Characteristics of Social Networks and Mortality Risk: Evidence from two Prospective Cohort Studies

Maarit Kauppi, Ichiro Kawachi, George David Batty, Tuula Oksanen, Marko Elovainio, Jaana Pentti, Ville Aalto, Marianna Virtanen, Markku Koskenvuo, Jussi Vahtera*, and Mika Kivimäki*

*Joint senior authors

Correspondence to Dr. Maarit Kauppi, Finnish Institute of Occupational Health, Lemminkäisenkatu 14-18 B (DataCity), 20520 Turku, Finland (e-mail: maarit.kauppi@ttl.fi; phone: +358 43 825 9460)

Author affiliations: Finnish Institute of Occupational Health, Turku and Helsinki, Finland (Maarit Kauppi, Tuula Oksanen, Ville Aalto, and Marianna Virtanen); Department of Social and Behavioral Sciences, Harvard T. H. Chan School of Public Health, Boston, Massachusetts, USA (Ichiro Kawachi); Department of Epidemiology and Public Health, University College London, London, the United Kingdom (G. David Batty and Mika Kivimäki); Institute of Behavioral Sciences, University of Helsinki, Helsinki, Finland (Marko Elovainio); National Institute for Health and Welfare, Helsinki, Finland (Marko Elovainio); Clinicum, Faculty of Medicine, University of Helsinki, Helsinki, Finland (Jaana Pentti, Markku Koskenvuo, and Mika Kivimäki); Department of Public Health, University of Turku, Turku, Finland (Jussi Vahtera); and Turku University Hospital, Turku, Finland (Jussi Vahtera)

This work was funded by the Academy of Finland (267727, 265977, 258598, 292824, 311492), NordForsk, the Nordic Research Programme on Health and Welfare, the Finnish Work Environment Foundation, and the UK Medical Research Council (K013351).

Conflict of interest: none declared.

Running head: Social Network Characteristics and Mortality

ABSTRACT

The size of social network is linked to health and longevity, but it is unclear whether the number of strong or weak social ties is most influential for health. We examined social network characteristics as predictors of mortality in the Finnish Public Sector (n=7,617) and the Health and Social Support (n=20,816) studies. Social network characteristics were surveyed at baseline in 1998. Information about mortality was obtained from the national death registry. During a mean follow-up of 16 years participants with a small social network (≤10 members) were more likely to die than those with a large social network (≥21 members) (adjusted hazard ratio (HR)=1.23, 95% confidence interval (CI): 1.04, 1.46). Mortality risk was increased among participants with small number of both strong (≤2 members) and weak ties (≤5 members) (hazard ratio=1.55, 95% confidence interval: 1.26, 1.79), and among those with large number of strong ties and small number of weak ties (hazard ratio=1.28, 95% confidence interval: 1.08, 1.52), but not among those with small number of strong ties and large number of weak ties (HR=1.04, 95%CI: 0.87, 1.25). These findings suggest that in terms of mortality risk the number of weak ties may be an important component of social networks.

Keywords: cohort study, interpersonal relations, longitudinal studies, mortality, social networks

Abbreviations: Finnish Public Sector Study (FPS), Health and Social Support Study (HeSSup), hazard ratio (HR), confidence interval (CI), metabolic equivalent (MET)

Observational studies have shown that people with larger social networks live healthier and longer lives than those who are lonely and socially isolated (1–4). The mechanisms underlying these associations are likely to involve behavioral, psychosocial, and physiological pathways (5). For example, interpersonal relationships may affect an individual's health habits via social influence and behavioral regulation (e.g., normative disapproval of smoking), offer social support that reduces psychosocial stress, and have physiological implications such as enhanced immune, endocrine and cardiovascular function (6,7).

Previous studies of the associations of social networks with health have been confined to an examination of structural aspects, such as overall size (e.g., number of friends and acquaintances) and frequency of social interactions in different domains of life. Less is understood about which specific aspects of social network are most influential (8–11) and what role does the closeness of social relations play in health risk and longevity. Due to their proximity, people most often rely on their closest relations for emotional support (12). These strong ties are often assumed to be more influential for health compared to weaker, more distant ties (13). However, recent research has suggested that more peripheral members of social networks may also importantly contribute to health and well-being (14,15). Beneficial associations between weak ties and well-being are plausible because they are less time-consuming and less emotionally taxing compared to strong ties, but they are also more likely to avoid negative aspects of social ties, such as conflicts and social pressure. Weak ties may also provide the person with access to people who could be useful in an emergency (e.g., medical professional, financial advisor), that is, those providing critical instrumental/informational support (12).

The social convoy model developed by Antonucci (16) depicts social relations in terms of three concentric circles according to distance from the ego; inner, middle and outer circles. Although the social convoy model was published more than three decades ago, few studies to date have sought to distinguish whether weak or the strong ties are more important for health. In this study, we used the social convoy model as a conceptual framework to examine whether the number of strong or weak ties or the overall social network size is more influential for health as indicated by risk of total mortality in two prospective cohort studies.

METHODS

Study population

We used data from an occupational cohort study, the Finnish Public Sector Study (FPS), and a population-based cohort study, the Health and Social Support Study (HeSSup), both of which have been described in detail elsewhere (17,18). In brief, in FPS data were drawn from personnel working at four hospital districts in Finland; a total of 7,617 participants (mean age 42.9 years) provided information about their social network size at the baseline survey in 1998 and had no missing data on baseline covariates (86% of eligible baseline respondents). In HeSSup, 20,816 participants (mean age 36.7 years) at the baseline survey in 1998 met the same inclusion criteria (80 % of eligible baseline respondents). FPS was approved by the ethics committee of the Finnish Institute of Occupational Health and the Helsinki University Central Hospital, and HeSSup was approved by the Turku University Hospital Ethics Committee.

Assessment of social networks

Social network size was assessed in both cohort studies at baseline using the social convoy model described by Antonucci (16). The model is based on a set of three concentric circles each of which is considered to represent different levels of closeness of the focal persons (**Figure 1**). The respondents were asked to place initials of those people that they felt so close that it was hard to imagine life without them in the innermost circle. The middle circle referred to those persons who felt not quite that close but still important and, in the outer circle, the respondent added the initials of those persons who were not already mentioned, but who were close and important enough to belong to the individual's personal network. Members in the inner circle were referred to as strong ties, while those in the middle and outer circles constitute weak ties. In **Web Table 1** we show that any differences in associations with mortality were small between the number of middle and outer circle social relations, providing an empirical justification for merging these two circle categories.

Overall network size was determined by summing the number of members in all circles and categorized into low (0-10 members), intermediate (11-20 members) and high (21 or more members) (19). A more granulated categorization, used in supplementary analysis, divided participants into groups with 0-2, 3-5, 6-10, 11-20 and 21 or more members in social network. We also divided members in the inner circle into groups with small (0-2 members) versus large (≥3 members) number of strong ties, corresponding to the threshold at the lowest quartile. On the same basis, the number of members in the middle and outer circles were combined and categorized into small (0-5 members) versus large (≥6 members) number of weak ties. We constructed a variable combining these categories into four groups: (1) small number of strong ties and small number of weak ties (small-small), 2) small number of strong ties and large number of weak ties (small-large), 3) large number of strong ties and small number of weak ties (large-small), and 4) large number of strong ties and large number of weak ties (large-large).

Assessment of covariate data

Baseline covariates included education (basic, intermediate and high); diagnosed chronic conditions (diabetes, rheumatoid arthritis, asthma, coronary heart disease, cancer) obtained using linkage to the records of the National Drug Reimbursement Register and the Finnish Cancer Registry (the total number of these conditions was calculated and classified into two categories ‘none’ and ‘at least one’); and history of depression assessed by the question “Have you ever been diagnosed of depression by a physician?” (yes/no).

Baseline covariates also included obesity, heavy alcohol consumption, smoking and low physical activity, all drawn from standard questionnaires. Body mass index (BMI) was calculated based on self-reported height and weight, and participants were classified into non-obese (body mass index <30 kg/m^2) and obese (≥30 kg/m^2). Alcohol intake, expressed as absolute ethanol in grams/week, was estimated on the basis of the reported average consumption of beer, wine and/or spirits. As previously (20), the threshold for heavy alcohol use was 288g/week in men (equivalent of 24 units per week) and 192g/week in women (equivalent of 16 units per week). Smoking status was categorized into non-smokers (including former smokers) and current smokers. Information about average time spent in physical activity with different intensities was used to estimate metabolic equivalent (MET), a validated measure of physical activity level (21). Metabolic equivalent is obtained by multiplying the time spent on each activity by its typical energy expenditure. We used the following metabolic equivalent values (activity metabolic rate divided by resting metabolic rate): 3.5 (for activity intensity corresponding to walking), 5 (vigorous walking), 8 (jogging), 11 (running), and expressed the activity level as the sum score of metabolic equivalent hours/week (21). As previously, participants whose physical activity level was less than 14 metabolic equivalent hours/week were regarded as physically inactive (22).

Ascertainment of mortality

Information about mortality was collected by linking the participants to the records from the national death register maintained by Statistics Finland using the unique personal identification code assigned to all persons residing in Finland. This database includes the exact dates of death, and provides virtually complete population mortality data (23).

Statistical analyses

Differences in baseline characteristics according to social networks were assessed by using t-test for continuous variables and chi-square test for categorical variables. No violation of the proportional hazard assumption was apparent in either of the cohort studies (24). Cox proportional hazards models were therefore used to examine separately the associations of the size of overall social network and the numbers of strong and weak ties with mortality during the follow-up period. The follow-up period started in 1998 and continued until the date of death or until the end of 2013 (FPS) or 2015 (HeSSup), whichever came first. Hazard ratios (HR) were adjusted for age and sex (Model 1), then education, chronic conditions, lifestyle and depression (Model 2). We then carried out mutual adjustment for the number of strong and weak ties (Model 3).

We then examined how the combinations of small and large numbers of strong and weak ties were associated with mortality risk. Hazard ratios for categories of 'small number of strong and weak ties', 'small number of strong ties but large number of weak ties' and 'large number of strong ties but small number of weak ties' were estimated with 'large number of both strong and weak ties' as the reference. To test the robustness of the associations according to different contexts, analysis was stratified by age, sex, and marital status. To examine reverse causation, further sensitivity analyses were performed after excluding the first five years of the follow-up.

The study-specific results were pooled into summary estimates by means of the fixed effect meta-analysis (25). In meta-analysis data from individual studies are weighted first and then combined, which avoids some problems of simple pooling, such as ecological fallacy (26). Statistical analyses of study-specific data were performed using SAS software, version 9.4 (SAS Institute Inc., Cary NC, USA), and the meta-analysis was computed using R statistical package (R version 3.2.3, R Foundation for Statistical Computing, Vienna, Austria).

RESULTS

The mean age of participants at baseline in the combined dataset was 38.3 years (range 19-63) and 67% were women. In both cohort studies, persons who were 50 years or over, men, single, had basic education, low physical activity, or a history of depression were more likely to have smaller number of strong and weak ties than younger persons, women, married/cohabiting, those with intermediate or high education, those physically active, and those without a history of depression (**Web Table 2**). In addition, in HeSSup, those who were obese, heavy alcohol users or smokers were more likely to have small number of strong and weak ties than those without these behavioral risk factors.

A total of 461,429 person-years at risk (mean follow-up 16 years) gave rise to 1,080 (3.8 %) deaths in the total study population. **Figure 2** shows distributions of network characteristics and mortality rates. For total social network size and the number of weak ties, increased number of deaths was apparent at the lower end of the distribution. This was not the case for the number of strong ties.

Table 1 shows minimally and multivariably adjusted results of the social network-mortality associations. After adjustment for age and sex, participants with a small social network (10 people or less) were 1.48 times more likely to die during the follow-up than those with a large social network (21 members or more, hazard ratio (HR) 1.48, 95% confidence interval (CI) 1.25, 1.75). After further adjustment for education, chronic conditions, lifestyle factors and depression, this association was markedly attenuated (hazard ratio 1.23, 95% confidence interval 1.04, 1.46). The pattern of results was similar in analyses using a more granulated categorization for overall network size (**Web Table 3**). Also, analyses treating overall network size as a continuous variable (log-transformed) showed a significant association with mortality, both before (hazard ratio 0.77, 95% confidence interval 0.71, 0.83, Model 1) and after (hazard ratio 0.87, 95 % confidence interval 0.80, 0.95, Model 2) adjustment for covariates (**Web Table 1**).

Table 1 also shows that compared to those with large number of weak ties (6 or more), mortality risk was significantly increased among participants who had small number of weak ties (0-5), both before (Model 1, hazard ratio 1.63, 95% confidence interval 1.43, 1.86) and after (Model 2, HR 1.37, 95% CI 1.20, 1.56) adjustment for covariates. Furthermore, the association remained after additional adjustment for the number of strong ties (Model 3, HR 1.34, 95% CI 1.17, 1.54). In contrast, the association of the number of strong ties and mortality was weaker and after adjustment for the number of weak ties was not statistically significant. Similarly, analyses treating the number of strong and weak ties as continuous variables showed a stronger association with mortality for weak ties than for strong ties (**Web Table 1**).

Analysis in which covariates were added individually showed that the most important contributors to the associations between network variables and mortality were education, smoking and having a history of depression (**Web Table 4**). Adjustment for these variables attenuated the age and sex adjusted association between network size and mortality by 47.9% (from a HR1.48 to a HR 1.25, 95% CI 1.06, 1.49), the association between the number of strong ties and mortality by 35.7% (from a HR 1.28 to a HR 1.18, 95% CI 1.03, 1.35) and the association between the number of weak ties and mortality by 36.5% (from a HR of 1.63 to a HR 1.40, 95% CI 1.23, 1.60).

Figure 3 presents findings from the analysis of a 4-category combination variable for the number of strong and weak ties. After adjustment for baseline covariates the risk of mortality was 1.55 times higher among those with small number of strong and weak ties (HR 1.55, 95% CI 1.26, 1.79), and 1.28 times higher among those who had large number of strong ties and small number of weak ties (HR 1.28, 95% CI 1.08, 1.52), when compared with those with large number of both strong and weak ties. In contrast, no increase in mortality risk was observed among those with small number of strong ties but large number of weak ties (HR 1.04, 95% CI 0.87, 1.25). The hazard ratios changed little after additional adjustment for overall network size (a continuous variable); the hazard ratio was 1.53 (95% CI 1.24, 1.88) for small number of strong and weak ties; 1.30 (95% CI 1.07, 1.57) for large number of strong ties and small number of weak ties; and 1.05 (0.87, 1.27) for small number of strong ties and large number of weak ties. Minimally adjusted hazard ratios, which did not materially differ from those presented above, are available in **Web Figure 1**. Furthermore, repeating the main analyses with body mass index and alcohol use modeled as continuous covariates did not change these findings (**Web Figure 2**).

Figure 4 shows that these results were also apparent in sub-group analyses, with the associations being similar in both men and women, younger and older individuals, and in single as well as married/cohabitating individuals. Formal tests of statistical interactions did not show significant differences between subgroups. In addition, findings of sensitivity analyses showed essentially no change in main results after excluding first five years of follow-up from the analyses, a standard approach to reduce reverse causation bias (**Web Figure 3**). Similarly, any differences in these (**Web Table 5**) or other associations (**Web Table 6**) between the two cohort studies were small. Thus, using an alternative analytic approach such as pooling the individual data from the two studies yielded very similar findings to our main analysis based on fixed effects meta-analysis (**Web Table 7**).

DISCUSSION

In this pooled analysis of two independent cohort studies of middle-aged adults followed up a mean of 16 years, excess mortality risk was observed among individuals having small number of weak ties, irrespective of the number of strong social ties. This association was apparent in the total cohort as well as subgroups of study members, including men and women, younger and older, and in the single and those married/cohabitating. Furthermore, the association between the number of weak ties and mortality was not attributable to differences in education, health status, lifestyle or depression measured at baseline. The associations of overall network size and the number of strong ties with mortality were weaker and the primacy of weak ties over other characteristics of social networks was observed in both studies, one based on a general population cohort and the other on an occupational cohort.

We are not aware of any previous studies on the number of strong and weak ties in relation to mortality risk. However, our results on overall social network size accord with studies showing small social network size and social isolation to be associated with poorer health (2,27,28). In our analyses adjusting for age and sex, people with an overall social network of only two people or less had almost two times greater risk of death than those with large social networks including 21 members or more. Nonetheless, results from multivariable adjustments suggested that much of this association was attributable to major risk factors, such as low education, depression and unhealthy lifestyle in the group of people with small social networks. The independent association of having no social network could be particularly hazardous, but in the present study the low number of participants reporting zero friends (N=6) precluded examining this issue.

Some studies have examined different types of social networks, such as friend-focused, family-focused, neighbor-focused and restricted networks (29,30). They have shown that among older adults, friend-focused and diverse networks are associated with lower mortality risk compared with restricted networks or lower number of friends in social network. These studies did not assess the closeness of the members in these particular networks, but it might be assumed that relationships with family members are likely to be the closest, followed by friends and neighbors (8). Furthermore, strong social ties are characterized by similarity between the members of the network whereas weaker social ties, including those with friends or between "friends of the friends" are likely to show greater network diversity (12). Thus, our results showing that it is the number of weak ties that accounts most to mortality risk are consistent with previous studies suggesting that diverse social networks are beneficial for health (31,32). In the present study, multivariable adjustments showed that nearly half of the association between social network variables and mortality was attributable to three factors, education, smoking and depression. This suggests that these factors may partially underlie the associations between social network and health.

The results of the primacy of weak ties may be seen as unexpected because emotional support is typically received from strong ties, often including spouse and relatives. However, in addition to emotional support there are at least two other factors explaining the association between social networks and health: informational / instrumental support which enable healthy choices, and negative aspects of interpersonal relationships, such as conflicts and group pressures which may cause stress and discourage healthy behaviors (33). Larger number of weak ties increase network diversity potentially allowing access to people useful in an emergency, that is, those providing critical instrumental/informational support (e.g., knowing the "best surgeon", the "best lawyer", the "best college admission official", the "best bank loan officer" etc.) (12). Interpersonal relationships in weak ties that are, by definition, less time consuming, emotionally intense and intimate, are also more likely to avoid a serious burden of negative social influences (12).

The strength of this investigation was that it was based on two large cohort studies, including both occupational and population-based data. In addition, the follow-up period was long, extending up to 17 years. Furthermore, information about mortality was obtained from the national death register, providing virtually complete mortality data of the Finnish population. The fact that the main finding was replicable across two different cohort studies support the generalizability of our findings.

Some limitations are noteworthy. First, this is an observational study and therefore cannot prove causality. Second, the social network was assessed only at baseline, and no information about changes in the size of social network or number of strong and weak ties was available during the follow-up. Some previous studies have shown social network to be relatively stable over time with respect to total size (34), but network turnover, that is, change in composition of network also occurs and has been shown to be associated with health (35,36). This should be taken into account in future studies. Third, reverse causation between baseline social network size and health-related factors, such as chronic conditions and depression, is an important source of bias results. We addressed this uncertainty by adjusting the final analyses for chronic conditions and depression. In addition, sensitivity analyses excluding the first five years of follow-up were conducted in order to deal with potential confounding of occult diseases. The results of these analyses remained practically unchanged, suggesting that reverse causation bias is an unlikely explanation to our findings.

In conclusion, our findings support the hypothesis that social networks with large number of weak ties protect against premature mortality. This evidence is consistent with policies increasing opportunities to interpersonal relationships which do not need to be highly time consuming, emotionally intense or intimate to benefit health. Examples of such social relationships could include patient support groups, support networks for healthy life, club memberships, and other resources to strengthen interpersonal relationships in the community. Trial and natural experiments are now needed to determine the extent to which increases in social networks may reduce risk of morbidity and mortality in younger and older people.

Acknowledgments

Author affiliations:

Finnish Institute of Occupational Health, P. O. Box 40, 00251 Helsinki, Finland (Maarit Kauppi, Tuula Oksanen, Ville Aalto, Marianna Virtanen); Department of Social and Behavioral Sciences, Harvard T. H. Chan School of Public Health, Boston, Massachusetts 02115, USA (Ichiro Kawachi); Department of Epidemiology and Public Health, University College London, London WC1E 6BT, the United Kingdom (David Batty, Mika Kivimäki); Institute of Behavioral Sciences, Siltavuorenpenger 1A, PO Box 9, 00014 University of Helsinki, Helsinki, Finland (Marko Elovainio); National Institute for Health and Welfare, Helsinki P.O. Box 30, 00271, Finland (Marko Elovainio); Department of Public Health, University of Turku and Turku University Hospital, Finland (Jussi Vahtera); Clinicum, Faculty of Medicine, Biomedicum 2, 00014 University of Helsinki, Helsinki, Finland (Jaana Pentti, Markku Koskenvuo, Mika Kivimäki).

Funding: The study was supported by the Academy of Finland (267727, 265977, 258598, 292824, 311492), NordForsk, the Nordic Research Programme on Health and Welfare, the Finnish Work Environment Foundation, and the UK Medical Research Council (K013351). Funding bodies for each participating cohort study are listed on their websites. The sponsors had no role in design and conduct of the study; collection, management, analysis, and interpretation of the data; and preparation, review, or approval of this manuscript.

Contributors: M Kauppi, I Kawachi, J Vahtera and M Kivimaki developed the hypothesis and study design and supervised this study. M Kauppi, J Pentti, and V Aalto performed statistical analyses. M Kauppi with M Kivimäki wrote the first draft. All authors

contributed to study concept and design, analysis and interpretation of data, and drafting or critical revision of the manuscript for important intellectual content, or in addition, data acquisition. M Kauppi, J Pentti and V Aalto had full access to data in the study and take responsibility for the integrity of the unpublished data and the accuracy of the data analysis. M Kauppi is guarantor.

Ethical approval: Each constituent study with individual participant data was approved by the relevant local or national ethics committee, and all participants gave informed consent to participate.

Data sharing: Statistical syntax and exposure data from the cohort studies are available. Sharing of record linkage data is not permitted.

Transparency: M Kauppi affirms that this manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned (and, if relevant, registered) have been explained.

Conflict of interest: All authors have completed the ICMJE uniform disclosure form at www.icmje.org/coi_disclosure.pdf and declare: no support from any organization for the submitted work other than those mentioned above; no financial relationships with any organizations that might have an interest in the submitted work in the previous three years; no other relationships or activities that could appear to have influenced the submitted work.

References

1. Berkman LF, Syme SL. Social networks, host resistance, and mortality: a nine-year follow-up study of Alameda County residents. *Am. J. Epidemiol.* 1979;109(2):186–204.

2. Holt-Lunstad J, Smith TB, Layton JB. Social relationships and mortality risk: a meta-analytic review. *PLoS Med.* 2010;7(7): 7(7):e1000316.

3. Smith KP, Christakis NA. Social Networks and Health. *Annu. Rev. Sociol.* 2008;34(1):405–429.

4. Elovainio M, Hakulinen C, Pulkki-Råback L, et al. Contribution of risk factors to excess mortality in isolated and lonely individuals: an analysis of data from the UK Biobank cohort study [Published online May 4, 2017]. *Lancet Public Heal.* 2017. http://dx.doi.org/10.1016/S2468-2667(17)30075-0

5. Umberson D, Montez JK. Social relationships and health: a flashpoint for health policy. *J. Health Soc. Behav.* 2010;51 Suppl:S54–66.

6. Umberson D, Crosnoe R, Reczek C. Social Relationships and Health Behavior Across Life Course. *Annu. Rev. Sociol.* 2010;36:139–157.

7. Yang YC, Boen C, Gerken K, et al. Social relationships and physiological determinants of longevity across the human life span. *Proc. Natl. Acad. Sci. U. S. A.* 2016;113(3):578–83.

8. Antonucci TC, Akiyama H, Takahashi K. Attachment and close relationships across the life span. *Attach. Hum. Dev.* 2004;6(4):353–370.

9. Manzoli L, Villari P, M Pirone G, et al. Marital status and mortality in the elderly: a systematic review and meta-analysis. *Soc. Sci. Med.* 2007;64(1):77–94.

10. Rasulo D, Christensen K, Tomassini C. The influence of social relations on mortality in later life: a study on elderly Danish twins. *Gerontologist*. 2005;45(5):601–8.

11. Rutledge T, Matthews K, Lui L-Y, et al. Social networks and marital status predict mortality in older women: prospective evidence from the Study of Osteoporotic Fractures (SOF). *Psychosom. Med.* 65(4):688–94.

12. Granovetter M. The Strength of Weak Ties. *Am. J. Sociol.* 1973;78(6):1360–1380.

13. Hakulinen C, Pulkki-Råback L, Jokela M, et al. Structural and functional aspects of social support as predictors of mental and physical health trajectories: Whitehall II cohort study. *J. Epidemiol. Community Health*. 2016;70(7):710–5.

14. Sandstrom GM, Dunn EW. Social Interactions and Well-Being. *Personal. Soc. Psychol. Bull.* 2014;40(7):910–922.

15. Christakis NA, Fowler JH. Social contagion theory: examining dynamic social networks and human behavior. *Stat. Med.* 2013;32(4):556–577.

16. Antonucci TC. Hierarchical mapping technique. *Generations*. 1986;10:10–12.

17. Kivimäki M, Lawlor DA, Davey Smith G, et al. Socioeconomic position, co-occurrence of behavior-related risk factors, and coronary heart disease: the Finnish Public Sector study. *Am. J. Public Health*. 2007;97(5):874–879.

18. Suominen S, Koskenvuo K, Sillanmäki L, et al. Non-response in a nationwide follow-up postal survey in Finland: a register-based mortality analysis of respondents and non-respondents of the Health and Social Support (HeSSup) Study. *BMJ Open*. 2012;2(2):e000657.

19. Vahtera J, Kivimäki M, Uutela A, et al. Hostility and ill health: role of psychosocial

resources in two contexts of working life. *J. Psychosom. Res.* 2000;48(1):89–98.

20. Halonen JI, Kivimäki M, Virtanen M, et al. Living in proximity of a bar and risky alcohol behaviours: a longitudinal study. *Addiction* 2013;108(2):320–8.

21. Ainsworth BE, Haskell WL, Herrmann SD, et al. 2011 Compendium of Physical Activities. *Med. Sci. Sport. Exerc.* 2011;43(8):1575–1581.

22. Kouvonen A, Vahtera J, Oksanen T, et al. Chronic workplace stress and insufficient physical activity: a cohort study. *Occup. Environ. Med.* 2013;70(1):3–8.

23. Official Statistics of Finland (OSF). Statistics Finland - Quality Description:Causes of death 2013. (http://www.stat.fi/til/ksyyt/2013/ksyyt_2013_2014-12-30_laa_001_en.html). (Accessed October 31, 2016)

24. Harrell F, Lee K. Verifying Assumptions of the Cox Proportional Hazards Model. In: *Proceedings of the Eleventh Annual. SAS User's Group International Conference.* Cary, N.C.: SAS Institute, Inc.; 1986:823–828.

25. Hedges L V, Vevea JL. Fixed- and random-effects models in meta-analysis. *Psychol. Methods*. 1998;3(4):486–504.

26. Bravata DM, Olkin I. Simple pooling versus combining in meta-analysis. *Eval. Health Prof.* 2001;24(2):218–30.

27. Kawachi I, Colditz GA, Ascherio A, et al. A prospective study of social networks in relation to total mortality and cardiovascular disease in men in the USA. *J. Epidemiol. Community Health*. 1996;50(3):245–251.

28. Orth-Gomér K, Johnson J V. Social network interaction and mortality. A six year follow-up study of a random sample of the Swedish population. *J. Chronic Dis.*

1987;40(10):949–57. (http://www.ncbi.nlm.nih.gov/pubmed/3611293). (Accessed September 1, 2016)

29. Litwin H, Shiovitz-Ezra S. Network type and mortality risk in later life. *Gerontologist*. 2006;46(6):735–743.

30. Giles LC, Glonek GF V, Luszcz MA, et al. Effect of social networks on 10 year survival in very old Australians: the Australian longitudinal study of aging. *J. Epidemiol. Community Health*. 2005;59(7):574–579.

31. Ellwardt L, van Tilburg T, Aartsen M, et al. Personal networks and mortality risk in older adults: a twenty-year longitudinal study. *PLoS One*. 2015;10(3):e0116731.

32. Barefoot JC, Grønbaek M, Jensen G, et al. Social network diversity and risks of ischemic heart disease and total mortality: findings from the Copenhagen City Heart Study. *Am. J. Epidemiol.* 2005;161(10):960–7.

33. Walen HR, Lachman ME. Social Support and Strain from Partner, Family, and Friends: Costs and Benefits for Men and Women in Adulthood. *J. Soc. Pers. Relat.* 2000;17(1):5–30.

34. Wellman B, Wong RY, Tindall D, et al. A decade of network change: Turnover, persistence and stability in personal communities. *Soc. Networks*. 1997;19(1):27–50.

35. Cornwell B, Laumann EO. The health benefits of network growth: new evidence from a national survey of older adults. *Soc. Sci. Med.* 2015;125:94–106.

36. Eng PM, Rimm EB, Fitzmaurice G, et al. Social ties and change in social ties in relation to subsequent total and cause-specific mortality and coronary heart disease incidence in men. *Am. J. Epidemiol.* 2002;155(8):700–709.

Figure 1. Fictitious Example of a Response to the Enquiry Regarding the Number of Members in the Inner Circle (Strong Ties) and in the Intermediate and Outer Circles (Weak Ties) of Social Network Using the Concentric Model Developed by Antonucci (adapted) (16)

Figure 2. Number of Members in Total Social Network (A), Number of Strong Ties (Inner Circle) (B) and Weak Ties (Outer Circles) (C), and Corresponding Numbers of Deaths. Summary Estimates Pooled From Study-specific (FPS and HeSSup) Results.

Figure 3. Hazard Ratios With 95% Confidence Intervals for All-cause Mortality According to Number of Strong (Small Number Refers to 0-2 and Large Number to ≥3 Members) and Weak (Small Number Refers to 0-5 and Large Number to ≥6 Members) Ties. Summary Estimates Pooled From Study-specific (FPS and HeSSup) Results and Adjusted for Age, Sex, Education, Chronic Conditions, Lifestyle and Depression.

Figure 4. Hazard Ratios With 95% Confidence Intervals for All-cause Mortality According to Number of Strong (Small Number Refers to 0-2 and Large Number to ≥3 Members) and Weak (Small Number Refers to 0-5 and Large Number to ≥6 Members) Ties and Stratified by Sex, Age and Marital Status. Summary Estimates Pooled From Study-specific (FPS and HeSSup) Results and Adjusted for Age, Sex, Education, Chronic Conditions, Lifestyle and Depression, as Appropriate.

Table 1. Hazard Ratios With 95% Confidence Intervals for All-cause Mortality According to Different Categorization of Social Network Size.

Social Network Size	No. of Deaths	Total No.	Model 1[a] HR[d]	Model 1[a] 95 % CI	Model 2[b] HR[d]	Model 2[b] 95% CI	Model 3[c] HR[d]	Model 3[c] 95% CI
Number of members in the total social network								
≥ 21 members	214	7394	1.00	Referent	1.00	Referent		
11-20 members	398	12955	1.02	0.86, 1.21	0.96	0.81, 1.13		
0-10 members	468	8084	1.48	1.25, 1.75	1.23	1.04, 1.46		
Number of strong ties								
≥ 3 members	747	22167	1.00	Referent	1.00	Referent	1.00	Referent
0-2 members	333	6266	1.28	1.13, 1.46	1.17	1.03, 1.33	1.10	0.96, 1.26
Number of weak ties								
≥ 6 members	713	23007	1.00	Referent	1.00	Referent	1.00	Referent
0-5 members	367	5426	1.63	1.43, 1.86	1.37	1.20, 1.56	1.34	1.17, 1.54

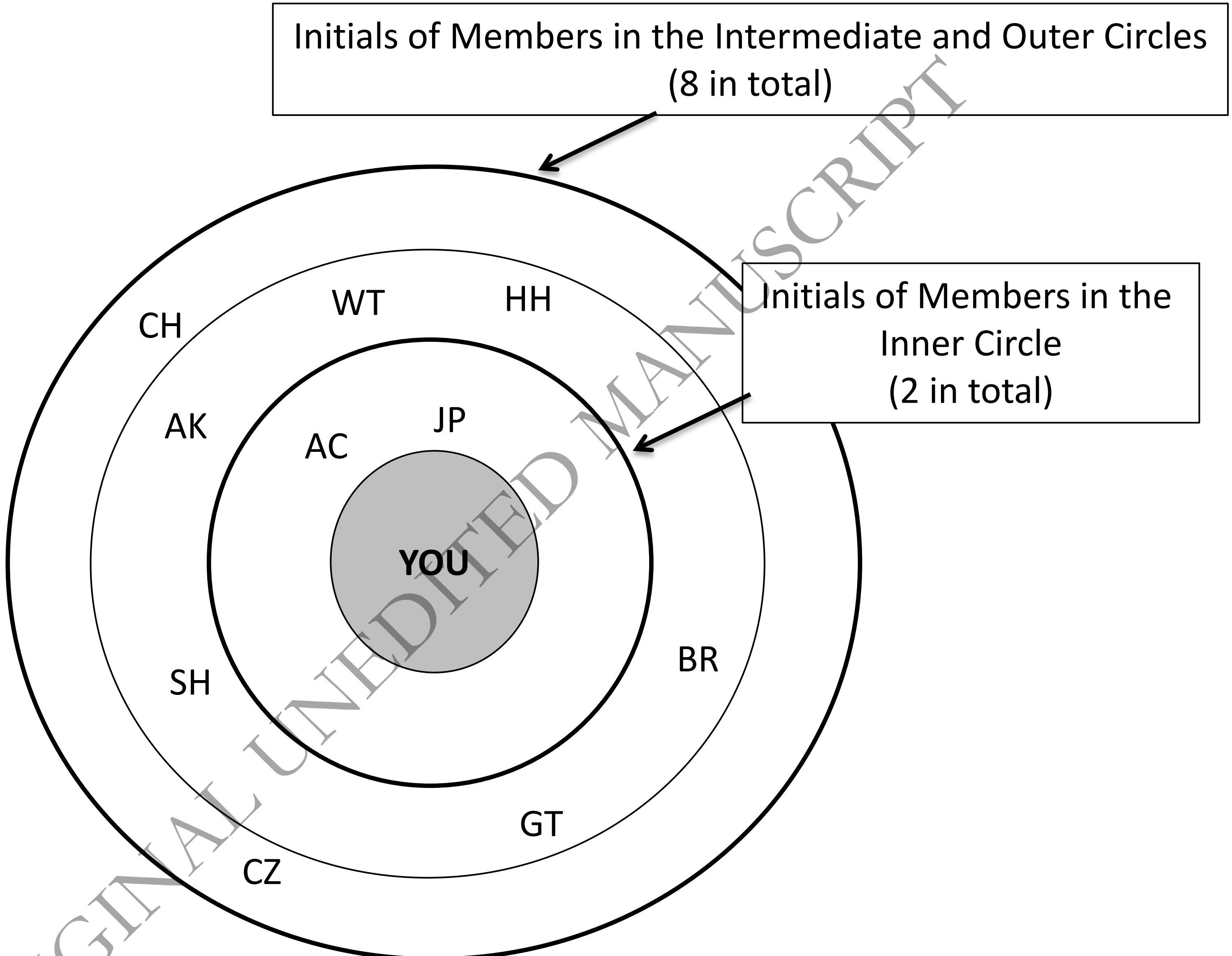
Abbreviations: CI, confidence interval; HR, hazard ratio

[a] Model 1: HRs are adjusted for age and sex

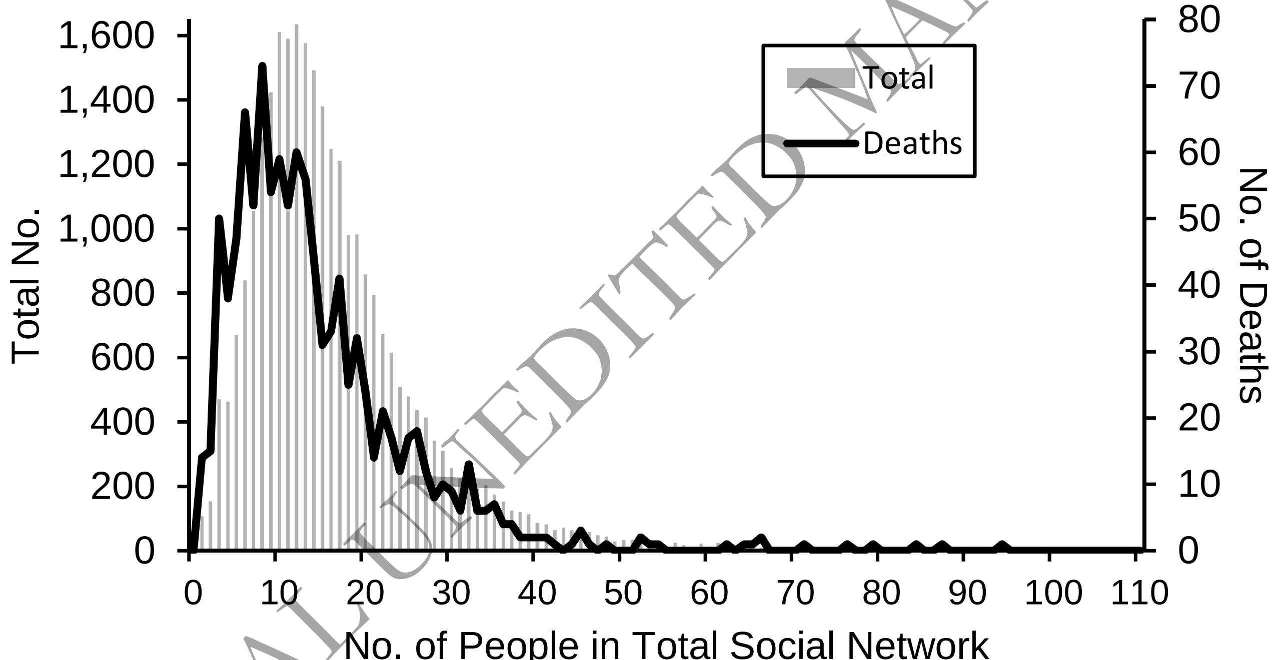
[b] Model 2: HRs are adjusted for age, sex, education, chronic conditions, lifestyle (obesity, smoking, alcohol use, physical activity) and depression

[c] Model 3: HRs are adjusted for age, sex, education, chronic conditions, lifestyle (obesity, smoking, alcohol use, physical activity) and depression. In addition, number of strong ties and weak ties are mutually adjusted

[d] Summary Estimates Pooled From Study-specific (FPS and HeSSup) Results

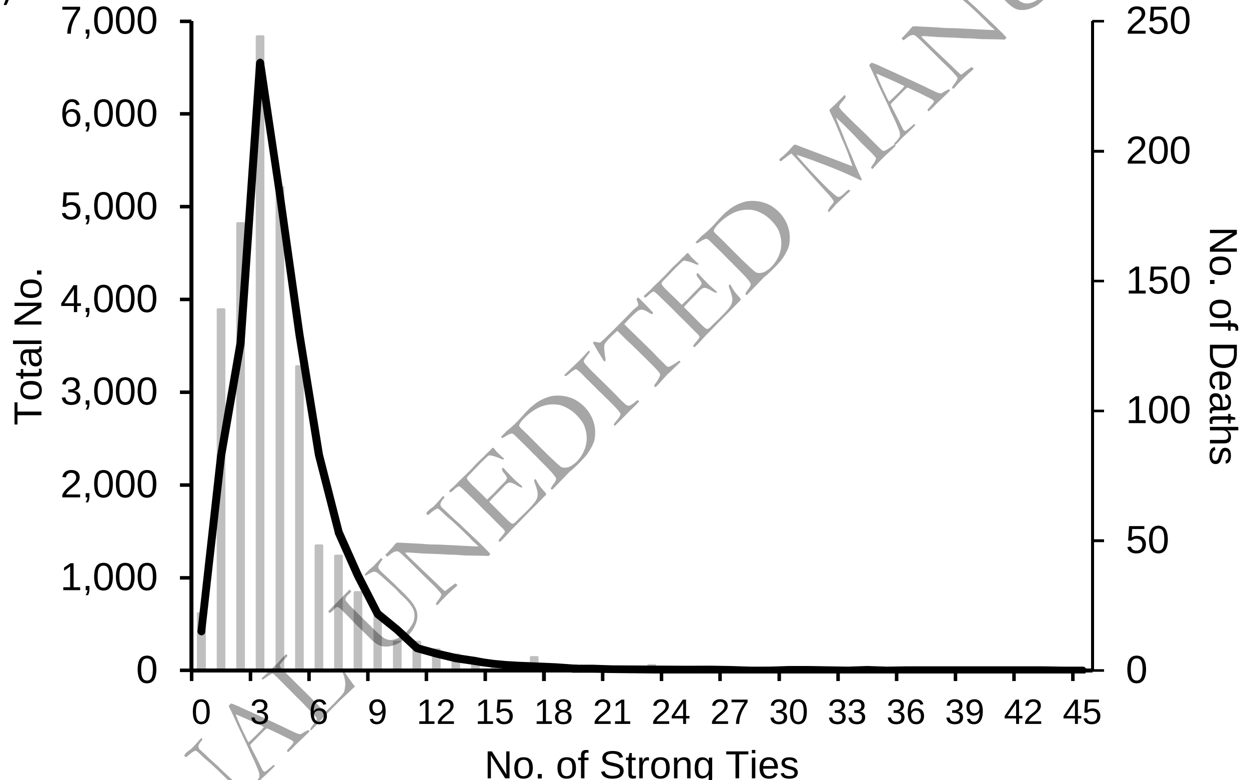

Initials of Members in the Intermediate and Outer Circles
(8 in total)
Initials of Members in the Inner Circle
(2 in total)
CH
WT
HH
AK
AC
JP
YOU
SH
BR
GT
CZ

A)

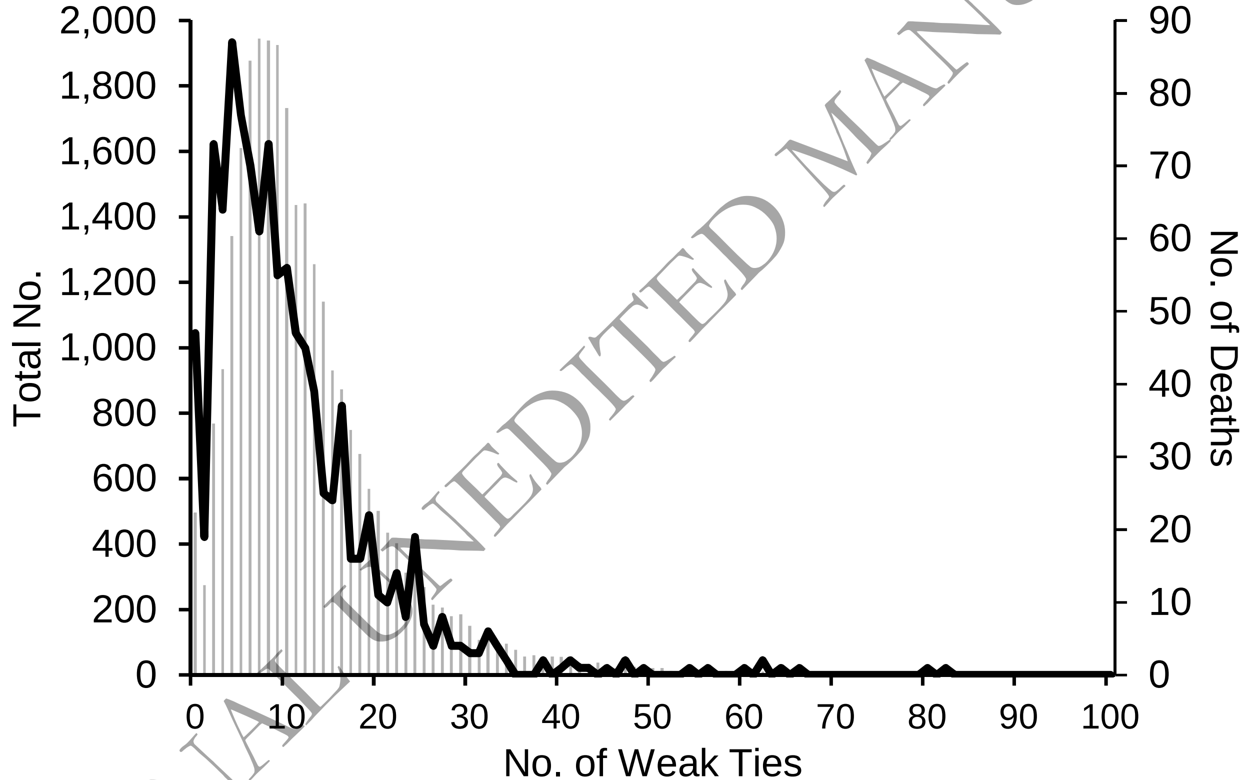


Total
Deaths
Total No.
No. of Deaths
No. of People in Total Social Network

B)

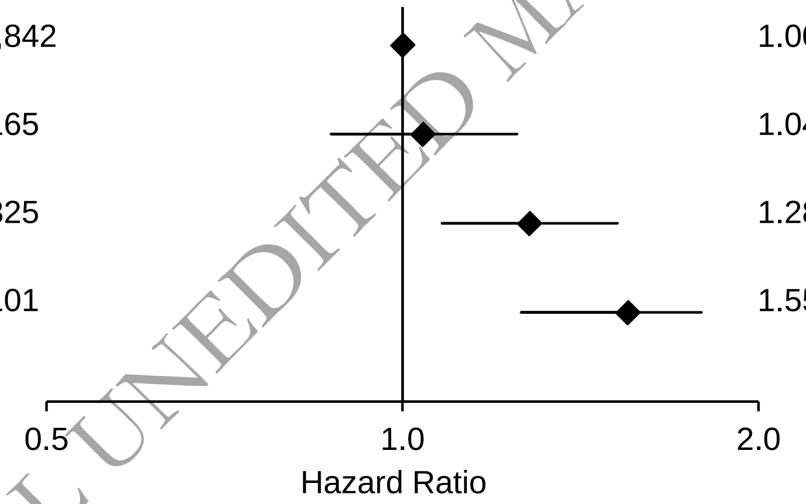

Total No.
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
No. of Deaths
250
200
150
100
50
0
0 3 6 9 12 15 18 21 24 27 30 33 36 39 42 45
No. of Strong Ties

c)



2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
Total No.
90
80
70
60
50
40
30
20
10
0
No. of Deaths
0
10
20
30
40
50
60
70
80
90
100
No. of Weak Ties

Nos. of Strong and Weak Ties	No. of Deaths	Total No.	HR	95% CI
Large/large	562	18,842	1.00	Referent
Small/large	151	4,165	1.04	0.87, 1.25
Large/small	185	3,325	1.28	1.08, 1.52
Small/small	182	2,101	1.55	1.26, 1.79



Demographic Characteristics and Nos. of Strong and Weak Ties	No. of Deaths	Total No.	HR	95% CI
Sex				
Women				
Large/large	326	13,973	1.00	Referent
Small/large	63	2,460	1.03	0.75, 1.30
Large/small	82	1,974	1.46	1.14, 1.87
Small/small	44	967	1.36	0.99, 1.87
Men				
Large/large	236	4,869	1.00	Referent
Small/large	88	1,705	1.05	0.82, 1.34
Large/small	103	1,351	1.17	0.92, 1.48
Small/small	138	1,134	1.54	1.24, 1.91
Age group				
<50 years				
Large/large	230	14,188	1.00	Referent
Small/large	55	3,080	0.98	0.73, 1.32
Large/small	67	2,373	1.30	0.98, 1.72
Small/small	56	1,321	1.77	1.31, 2.39
≥50 years				
Large/large	332	4,654	1.00	Referent
Small/large	96	1,085	1.06	0.84, 1.33
Large/small	118	952	1.33	1.07, 1.65
Small/small	126	780	1.47	1.18, 1.82
Marital status				
Single				
Large/large	182	5,296	1.00	Referent
Small/large	54	1,400	0.80	0.59, 1.09
Large/small	76	1,040	1.37	1.04, 1.80
Small/small	80	852	1.11	0.84, 1.47
Married/cohabiting				
Large/large	380	13,546	1.00	Referent
Small/large	97	2,765	1.13	0.90, 1.42
Large/small	109	2,285	1.20	0.96, 1.49
Small/small	102	1,249	1.61	1.28, 2.02