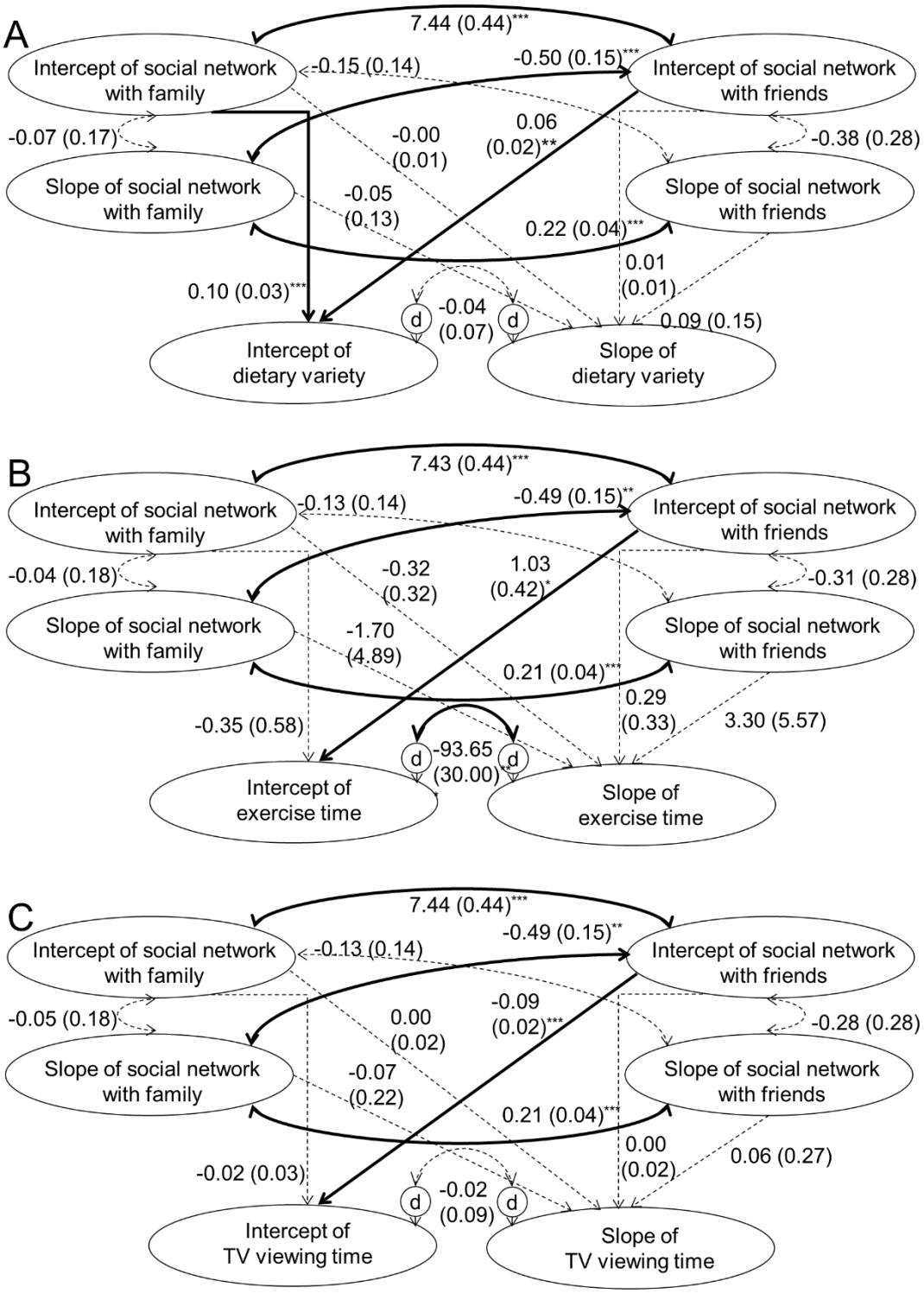
Supplementary Table 1. Longitudinal changes in health behavior and social network at each wave

	Wave 1		Wave 2			Wave 3		
	n	M (SD)	n	M (SD)	p-value[a]	n	M (SD)	p-value[a]
Dietary variety (score)	892	3.6 (2.2)	845	3.7 (2.2)	0.745	779	3.7 (2.3)	0.340
Exercise time (minutes per day)	746	36.6 (41.4)	810	38.7 (43.3)	0.837	756	**41.7 (44.2)**	**0.045**
TV viewing time (hours per day)	826	3.9 (2.4)	790	3.9 (2.4)	0.514	723	**4.1 (2.5)**	**0.002**
Social network with family (score)	897	8.2 (3.5)	852	8.2 (3.5)	0.525	790	8.2 (3.5)	0.784
Social network with friends (score)	897	7.9 (4.6)	851	7.8 (4.6)	0.820	789	**7.6 (4.5)**	**0.005**

[a]Changes from Wave 1 estimated by a linear mixed model with setting variance of intercept as a random effect.

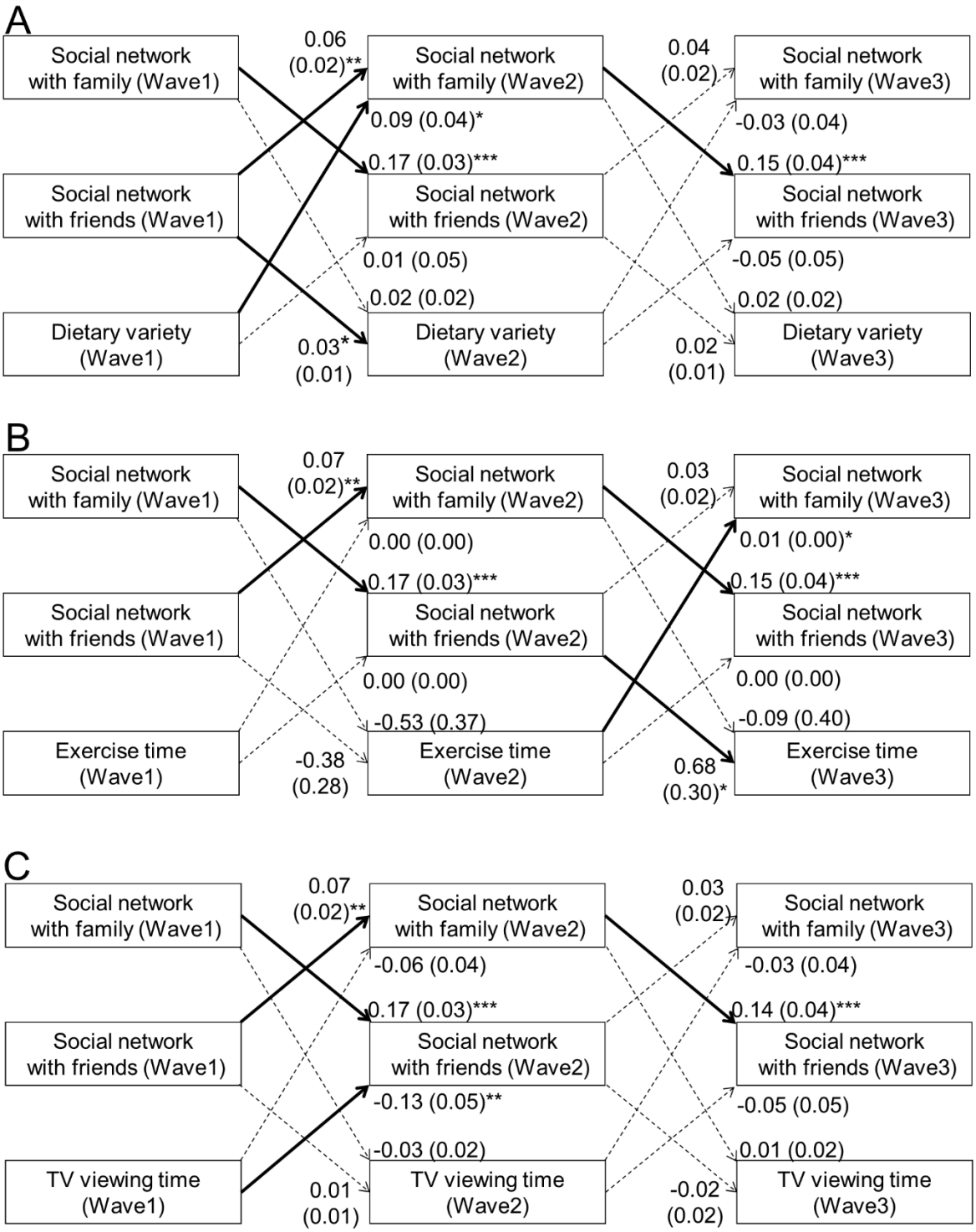
Supplementary Table 2. Pearson's correlation coefficients among basic factors, health behaviors, and social network variables at Wave 1

	1	2	3	4	5	6	7	8	9	10
1.Age (years)										
2.Gender (women)	**-0.35 (p<0.001)**									
3.Educational background (beyond high school)	**-0.16 (p<0.001)**	-0.04 (p=0.213)								
4.Living alone (yes)	**0.09 (p=0.009)**	**-0.21 (p<0.001)**	**-0.07 (p=0.043)**							
5.Current employment (yes)	**-0.19 (p<0.001)**	-0.04 (p=0.218)	0.05 (p=0.186)	-0.02 (p=0.507)						
6.Frailty (yes)	**0.08 (p=0.013)**	**-0.09 (p=0.007)**	-0.05 (p=0.167)	**0.14 (p<0.001)**	**-0.09 (p=0.010)**					
7.Dietary variety (score)	-0.03 (p=0.323)	**0.31 (p<0.001)**	0.05 (p=0.144)	**-0.16 (p<0.001)**	**-0.08 (p=0.024)**	**-0.11 (p=0.001)**				
8.Exercise time (minutes per day)	**0.19 (p<0.001)**	**-0.20 (p<0.001)**	0.02 (p=0.575)	0.00 (p=0.906)	**-0.23 (p<0.001)**	-0.06 (p=0.087)	**0.08 (p=0.034)**			
9.TV viewing time (hours per day)	**0.08 (p=0.018)**	-0.05 (p=0.166)	**-0.10 (p=0.005)**	**0.11 (p=0.001)**	**-0.30 (p<0.001)**	**0.12 (p<0.001)**	-0.05 (p=0.169)	0.05 (p=0.231)		
10.Social network with family	-0.03 (p=0.367)	**0.15 (p<0.001)**	**0.08 (p=0.013)**	**-0.23 (p<0.001)**	0.03 (p=0.338)	**-0.18 (p<0.001)**	**0.17 (p<0.001)**	0.04 (p=0.314)	-0.05 (p=0.141)	
11.Social network with friends	0.03 (p=0.416)	**0.13 (p<0.001)**	**0.15 (p<0.001)**	**-0.11 (p=0.001)**	0.02 (p=0.565)	**-0.20 (p<0.001)**	**0.16 (p<0.001)**	**0.12 (p=0.001)**	**-0.12 (p=0.001)**	**0.47 (p<0.001)**



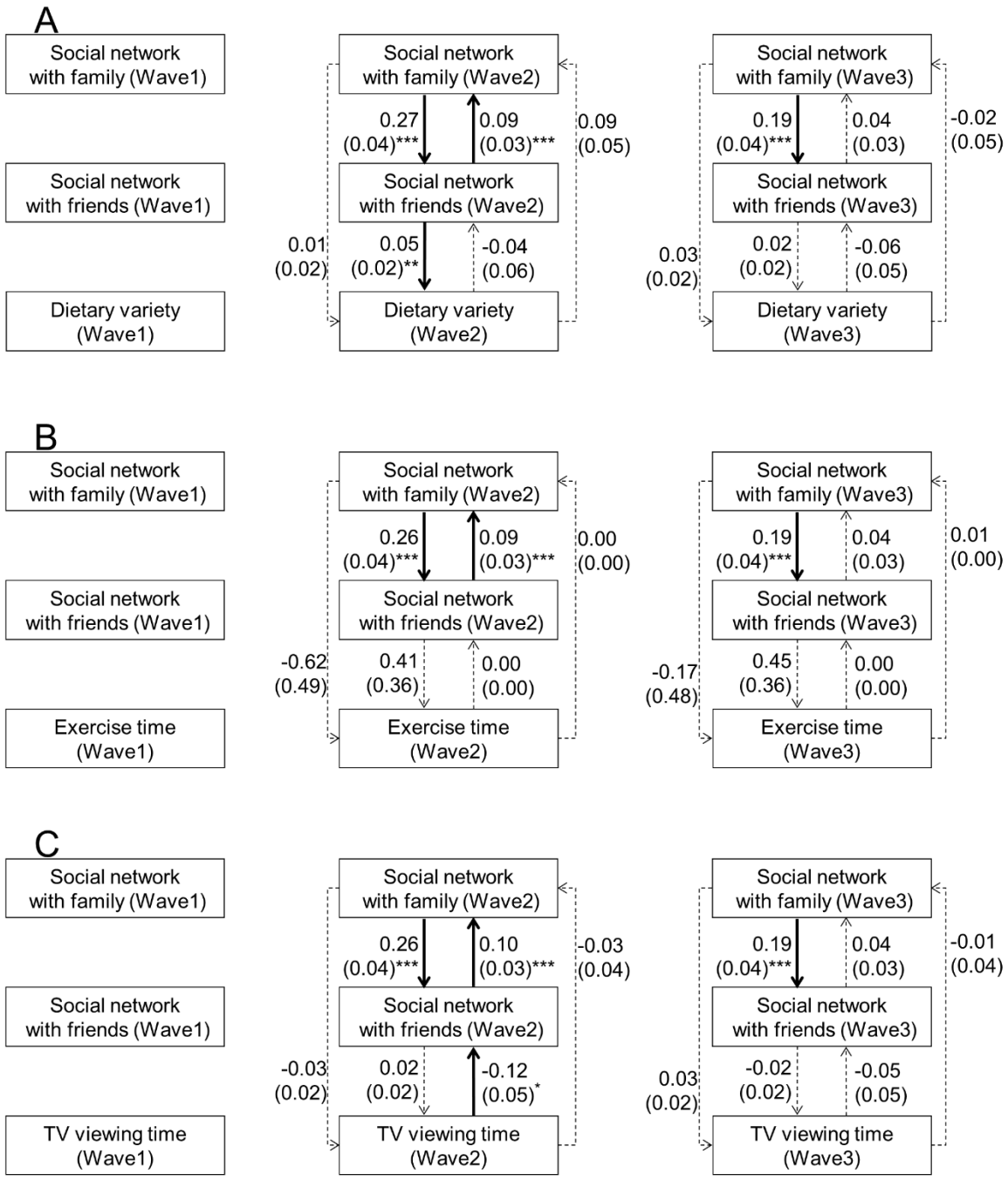
Supplementary Figure 4. Results of latent growth model for associations of social network with dietary variety (A), exercise time (B), and TV viewing time (C), including the non-respondents of both Waves 2 and 3. The present study handled the data of non-respondents through full information maximum likelihood. The values represent unstandardized path coefficients and

standard errors. Bold lines represent significant paths and dashed lines represent insignificant paths. For clarity, observed variables at each wave were not displayed. Model fit indices were $\chi^2(20)=65.43(p<0.001)$, CFI = 0.988, TLI = 0.974, and RMSEA = 0.037 for dietary variety; $\chi^2(20)=63.67(p<0.01)$, CFI = 0.988, TLI = 0.973, and RMSEA = 0.036 for exercise time; and $\chi^2(20)=64.46(p<0.001)$, CFI = 0.988, TLI = 0.974, and RMSEA = 0.037 for TV viewing time. *p<0.05, **p<0.01, ***p<0.001.



Supplementary Figure 5. Results of cross-lagged model for associations of social network with dietary variety (A), exercise time (B), and TV viewing time (C), including the non-respondents of both Waves 2 and 3. The present study handled the data of non-respondents through full information maximum likelihood. The values represent unstandardized path coefficients and

standard errors. Bold lines represent significant paths and dashed lines represent insignificant paths. For clarity, autoregressive paths within social network variables and health behaviors, paths from basic factors, cross-sectional correlations among social network variables and health behaviors, and cross-sectional correlations among basic factors were not displayed. Model fit indices were $\chi 2(42)=80.99(p<0.001)$, CFI=0.992, TFI=0.977, and RMSEA=0.024 for dietary variety; $\chi 2(42)=97.46(p<0.001)$, CFI=0.988, TFI=0.965, and RMSEA=0.028 for exercise time; and $\chi 2(42)=61.79(p=0.024)$, CFI=0.996, TFI=0.988, and RMSEA=0.017 for TV viewing time. *p<0.05, **p<0.01, ***p<0.001.



Supplementary Figure 6. Results of simultaneous model for associations of social network with dietary variety (A), exercise time (B), and TV viewing time (C), including the non-respondents of both Waves 2 and 3. The present study handled the data of non-respondents through full information maximum likelihood. The values represent unstandardized path coefficients and standard errors. Bold lines represent significant paths, and dashed lines represent insignificant paths. For clarity, autoregressive paths within social network variables and health behaviors,

paths from basic factors, cross-sectional correlations among social network variables and health behaviors, and cross-sectional correlations among basic factors were not displayed. Model fit indices were $\chi 2(48)=84.65(p=0.001)$, CFI=0.992, TFI=0.981, and RMSEA=0.021 for dietary variety; $\chi 2(48)=107.14(p<0.001)$, CFI=0.987, TFI=0.967, and RMSEA=0.027 for exercise time; and $\chi 2(48)=61.77(p=0.025)$, CFI=0.996, TFI=0.988, and RMSEA=0.017 for TV viewing time. *p<0.05, **p<0.01, ***p<0.001.