Occupational Social Interaction Is Associated With Reduced Dementia Risk: The Trøndelag Health Study (HUNT)

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Abstract

Lifetime social engagement could build cognitive reserve and lower the risk of dementia through compensatory effects on brain health. We aimed to investigate whether social interaction at work is protective of later life cognitive impairment. Data from 9,248 participants of the population-based Norwegian HUNT4 70+ Study (2017-19), with cognitive assessments at or after age 70, were linked retrospectively to longitudinal registry-based employment information spanning ages 30-65 years. An occupational social interaction score was computed using occupational characteristics from the O*NET database. Multinomial logistic regression was used to estimate the associations between occupational social interaction and dementia and mild cognitive impairment (MCI), while linear regression was used to model the association with cognition using the Montreal Cognitive Assessment (MoCA). The models were subsequently adjusted for confounding variables age, sex, education, and apolipoprotein E (APOE)-ε4 genotype, as well as for midlife family, health, and lifestyle related variables collected from national registries and earlier HUNT study waves. Higher occupational social interaction was associated with reduced risks of dementia and MCI, and better MoCA performance. Adjusted for confounding from age, sex, education, and APOE-ε4, each standard deviation higher occupational social interaction score was associated with a relative risk ratio of 0.89 for dementia ($p=0.003$), 0.88 for MCI ($p<0.001$), and a 0.31-point higher MoCA-score ($p<0.001$). Our findings highlight the importance of occupational social interaction in preserving and promoting cognitive health in later life.

Public Significance Statement:

High levels of social interaction at work are associated with reduced risk of dementia and mild cognitive impairment (MCI) in later life, as well as better cognitive performance. While this observational study cannot determine causality, our findings suggest that social engagement in the workplace may promote cognitive health.

Keywords: Cognitive reserve, modifiable risk factors, intrinsic capacity, work histories, occupational health

Introduction

Cognitive health in aging is influenced by multiple factors, including lifestyle, education, and social interaction. Social isolation and loneliness are known risk factors for dementia (Livingston et al., 2024), while engagement in diverse types of social activities throughout life may help compensate for limited early life resources, particularly for those with less formal education (Jackson et al., 2020). Research suggests that engaging in enriching social, mental, and physical activities, in early and midlife have long-lasting benefits for cognitive function (Frank et al., 2023), including positive effects on episodic memory and executive function (Sharifian et al., 2020). People who are more socially (Evans et al., 2019), intellectually, and physically active are less likely to develop dementia (Marioni et al., 2015).

For many, especially those who are single, work plays a crucial role in providing and maintaining social interactions (Hampton et al., 2009). A study by the Pew Research Center found that 30% of single adults in the United States identified their workplace as their primary source of social interaction, compared to 17% of married adults (Hampton et al., 2009). As work affects our lifestyles and health risk factors, features of the workplace may have lasting implications for cognitive health, particularly in later adulthood, after employment has ended (Kivimäki et al., 2021; Stoykova et al., 2011; Wang et al., 2024).

The cognitive reserve theory offers a framework for understanding how social interaction may buffer against cognitive decline. Cognitive reserve refers to the brain's ability to function more efficiently than expected given age-related changes and pathology (Stern et al., 2023). Consistent with the cognitive reserve theory, our previous research has demonstrated that working in cognitively stimulating occupations was associated with a lower risk of

developing later-life cognitive impairment (Edwin et al., 2024). However, the cognitive stimuli experienced at work spans multiple dimensions, including the complexity of working with people, working with data, and working with things or machinery (Council, 1980). Among these, the complexity of work involving people or social interactions, such as communicating, building relationships, resolving conflicts, and interacting with both internal and external parties, appears to be particularly beneficial for cognitive health in older adults (Coleman et al., 2023; Curreri et al., 2022; Hussenoeder et al., 2019). However, most prior research in this area is constrained by its reliance on subjective assessments of work histories, small sample sizes, or differences in dementia diagnostics, reducing the ability to draw robust conclusions.

More research is needed to understand the relationship between social interaction at work and future cognitive health. The present study combines objective, longitudinal registry-based occupational data across adulthood with detailed cognitive assessment data at older age from the population-based HUNT4 70+ Study (2017-2019). We hypothesized that working in occupations that require high levels of social interaction would be associated with a lower risk of dementia and MCI and better performance on the MoCA test, even after adjusting for the confounding variables age, sex, education, apolipoprotein E (APOE)-ε4 genotype. We also addressed whether these associations were influenced by accounting for midlife factors related to family, health, and lifestyle. Moreover, we aimed to investigate interaction effects by examining whether the association between the level of occupational social interaction and cognitive impairment differed by APOE-ε4 genotype, sex, mode of retirement, and levels of education and occupational complexity. We further assessed whether estimates were impacted by selective participation in the HUNT4 70+ Study. Finally, we examined whether accounting

for occupational social interaction affected estimated associations between other covariates and old-age cognition.

Methods

Transparency and Openness

We used data from the Trøndelag Health Study (HUNT) (Krokstad et al., 2012; Åsvold et al., 2022), matched with records collected from administrative demographic, education, and employment registers. The HUNT study is a collaboration between HUNT Research Centre (Faculty of Medicine and Health Sciences (MH), Norwegian University of Science and Technology – NTNU), Trøndelag County Council, Central Norway Regional Health Authority, and the Norwegian Institute of Public Health. The genotyping in HUNT was financed by the National Institutes of Health (NIH) (grant number NIH R35 HL135824-03); Stiftelsen Kristian Gerhardt Jebsen (grant number SKGJ-MED-015); University of Michigan; the Research Council of Norway; the Liaison Committee for Education, Research and Innovation in Central Norway; and the Joint Research Committee between St Olav's Hospital and the Faculty of Medicine and Health Sciences, NTNU, and the National Institutes of Health; University of Michigan; USA. The GCF is funded by the Faculty of Medicine and Health Sciences at NTNU and the Central Norway Regional Health Authority. The genotyping and imputation efforts in HUNT were a collaboration between researchers from the Department of Public Health and Nursing (ISM) (MH, NTNU), and the University of Michigan Medical School and the University of Michigan School of Public Health. The genotyping was performed at the Genomics Core Facility (GCF) (MH, NTNU) (Brumpton et al., 2022; Næss et al., 2024). Researchers affiliated with a Norwegian research institution can apply for the use of HUNT data upon approval from the Regional Committee for Medical and Health Research Ethics (REC). International researchers may collaborate with and apply

through a Norwegian principal investigator. Information about data access can be found at NTNU (n.d). The application procedure for access to register data is available from Statistics Norway (n.d.). Other aspects related to work and their association with later life cognitive health have previously been examined in HUNT. For example, Edwin et al. (2024) explored the association between trajectories of occupational cognitive demands, measured by the routine task intensity index, and the risk of MCI and dementia. Additionally, Zotcheva et al. (2023) investigated how trajectories of occupational physical activities are linked to the risk of MCI and dementia. To our knowledge, the variables and relationships examined in this article, specifically regarding occupational social interaction, have not been previously studied. The design and analysis of this study were not preregistered. Data curation, including sampling procedure and variable definitions, is described in the Methods section. The Stata code we used is available upon request from the authors. All analyses were performed in Stata 17.0.

Study population

We employed a historical cohort design that linked data from the HUNT4 70+, a study of participants aged 70 years and older, with retrospective registry data. The HUNT Study (Krokstad et al., 2012; Åsvold et al., 2022) is an ongoing population-based health study in which all adult residents of the former Nord-Trøndelag County were invited to participate across four waves: HUNT1 (1984-1986), HUNT2 (1995-1997), HUNT3 (2006-2008), and HUNT4 (2017-2019). In HUNT4, residents aged 70 years and older (N=19,403) were also invited to participate in the 70+ sub-study, with 9,930 individuals aged 70-105 years participating. Cognitive assessments were conducted as part of the sub-study, and these data were linked to social interaction scores of occupations held by the individuals during their working life between the ages of 30-65 years. We have restricted the analysis sample to the

9,248 participants with valid data on cognitive diagnosis, education, genotype, and occupation. The mean year of birth in the analysis sample was 1940 (range 1914-1949). Supplemental material, Figure S1 provides an overview of the study sampling scheme and Table S1 gives the age and sex distribution of the analysis sample.

Standard Protocol Approvals, Registrations, and Patient Consents

The HUNT4 70+ data collection was approved by the Norwegian Data Protection Authority. Participants gave informed written consent. For nursing home residents deemed incapable of providing consent by healthcare professionals, consent was obtained from their closest proxy. The Regional Committee for Medical and Health Research Ethics in Norway (REK) approved our study (REK Southeast A 184373).

Occupational data

For participants in the HUNT4 70+ Study, we collected data on occupations held over their working life from decennial censuses (1960, 1970, and 1980) and the employer-employee register, which covers the jobs of all wage earners in Norway starting in 1995. Since 2003, the employer-employee register records include information on occupation, from which we extracted the four-digit ISCO-88 occupation code. For the years 1995-2002, we assessed the ISCO-88 occupation code using a crosswalk from a matrix with cells given by four-digit educational attainment and four-digit industry of employment codes. Similarly, we used a crosswalk to convert the Nordic Standard of Occupation codes available in 1960-1980 census data to the ISCO-88 standard. In total, the analysis sample covered 291 four-digit ISCO-88 occupations held by survey participants between the ages of 30 and 65 years.

We obtained data on occupational characteristics from the Occupational Information Network (O*NET) database. O*NET is an ongoing data collection sponsored by the U.S. Department of Labor, containing standardized information on worker and job characteristics covering more than 900 occupations. To match occupational observation years of the study sample, we used occupational characteristics extracted from the 5.0 (2003) release of the O*NET database. We used crosswalks provided by O*NET (O*NET OnLine, 2022), the U.S. Bureau of Labor Statistics (U.S.), and Statistics Norway (2002) to covert the data on characteristics from the Standard of Occupations (SOC) classification of O*NET, via 2000 U.S. Census of Occupations codes, to the ISCO-88 standard. For ISCO-88 codes with more than one match in the original O*NET extract, we used the average of occupational characteristics across SOC codes.

To measure the social interaction content of occupations, we extracted six elements from the O*NET database describing the nature of interactions with other people that occur while performing the job. These cover the extent to which the job entails translating and interpreting information for others; communication with co-workers; communication with people outside the organization; establishing and maintaining interpersonal relationships; resolving conflicts and negotiating with others; and performing and working directly with the public. The O*NET elements were scored on a scale between 1 and 5, with higher numbers meaning more social interaction. For each occupation, we formed a composite occupational social interaction score by averaging the six elements from the O*NET database. Finally, for each study participant, we averaged the composite score over occupations held between ages 30 and 65 to form a lifetime occupational social interaction score. Supplemental material (Table S2, Table S3) contains a detailed listing and sample summary statistics of each element used to compute the occupational social interaction measure. Because the scale of the social

interaction score does not have an intuitive interpretation, we standardized the measure to have mean zero and standard deviation (SD) unity in the sample (Figure S2). Accordingly, reported associations provide the estimated change in the outcome measure for a one SD increase in the occupational social interaction score.

Cognitive outcomes: Dementia, MCI, and MoCA score

The participants in HUNT4 70+ were assessed at field stations, at home, or in nursing homes using standardized protocols to collect information from the participants, the next-of-kin or healthcare professionals at nursing homes (Gjøra et al., 2021). Assessments covered cognitive symptoms, activities of daily living, neuropsychiatric symptoms, and symptom debut and course of potential dementia symptoms. Cognitive assessments included the Montreal Cognitive Assessment (MoCA) scale (Nasreddine et al., 2005) and the Word List Memory Test from the Consortium to Establish a Registry of Alzheimer's disease (Morris et al., 1989). For residents of nursing homes, a modified interview protocol was utilized, with medical staff providing information about disease course. Moreover, in nursing homes, the Severe Impairment Battery-8 (Schmitt et al., 2013) was administered as a substitute for the MoCA to residents identified with moderate to severe dementia. From a team of nine medical doctors, specialists in geriatrics, neurology, or psychiatry, associated with the study, at least two were involved in determining the cognitive diagnosis of each participant. The DSM-5 criteria (American Psychiatric Association, 2013) were used to classify individuals as having no cognitive impairment, mild neurocognitive disorder (MCI), or major neurocognitive disorder (dementia). For further details on the diagnostic workup, see (Gjøra et al., 2021).

Other covariates

We collected data on the confounding variables age, sex, and educational attainment (compulsory, upper secondary, or tertiary education) from administrative demographic and education registers, and APOE-ε4 status from the HUNT4 study. APOE-ε4 status was categorized into three groups specified as having 0, 1, or 2 ε4 alleles (Brumpton et al., 2022). Data on marital status and number of children at age 65 years were collected from the central population register. Similarly, we determined the age of retirement, defining *early retirement* as retirement before 63 years of age, and whether participants retired with a disability pension, from the registers of the tax and social insurance administrations. A majority of the study sample also participated in the earlier waves of the HUNT Study, and we used health and lifestyle information from questionnaires and measurements collected through HUNT1 (1984-1986) and HUNT2 (1995-1997) to account for midlife health and lifestyle status of participants. Included were variables indicating the number of close friends, and whether the participant sometimes feels lonely. Further, a set of dichotomous variables were used to classify participants as smokers from self-reports of daily smoking and alcohol consumers for those reporting consuming five or more units of alcohol over the last two weeks. Participants were classified as physically inactive if they reported less than 30 minutes of physical activity per day and as obese if their body mass index (BMI) at the time was ≥30 kg/m2. The diabetes variable is based on the information from self-reported responses or measurement of elevated blood glucose levels (11.1 mol/l or higher). Hypertension was determined either through blood pressure measurements (≥140 mmHg systolic blood pressure and/or ≥90 diastolic blood pressure) or reported use of antihypertensive drugs. Hearing impairment was identified if participants reported having moderate or severe levels of impaired hearing, while psychiatric disorders were noted based on reported moderate or severe levels of psychiatric impairment (the early surveys did not ask for diagnosis). We refer to the model accounting for age (i.e., birth year), sex, education, and genotype as the "baseline model," as these covariates are pre-

determined confounders. Covariates capturing midlife family and lifestyle factors, while measured up to 33 years before assessment of old-age cognition, may be influenced by occupational choices made early in the working career and could act as intermediaries in the relationship between occupational social interaction and later cognitive health.

Previous studies using the HUNT cohort have also examined associations of family and work-related factors on the risks of dementia or MCI, and the Lancet Commission on dementia prevention, intervention, and care have published effect sizes from meta-analyses of 14 identified risk factors for dementia (Livingston et al., 2024). To facilitate comparisons of results across studies, as well as comparisons of explanatory variables measured on different scales, we standardized results to reflect associations between the dementia and MCI outcomes and standard deviations of any underlying index value. For example, in addition to reporting the estimated risk of dementia linked to low education, we also report the implied risk associated with a one SD lower educational attainment after rescaling the coefficient with the SD difference in years of schooling between study participants with high and low education.

Statistical analyses

Covariates collected from national registries and the HUNT4 70+ study were complete, and for the survey-based lifestyle measures collected from HUNT1 and HUNT2, missing values were imputed using a multiple imputation procedure with 20 iterations (Supplemental material). For robustness, we also re-estimated all statistical models in the subsample with complete data (Supplemental material, Figure S3).

We generated three binned scatter plots (Figure 1) to visually illustrate the associations between the occupational social interaction score and dementia and MCI prevalence, as well as MoCA scores. The prevalence of dementia was computed after omitting those with an MCI diagnosis, and the prevalence of MCI after omitting those with a dementia diagnosis. The bins account for sex and age and were constructed so that each scatter point represents five percent of the sample.

Because the MCI diagnosis does not necessarily progress to dementia, we treated MCI and dementia as ordinal outcomes and used multinomial logistic regressions to analyze the associations between occupational characteristics and these outcomes. For the continuous MoCA measure, we used ordinary least squares regression to analyze its association with the occupational social interaction score. All statistical analyses accounted for age and sex, and, to study attenuation of the association between occupational social interaction and cognitive impairment, we progressively added sets of control variables to the models capturing educational attainment, APOE-ε4 genotype (0, 1, and 2 alleles), marital status, number of children, number of friends, loneliness, smoking status, alcohol consumption, physical inactivity, obesity, diabetes, hypertension, hearing impairment, and psychiatric disorder. Next, in heterogeneity analyses, we used interaction terms to examine whether the association between the occupational social interaction score and cognitive impairment differed by APOE-ε4 genotype (0 vs 1 or 2 alleles), sex, mode of retirement (ordinary vs early vs disability retirement), and educational attainment (compulsory, upper secondary, or tertiary education). While we controlled for 1 and 2 APOE-ε4 alleles in the regression analyses, in the heterogeneity analysis we combined these into one category because of the limited number of observations with 2 alleles (N= 252, 2.7% of the sample). In supplementary analyses, we examined whether the association between occupational social interaction and late-life

cognition differed across levels of occupational complexity using complexity trajectories previously estimated over the same work-life period (Edwin et al., 2024). Finally, we used the longitudinal data extract covering participants, non-participants, and those deceased to address whether estimates were affected by bias from selective participation.

Results

Descriptive statistics

Table 1 presents descriptive statistics for the characteristics of the analysis sample (N= 9,248) and the subsample with a valid MoCA score (N= 8,850). In the analysis sample, 1,353 (14.6%) participants were diagnosed with dementia and 3,245 (35.1%) participants were diagnosed with MCI. In the subsample with MoCA scores, the average score (on the 30-point scale) was 22.6 (SD 4.7). The occupational social interaction score (range 1-5) was on average 2.73 in both samples. Supplemental material, Figure S2 shows the distribution of the occupational social interaction score in the analysis sample. To aid interpretation of results, Figure S2 specifies occupational social interaction index values for selected well-represented occupations that appear as spikes in the histogram. As shown, the analysis sample spans a diverse range of occupations, from welders, machine operators, and cleaners with low occupational social interaction scores to teachers, nurses, and managers with high scores.

The binned scatter plots, accounting for sex and age, revealed strong associations with the prevalence of dementia and MCI declining sharply as values of the social interaction score increased. Additionally, the MoCA score showed a marked positive relationship with the social interaction score (Figure 2).

Regression results

A one SD higher occupational social interaction score (greater score is indicative of higher social interaction) was associated with relative risk ratio (RRR) = 0.75, 95% confidence interval (CI) [0.70, 0.80] for dementia and 0.79, 95% CI [0.75, 0.83] for MCI, and 0.86 higher absolute MoCA score 95% CI [0.77, 0.95] (Figure 2; Supplemental material, Table S4 and S5 report the complete set of regression results). As Figure 2 illustrates, these associations were attenuated after adjustment for educational attainment and were only modestly affected by further inclusion of APOE-ε4 genotype and inclusion of midlife family, health, and lifestyle variables. According to the model that adjusted for confounding from age, sex, education, and APOE-ε4 genotype, a one SD higher the occupational social interaction score was associated with lower risk of dementia (RRR= 0.89, 95% CI [0.82, 0.96]) and lower risk of MCI (RRR= 0.88, 95% CI [0.83, 0.93) and an increased MoCA score by 0.31 points 95% CI [0.21, 0.41]. After further adjustment for family constellation and number of children, as well as midlife social factors such as number of friends, health, and lifestyle measures, a one SD increase in the occupational social interaction score was associated with lower risk of dementia (RRR= 0.91, 95% CI [0.84, 0.98]), and lower risk of MCI (RRR= 0.89, 95% CI [0.84, 0.94]), and an increase of the MoCA score by 0.28 points, 95% CI [0.18, 0.38].

Heterogeneity

Inspection of the frequency distributions of the occupational social interaction score across subgroups defined by APOE-ε4 genotype (0 vs 1 or 2 alleles), sex, retirement mode (ordinary vs early vs disability retirement), and educational attainment (compulsory, upper secondary, or tertiary education) revealed some variation across groups, with marked differences by sex

and a concentration of high social interaction scores among study participants with tertiary education (Supplemental material, Figure S4-7).

Figure 3 shows binned scatter plots of the associations between occupational social interaction and the cognitive outcome measures by subgroup of APOE-ε4 genotype, sex, retirement mode, and educational attainment. Figure 4 shows estimated relative risk ratios for dementia and MCI and coefficient estimates from the MoCA model, all based on the model that accounts for age, sex, educational attainment, and APOE-ε4 genotype. Notwithstanding the large confidence intervals for certain subgroups, reflecting small sample sizes, these results reveal that the estimate for dementia remains around the estimate from the full sample (Figure 2, RRR= 0.89, 95% CI [0.82, 0.96]). Although differences by retirement mode and education were not statistically significant (Supplemental material, Table S6), estimates point to occupational social interaction being more strongly associated with MCI and MoCA score for those with ordinary retirement and the highly educated than for other study participants. Similarly, while social interaction appeared more preventive for dementia among workers in occupations characterized by low routine task complexity, i.e., more cognitively stimulating employment (Supplemental material, Figure S8 RRR= 0.62, 95% CI [0.43, 0.92]) than for other workers, there were no statistically significant differences in the associations between social interaction and the dementia and MCI outcomes across levels of occupational complexity. For the MoCA outcome, low and high complexity occupations were more strongly association with occupational social interaction than workers in occupations with intermediate levels of complexity (Supplemental material, Figure S8).

Selection

Individuals who worked in occupations with high social interaction scores were more likely to participate in the HUNT4 70+ study than those in occupations with low social interaction scores. Such selection may cause bias leading to underestimation of the role of social interaction (Supplemental material, Table S7, Table S8, and Figure S9). In Figure S10, the coefficient plot of the multinomial logistic regression models for dementia and MCI is shown for both the analysis sample and the subsample with MoCA scores. Consistent with the above arguments of selection bias in the direction of non-detection, we found that the estimated relative risk ratio for dementia (baseline model RRR = 0.92, 95% CI [0.85, 1.00]) was somewhat attenuated in the restricted sample when compared to the estimate from the analysis sample (RRR = 0.89, 95% CI [0.82, 0.96]).

Importance of accounting for occupational social interaction

To study the importance of accounting for occupational social interaction on the coefficient estimates of other covariates, we re-estimated the baseline model, which included sex, age, education, and APOE-ε4 genotype, both with and without the occupational social interaction score. This analysis revealed that the coefficients for sex and educational attainment changed substantially after removing the occupational social interaction score, while the coefficients for the other covariates remained largely unchanged (Supplemental material, Table S9. Compared to models that do not account for occupational social interaction, sex differences attenuated by 26% for dementia, 24% for MCI, and 19% for MoCA. Additionally, the benefit associated with tertiary education was reduced by 13% for dementia, 22% for MCI, and 12% for MoCA when we added the occupational social interaction score to the model specification.

Comparison with previous studies

Table 2 provides a broader overview of risk and protective factors for dementia and MCI in the HUNT cohort. To facilitate comparison across variables measured on different scales, we standardized risk factors associated with work, education, family, and social contact, from this as well as previous HUNT studies, and report the risk ratio linked to one SD of the underlying factor. Moreover, we included factors identified by the Lancet Commission on dementia prevention, intervention, and care (Livingston et al., 2024). According to the standardized estimates, workers in occupations with a one SD higher social interaction score had an 11% reduced risk of dementia (RRR = 0.89, 95% CI [0.83, 0.96]), compared to 12% increased risk (standardized RRR = 1.12, 95% CI [1.00, 1.25]) from lower occupational routine task complexity (Edwin et al., 2024), and 22% increased risk (standardized RRR = 1.22, 95% CI [1.10, 1.36]) from higher occupational physical demands (Zotcheva et al., 2023). Moreover, leisure-time social interaction (proxied by number of friends) gives a similar effect size as the occupational social interaction score, with a one SD higher number of friends associated with a 10% reduced risk of dementia (standardized RRR = 0.90, 95% CI [0.84, 0.96]). Other important risk factors for dementia in our cohort are carrying APOE-ε4 (two alleles: RRR = 5.77, 95% CI [4.05, 8.22]; one allele: RRR = 1.81, 95% CI [1.56, 2.09]), having diabetes (RRR= 2.11, 95% CI [1.39,3.20]), low education (standardized RRR= 1.56, 95% CI [1.32,1.85]), or a psychiatric disorder (RRR = 1.89, 95% CI [1.31, 2.73]).

Discussion

In this large population-based cohort study with objective occupational data from age 30 to 65 years on over 9,000 individuals covering almost 300 occupations, we found that higher occupational social interaction was associated with a lower risk of dementia and MCI, and a higher MoCA score at or after the age of 70 years. Results were similar across APOE-ε4

genotype, sex, mode of retirement, educational attainment, and levels of occupational complexity, pointing to a robust association between occupational social interaction and late-life cognitive health.

Our finding of 11% reduction in dementia risk and 12% reduction in MCI risk with a one SD higher occupational social interaction score, aligns with results from a recent study where one SD increase in complexity of work with people was linked to a 9–12% lower risk of dementia or MCI (Coleman et al., 2023). Furthermore, that study found that a one SD increase in complexity led to a 0.14–0.19 SD improvement in episodic memory, and a 0.18–0.25 SD increase in brain reserve, measured as the difference between overall cognitive function and a measure of brain atrophy derived from magnetic resonance imaging. Although not entirely comparable due to differing outcome measures, these associations were greater than the improvement in MoCA found in our study (0.31point improvement corresponded with a 0.07 SD increase in MoCA score). Other studies likewise report that higher complexity of work with people is associated with better performance on cognitive tests, such as MMSE (Andel et al., 2007; Curreri et al., 2022), improved executive functioning over long-term follow-up (Velez-Coto et al., 2021), and resilience against ischemic lesions or hippocampal atrophy (Curreri et al., 2022). However, not all research supports these findings, a study of 624 older adults in Brazil found no association between occupational social interaction and MMSE scores (Correa Ribeiro et al., 2013), and earlier studies also found no association between high complexity of work with people and reduced dementia risk (Andel et al., 2005; Dekhtyar et al., 2015). The discrepancy between findings could reflect variation in the measures of occupational social interaction across studies, which makes direct comparisons of estimates difficult. Moreover, methodological differences may affect cross-study comparisons, as occupational social interaction is measured at varying time points, is not always based on

longitudinal data, and does not always account for the duration of work in socially complex roles. For example, one study found that high social complexity of work was associated with a reduced risk of dementia and Alzheimer's disease only for those who held their occupation for more than 23 years (Kröger et al., 2008). Due to short follow-up periods in many studies, the causal direction thus remains uncertain. Our study adds valuable insights due to the extended follow-up period and the substantial time interval between the measurements of workplace social interactions and cognitive assessments, which minimizes the risk of reverse causation.

Our findings are consistent with the cognitive reserve theory (Stern et al., 2023), which posits that lifelong engagement in enriching experiences, including social interactions, enhances an individual's capacity to adapt to age-related and pathological brain changes. Frequent and diverse types of social interaction may enhance neural plasticity and promote compensatory mechanisms that support brain health (Reuter-Lorenz & Park, 2014). Moreover, participating in discussions and debates promotes cognitive flexibility, which can stimulate cognition and enhance critical thinking skills (Mercier & Sperber, 2011). Humans have evolved brains that are highly specialized for social interaction, as evidenced by the development of brain structures involved in language processing and the expansion of the prefrontal cortex (Dunbar, 1998). Notably, face-to-face interactions are associated with better daily well-being in older adults, including higher positive affect and lower loneliness, compared to telephone or digital communication (Macdonald et al., 2021). Our results further demonstrate that occupational social interaction is crucial for preserving brain function throughout life. Technological advancements and societal transformations are reshaping the workforce, leading to the automation and offshoring of routine, low-interaction jobs (Coupe, 2019; Nedelkoska & Quintini, 2018). This shift may result in workers transitioning to roles that

require higher levels of social engagement, which could enhance cognitive health and resilience. On the other hand, demographic trends, such as more people living alone, smaller families, and fewer individuals marrying or having children (Smock & Schwartz, 2020), further underscore the importance of occupational social interaction. In light of the transition toward telework following the COVID-19 pandemic, it is uncertain whether occupational social interactions conducted via digital platforms offer the same cognitive and emotional benefits as those occurring face-to-face (Macdonald et al., 2021).

Educational attainment attenuated the associations between working in occupations with high social interaction scores and better later-life cognitive health. A Swedish study (Dekhtyar et al., 2015) that followed approximately 7,500 individuals for 21 years reported a reduced dementia risk associated with tertiary education versus elementary education, that was mediated by occupational complexity (by 26% according to our calculations from their results). Likewise, a large population-based cohort study with nearly 7,400 individuals from the U.S. found that a substantial portion (11%–22%) of the cognitive benefit linked to higher education levels was mediated by occupational complexity (Fujishiro et al., 2019). In our analyses, accounting for occupational social interaction attenuated the associations between educational attainment and cognitive outcomes. Specifically, the inclusion of the occupational social interaction score reduced the benefit associated with tertiary education by 13% for dementia, 22% for MCI, and 12% for MoCA, compared to the model that did not account for occupational social interaction. In the heterogeneity analysis, where we stratified the association between occupational social interaction and cognitive outcomes by education level, the point estimates, though accompanied by wide confidence intervals, indicate that high occupational social interaction scores are more strongly associated with the MCI and MoCA outcomes among individuals with tertiary education compared to those with lower

education levels. However, it remains challenging to determine whether the observed association between occupational social interaction and later-life cognitive health is independent of education, as higher education likely facilitates access to more intellectually stimulating occupations.

APOE-ε4, a well-established genetic risk factor for Alzheimer's disease (Genin et al., 2011) can serve as a proxy for increased susceptibility to Alzheimer pathology, in the absence of direct assessment. In our analyses, APOE-ε4 carriers remained at a higher risk of cognitive impairment relative to non-carriers regardless of occupational social interaction scores. These findings align with another study which found no significant interaction between the occupational cognitive demands and APOE-ε4 status ($p = 0.11$) (Pool et al., 2016). In contrast, other studies report that higher occupational cognitive demands were associated with a weaker impact of APOE-ε4 on cognitive decline (Kleineidam et al., 2022; Rodriguez et al., 2021). Although the interaction analyses with APOE-ε4 were not statistically significant in our study, the point estimates suggest that high occupational social interaction may be less effective in protecting against cognitive impairment in individuals with at least one APOE-ε4 allele than in those without the allele. Although occupational social interaction may enhance cognitive reserve, it might not mitigate the genetic risk associated with late onset dementia (Alzheimer's disease).

We did not find sex differences in the associations between working in occupations with high social interaction scores and better later-life cognitive health (Supplemental material, Table S6). This suggests that the level of occupational social interaction is equally important for both men and women in our cohort. Previous studies on leisure time social interaction, have reported sex differences, with men more likely to be involved in work-related networks and

women more likely to be involved in family-related networks (Kim et al., 2019). Another study found that co-residence with children, and engagement in religious activities were associated with improved cognitive function among older men but not among older women (Pothisiri & Vicerra, 2021). Our results indicate that, regardless of these differences in social network roles, the cognitive benefits from occupational social interactions are similar for both sexes. We did, however, find that the benefit associated with tertiary education and being female was reduced when we added the occupational social interaction score to the model specification. The implication is that sex differences and estimated impacts of tertiary education are mediated by occupational social interaction, reflecting variation in occupational social interaction by sex and educational attainment.

We found significant associations between occupational social interaction scores and performance on the MoCA test for all modes of retirement. Although differences were not statistically significant, those with early and disability retirement exhibited weaker associations between occupational social interaction and MCI and MoCA score than those with longer work careers. Our earlier research showed that the elevated dementia risk associated with early retirement was largely influenced by the heightened risk of dementia among individuals who left the workforce early due to work-related disabilities (E Zotcheva et al., 2023). The findings of the current study suggest that occupational social interactions may play a protective role in cognitive health across all retirement modes, but particularly among those who retire ordinarily.

Our finding that a one SD increase in occupational social interaction is associated with an 11% reduced risk of dementia aligns with previous research on occupational factors in the

HUNT cohort. Specifically, lower occupational task complexity and higher physical demands have been linked to increased dementia risk, by 12% and 22% respectively (standardized measures) (Edwin et al., 2024; Zotcheva et al., 2023). Notably, the effect of higher levels of occupational social interaction were comparable to that of leisure-time social engagement, as proxied by number of friends (standardized RRR = 0.90, 95% CI [0.84, 0.96]). Genetic predisposition, particularly carrying two APOE-ε4 alleles, remains the strongest risk factor (RRR = 5.77, 95% CI [4.05, 8.22]). Diabetes, low education, and psychiatric disorders also show substantial associations in our cohort. Nonetheless, given the long duration of working life for most individuals, the job could represent a source of cognitive stimulation in adulthood.

The strengths of this study include the use of objective prospective registry data, which summarize occupational histories over several decades and connects them to clinical outcomes related to cognitive health in later life, all within a large general population cohort. Experienced physicians diagnosed dementia and MCI following an evaluation in accordance with accepted clinical standards. Moreover, the study included variables, such as education and income from administrative registries, and health- and lifestyle factors measured decades before the cognitive assessments. By using this approach, we reduced the risk of recall bias and reverse causation. Even though some prior studies have employed objective measures of occupational characteristics, many used the Dictionary of Occupational Titles, which predominantly covers blue-collar work and does not adequately capture the shift from manual to cognitive labor in recent times (Gordo & Skirbekk, 2013).

Our study has several limitations. Although our estimates were adjusted for age, sex, education, APOE-ε4, and a wide range of health- and lifestyle factors, we did not account for

other potentially important confounders such as traumatic brain injury, pollution, diet, childhood cognitive endowment, or educational quality (Huh et al., 2024; Livingston et al., 2024). Also, the lack of biomarker data may cause misclassification. Moreover, our analysis did not take into account the evolution of work tasks over time within the same job category, and the 2003 O*NET version may not fully reflect the demands of some occupations observed for older participants between 1960 and 1980. O*NET was developed in the United States, and because work cultures may vary between nations, there could be discrepancies between the requirements of American and European job activities (Gordo & Skirbekk, 2013). Additionally, people with the same job titles may have various tasks and, as a result, face differing demands for occupational social interaction. Another weakness is the low statistical power of analyses aimed at disentangling the effects of occupational factors that are highly correlated. In particular, although our findings suggest that associations between occupational social interaction and dementia are consistent across levels of occupational complexity, the precision of these estimates is limited due to the strong correlation between the two measures.

Individuals who worked in occupations with high social interaction scores were more likely to participate in the HUNT4 70+ study than those in occupations with low social interaction scores, and bias from such selection likely yields conservative estimates. Therefore, our results probably represent the lower bound of the association between occupational social interaction and later-life cognitive outcomes. Additionally, a persons' perceptions of their abilities can influence their educational and career choices (Sheu et al., 2010), meaning that those with lower social skills may self-select into jobs with less social interaction demands. Moreover, there might be selection bias linked to the HUNT study originating from a specific region in Norway, where participants benefit from strong social support networks and a robust

welfare system. This may limit the generalizability of the findings to populations in different socio-economical settings.

Conclusion and Implications

High levels of occupational social interaction were associated with a reduced risk of cognitive impairment after the age of 70, even after adjusting for key demographic, health- and lifestyle factors, as well as APOE-ε4 genotype. The long follow-up period and extended interval between occupational social interaction measurements and cognitive assessments reduce the likelihood of reverse causation and strengthen the credibility of these associations. While we cannot infer causality, our findings can help inform public health and occupational policies aimed at fostering a more socially interactive work life, potentially supporting healthier cognitive aging.

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Table 1: Descriptive statistics

	Analysis sample[a]	Subsample with MoCA score[b]
Dementia (N/mean)	1,353/0.146	994/0.112
MCI (N/mean)	3,245/0.351	3,214/0.363
MoCA score (mean/SD)		22.6/4.7
Occupational social interaction index:		
Raw score (mean/SD)	2.727/0.663	2.732/0.661
Standardized score (mean/SD)	0/1	0.007/0.999
Female	0.528	0.522
Age (mean/SD)	78.0/6.3	77.6/6.0
Educational attainment:		
Compulsory	0.244	0.234
Secondary	0.544	0.549
Tertiary	0.212	0.217
APOE-ε4 genotype:		
One APOE-ε4 allele	0.276	0.271
Two APOE-ε4 alleles	0.027	0.025
Marital status age 65:		
Single	0.043	0.042
Married	0.775	0.778
Widow(er)	0.089	0.086

Divorced	0.093	0.095
Children:		
No children	0.064	0.062
1 child	0.074	0.072
2 children	0.337	0.340
3 children	0.324	0.328
4+ children	0.201	0.199
HUNT1/2 covariates:		
Friends (mean/SD)	6.4/3.2	6.4/3.2
Lonesome	0.282	0.280
Smoker	0.283	0.285
Alcohol	0.085	0.086
Inactive	0.461	0.460
Obese	0.160	0.140
Diabetes	0.022	0.021
Hypertension	0.533	0.526
Hearing impairment	0.068	0.066
Psychiatric disorder	0.032	0.031

Note. Reported are fractions of sample, unless otherwise indicated. Because of non-participation and non-responses in the HUNT1 and HUNT2 waves, observation counts may be lower for covariates listed between "Friends" and "Psychiatric disorder;" see Supplemental material. APOE = apolipoprotein E, MCI = Mild Cognitive Impairment, MoCA = Montreal Cognitive Assessment, SD= standard deviation.

[a] N=9,248

[b] N=8,850

Table 2: Overview of selected risk and protective factors of dementia and MCI in the HUNT study

		Dementia		MCI	
	Reference	RRR [95% CI]	Standardized RRR[1]	RRR [95% CI]	Standardized RRR[1]
A. Occupational factors					
Low vs high complexity[2]	Edwin et al. (2024)	1.37 [1.01,1.86]	1.12 [1.00,1.25]	1.74 [1.35,2.06]	1.22 [1.13,1.31]
High vs low physical demands[2]	Zotcheva et al. (2023)	1.59 [1.25,2.03]	1.22 [1.10,1.36]	1.90 [1.63,2.21]	1.32 [1.23,1.41]
Social interaction[2]	Figure 2/Table S4		0.89 [0.83,0.96]		0.88 [0.83,0.93]
B. Personal factors					
Low education[3]	Mekonnen et al. (2025)	1.99 [1.55,2.61]	1.56 [1.32,1.85]	N/A	
Divorced[2,4]	Skirbekk et al. (2023)	1.60 [1.10,2.34]		1.11 [0.87,1.42]	
Childless[5]	Mekonnen et al. (2025)	1.30 [1.12,1.51]	1.18 [1.07,1.30]	N/A	
Female[6]	Table S4	0.88 [0.76,1.02]		0.81 [0.74,0.90]	
One APOE-ε4[6]	Table S4	1.81 [1.56,2.09]		1.15 [1.03,1.27]	

Two APOE-ε4[6]	Table S4	5.77 [4.05,8.22]		1.65 [1.22,2.23]	
Friends[6]	Table S4	0.96 [0.94,0.98]	0.90 [0.84,0.96]	0.98 [0.97,0.99]	0.94 [0.89,0.98]
Loneliness[6]	Table S4	1.17 [0.99,1.37]		1.19 [1.07,1.33]	
Smoking[6]	Table S4	1.46 [1.24,1.72]		1.24 [1.11,1.39]	
Alcohol[6]	Table S4	1.17 [0.89,1.54]		1.01 [0.83,1.21]	
Inactivity (leisure) [6]	Table S4	1.13 [0.98,1.31]		1.09 [0.98,1.20]	
Obesity[6]	Table S4	1.21 [1.00,1.46]		1.09 [0.96,1.25]	
Diabetes[6]	Table S4	2.11 [1.39,3.20]		1.32 [0.94,1.87]	
Hypertension[6]	Table S4	1.24 [1.06,1.43]		1.10 [1.00,1.22]	
Hearing impairment[6]	Table S4	1.35 [1.04,1.74]		1.09 [0.89,1.33]	
Psychiatric disorder[6]	Table S4	1.89 [1.31,2.73]		1.43 [1.06,1.92]	

[1]Standardized estimate rescales the coefficient from the multinomial logistic model with the difference in underlying standardized index values. E.g., workers with low occupational complexity trajectories experienced on average a 2.8 SD higher value of the underlying lifetime routine task intensity index (RTI) than workers with high complexity trajectories, and workers with high physical demands trajectories experienced on average a 2.3 SD higher value of the underlying occupational physical demands scale than workers in occupations with low physical demands.

Further, those with low education completed on average 4.5 fewer years of schooling than those with high education (1 SD= 2.9 years); the SD of number of children is 1.3; and the SD of *Friends* is 3.2 (the standardized RRR gives the risk reduction of having 3.2 additional friends).

[2]Model adjusts for age, sex, and educational attainment.

[3]Reference category is completed education beyond compulsory schooling before age 44. Model adjusts for age, sex, APOE-ε4 genotype, and height.

[4]Reference category is *married*. RRR refers to the comparison of individuals who were continuously married or divorced over the observation period. The study also considers individuals who were intermittently married and divorced, finding smaller differences.

[5]Reference category is *2 children*. Model adjusts for age, sex, educational attainment, marital status, and religion.

[6]Fully adjusted model, model 5.

Figure 1: Binned scatter plots of associations between occupational social interaction score and cognitive outcome measures

Note. Occupational social interaction scores are standardized values. Each scatter point represents 5% of sample. Scatter points account for age and sex. Panel A excludes MCI cases and Panel B excludes dementia cases. Vertical axes of Panels A and B measure prevalence (fraction); vertical axis of Panel C measures the average MoCA score within cell. Observation counts are 6,003 (Panel A), 7,895 (Panel B), and 8,850 (Panel C). APOE = apolipoprotein E, MCI = Mild Cognitive Impairment, MoCA = Montreal Cognitive Assessment, std = standardized.

Figure 2: Coefficient plot, multinomial logistic (Panels A and B) and ordinary least squares regression models (Panel C)

Note. Panels A and B display relative risk ratios (and their 95% confidence interval) of one standard deviation increase in social interaction score; Panel C displays the coefficient of the social interaction measure from linear models where MoCA score is the dependent variable. N= 9,248 (Panels A and B) and 8,850 (Panel C). See Supplemental material, Tables S4 and S5 for complete sets of coefficient estimates. APOE = apolipoprotein E, MCI = Mild Cognitive Impairment, MoCA = Montreal Cognitive Assessment, mlogit = Multinomial logistic regression, RRR = relative risk ratio.

Figure 3: Binned scatter plots of associations between occupational social interaction score and cognitive outcome measures, by subsamples defined by APOE-ε4 genotype, sex, retirement mode, and educational attainment

Note. Occupational social interaction scores are standardized values. Each scatter point represents 5% of subsample. Scatter points account for age and sex. Dementia panels exclude MCI cases and MCI panels exclude dementia cases. APOE = apolipoprotein E, MCI = Mild Cognitive Impairment, MoCA = Montreal Cognitive Assessment, std = standardized.

Figure 4: Heterogeneity analysis: coefficient plot, multinomial logistic and ordinary least squares regression models by subsample

Note. Panels A and B display relative risk ratios (and their 95% confidence interval) of one standard deviation increase in social interaction score on dementia and MCI, estimated from multinomial logit models; Panel C displays the coefficient of the social interaction measure from ordinary least squares regression models where MoCA score is the dependent variable. Models account for age, sex, educational attainment, and APOE-ε4 genotype. N= 9,248 (Panels A and B) and 8,850 (Panel C). APOE = apolipoprotein E, MCI = Mild Cognitive Impairment, MoCA = Montreal Cognitive Assessment, mlogit = Multinomial logistic regression, RRR = relative risk ratio.