Nationwide evidence that education disrupts the intergenerational transmission of disadvantage

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Despite overall improvements in health and living standards in the Western world, health and social disadvantages persist across generations. Using nationwide administrative databases linked for 2.1 million Danish citizens, we leveraged a three-generation approach to test whether multiple, different health and social disadvantages—poor physical health, poor mental health, social welfare dependency, criminal offending, and Child Protective Services involvement—were transmitted within families and whether education disrupted these statistical associations. Health and social disadvantages concentrated, aggregated, and accumulated within a small, high-need segment of families: Adults who relied disproportionately on multiple, different health and social services tended to have parents who relied disproportionately on multiple, different health and social services and tended to have children who evidenced risk for disadvantage at an early age, through appearance in protective services records. Intra- and intergenerational comparisons were consistent with the possibility that education disrupted this transmission. Within families, siblings who obtained more education were at a reduced risk for later-life disadvantage compared with their cosiblings who obtained less education, despite shared family background. Supporting the education potential of the most vulnerable citizens might mitigate the multigenerational transmission of multiple disadvantages and reduce health and social disparities.

intergenerational transmission | disadvantage | inequality | administrative registers | education

The Western world has witnessed substantial improvements in living standards and health. However, not all citizens have benefited equally. Health and social disadvantages are either constant (1, 2) or on the rise (3, 4). Moreover, health and social disadvantages are not redistributed anew in each generation. Rather, they run in families (5–8). The study of intergenerational transmission of disadvantage typically focuses on two generations and on the transmission of specific disadvantages, such as welfare dependence, crime, or poor health. This limits the understanding of the phenomenon of intergenerational transmission—its source, magnitude, and potential remedy—to the extent that 1) multiple, different health and social disadvantages aggregate in the same small segment of the population (9, 10) and 2) this population segment may extend across multiple generations (11). Here, we leverage a three-generation approach to test the intergenerational transmission of disadvantage and its disruption via education. We use "transmission" to refer to statistical associations between measures of disadvantage across generations and "disruption" to refer to the disruption of these statistical associations.

Using nationwide administrative data linkage on about 2.1 million Danish citizens, we measured multiple health and social disadvantages in a cohort of young adults ("Generation 2 [G2]"), their parents ("Generation 1 [G1]"), and their children ("Generation 3 [G3]"). We measured the degree of concentration, or inequality, in the distributions of citizens' contacts with five public sectors that signal health and social problems: public hospital stays for physical health difficulties, psychiatric hospital stays for mental health difficulties, social welfare benefit use, convictions for crime, and Child

Protective Services involvement (Methods). We also measured the aggregation and accumulation of these disadvantages: the extent to which the same small segment of citizens accounted for a disproportionate share of events across multiple health and social sectors (Methods). Using this multigeneration resource, we tested two hypotheses across a sequence of analyses (Fig. 1).

First, we tested the hypothesis that the concentration, aggregation, and accumulation of multiple health and social disadvantages runs within a small segment of families: that adults who rely disproportionately on multiple, different health and social services 1) tend to have parents who rely disproportionately on multiple, different health and social services and 2) tend to have children who evidence risk for disadvantage at an early age, through appearance in protective services records (12). If so, this would suggest intergenerational transmission as one potential driver of persistence in health and social disadvantages, and these families would be a high-priority prevention target.

Second, we tested the hypothesis that education disrupts the transmission of multiple health and social disadvantages: that attaining education attenuates both 1) intergenerational continuity of health and social disadvantage and 2) risk of protective services involvement among children of disadvantaged adults. Education is an attractive policy lever because it is modifiable and the focus of prevention programs (13, 14). However, policy making requires evidence

Fig. 1. Testing hypotheses about the transmission and disruption of health and social disadvantage across three generations. The figure depicts the study populations used and sequence of analyses conducted in the current study. "Transmission" refers to statistical associations between measures of disadvantage across generations, and "disruption" refers to disruption of these statistical associations. Age range and mean age at the start of observation is indicated by [a]. Age range during the full observation period and mean age at the end of observation is indicated by [b]. Because G3 children were born both prior to and during the 2006 to 2016 observation period (birth years = 1988 to 2016), mean age at the end rather than the start of observation is reported to incorporate data from all children. <1 y of age includes children who were born at any time during the last year of the observation period.

that isolates education as an active ingredient in life outcomes, and causal inference with observational data necessitates several assumptions (*SI Appendix,* Fig. S1). We therefore linked data between G2 siblings to also test the association between education and later-life health and social disadvantage, independent of shared familial risks.

Denmark is a useful setting in which to measure the intergenerational transmission of disadvantage. Income inequality in Denmark is low relative to other Western countries, but it has risen in recent years [after-tax Gini coefficient = 0.25 in 2004 and 0.28 in 2018 (15)]. Furthermore, despite Denmark's extensive income redistribution and cradle-to-grave public healthcare and social welfare systems, intergenerational associations in disadvantages are still high and often indistinguishable from levels in countries such as the United States that have less extensive welfare systems (e.g., ref. 16). Thus,

Denmark presents a useful context in which to investigate the factors that drive persistence in disadvantage, despite efforts to reduce inequality.

Results

Health and Social Disadvantage Concentrate, Aggregate, and Accumulate in a Small Segment of Citizens. Our index population (G2) included the 636,385 individuals who were born in Denmark between 1974 to 1984, resided in the country for any time between 2006 to 2016, and had parental data to indicate whether or not public services were used, to enable intergenerational analyses. The G2 population was 22 to 32 y of age at the start of the observation period (mean = 26.7) and was followed up to ages 32 to 42 (Fig. 1 and *SI Appendix,* Fig. S2A).

Between 2006 and 2016, 38.0% of the G2 population were admitted to public hospitals for physical health problems, totaling

1,493,251 bed nights; 3.3% were admitted to psychiatric hospitals for mental health problems, totaling 1,969,990 bed nights; 22.0% received social welfare benefits, totaling 27,927,000 benefit weeks; and 10.2% were convicted for adult crimes, totaling 165,495 convictions. (Although a much smaller percentage of the G2 population was admitted to hospitals for psychiatric than physical health problems, the length of stay for psychiatric admissions was much longer than for physical health admissions.)

Health and social disadvantages were concentrated within a small segment of citizens. Gini coefficients of inequality (17, 18) for the G2 population indicated high levels of concentration in the distributions of events in each sector, ranging from 0.99 for psychiatric hospitalizations to 0.87 for physical health hospitalizations (*SI Appendix*, Fig. S3*A*; see *SI Appendix*, Fig. S3 caption for additional metrics of inequality for each sector). To illustrate, the top 5% of the G2 population in each sector accounted for a disproportionate share of events, comprising 100.0% of psychiatric hospitalizations, 77.3% of criminal offenses, 62.7% of physical health hospitalizations, and 58.5% of benefit weeks (see *Methods* for a description of our rationale for selecting a 5% cutoff). Hereafter, we refer to this top 5% of the population as the "high-need users" of each sector.

Health and social disadvantages also aggregated within G2 individuals. G2 individuals who appeared as high-need in one sector had a fivefold or greater increased odds of appearing as high-need in a second sector, with the exception of the relation between physical health hospitalizations and convictions (odds ratio [OR] = 3.44, 95% CI [3.31 to 3.58]; *SI Appendix*, Table S1 and Fig. S3*B*). Furthermore, health and social disadvantages accumulated within G2 individuals: The observed distribution of high-need users across multiple sectors deviated from the expectation of a random distribution [$\chi^2_{(4)}$ = 358,558.76, $P < 0.001$], such that there were more individuals than expected who belonged to multiple high-need groups (*SI Appendix*, Table S2 and Fig. S3*C*).

Risk for Health and Social Disadvantage Was Transmitted from the Previous Generation. We linked data from our index population (G2) to data from their parents (G1) to test whether risk for health and social disadvantage was transmitted from the previous generation (*Methods*). We assessed G1 parents' health and social service involvement between 1984 and 1994, when they were close in age to the age we observed their G2 offspring (mean age at start of observation = 32.3 y [mothers], 34.9 y [fathers], $N_{mothers}$ = 421,691, $N_{fathers}$ = 397,609; Fig. 1 and *SI Appendix*, Fig. S2 *B* and *C*). There was intergenerational continuity in health and social problems: G1 parents who appeared as high-need users (top 5%) in each health and social sector were likely to have G2 offspring who appeared as high-need in all other sectors (Fig. 2 and *SI Appendix*, Table S3*A*). Of the G2 offspring in the high-need group in the physical health, psychiatric, social welfare, and crime sectors, 7.8%, 8.3%, 19.7%, and 12.9%, respectively, had a G1 mother in the high-need group in the same sector, and 7.1%, 7.8%, 16.7%, and 10.1%, respectively, had a G1 father in the high-need group in the same sector (*SI Appendix*, Table S4*A*).

G2 offspring whose G1 mothers and fathers belonged to multiple high-need groups were at elevated risk for belonging to multiple high-need groups themselves ($\beta_{mothers}$ = 0.155 [0.153 to 0.158]; $\beta_{fathers}$ = 0.120 [0.118 to 0.122]). The proportion of offspring who belonged to three or more high-need groups was 9.3 times greater among those whose mothers belonged to three or more high-need groups (5.00%) than those whose mothers belonged to no high-need group (0.54%) and 6.5 times greater among those whose fathers belonged to three or more high-need groups (3.38%) than those whose fathers belonged to no high-need group (0.52%).

Risk for Health and Social Disadvantage Was Transmitted to the Next Generation. We linked data from G2 to data from their children (G3; mean age at end of observation = 7.9 y, n = 627,900; Fig. 1 and *SI Appendix*, Fig. S2*D*) to test whether risk for health and

social disadvantage was transmitted to the youngest generation in a family. Because most G3 children were too young to have conviction, hospital, or benefit records, we measured a salient early-life indicator of disadvantage: protective services involvement (*Methods*). Only 1.34% of G2 parents had children who appeared in protective services records, as most children had not yet reached the teenage years (the peak period of risk for foster care involvement in Denmark; *SI Appendix*, Fig. S2*D*). Despite the low overall rate of protective services involvement, G2 parents who appeared as high-need in each sector were substantially more likely to have children in protective services records than parents who did not appear as high-need (Fig. 3 and *SI Appendix*, Table S5). Children had a nearly fourfold increased odds of appearing in protective services records for each additional high-need group to which their mother belonged (OR = 3.65 [3.51 to 3.79]) and a nearly threefold increased odds for each additional high-need group to which their father belonged (OR = 2.75 [2.64 to 2.87]; Fig. 3 and *SI Appendix*, Table S5). Of the G3 children in protective services records, 6.7%, 15.0%, 22.0%, and 24.5% had a G2 mother in the high-need group in the physical health, psychiatric, social welfare, and crime sectors, respectively, and 5.1%, 9.8%, 18.8%, and 8.6% had a G2 father in the physical health, psychiatric, social welfare, and crime sectors, respectively (*SI Appendix*, Table S4*B*).
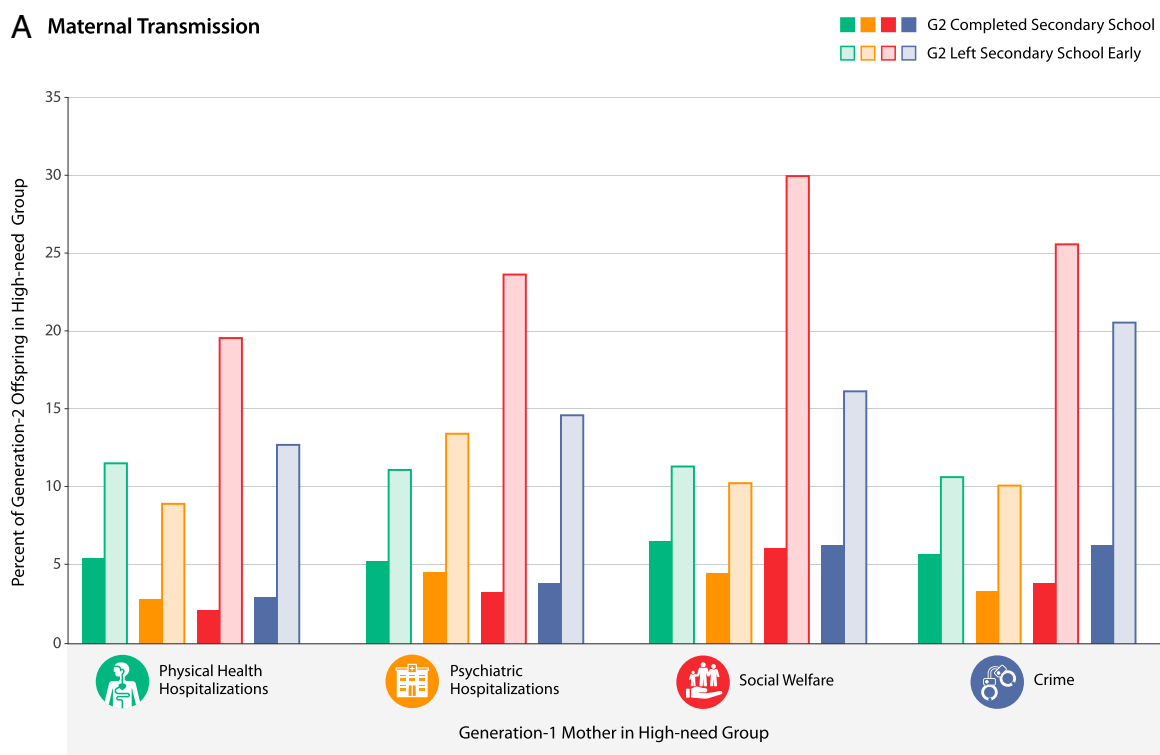
Education Disrupted the Transmission of Risk from the Previous Generation. We tested the disruption of intergenerational transmission via education in three ways. First, we linked school completion records to health- and social service–use records in G2 to test whether completing 12 or more years of education was associated with the transmission of risk for high-need service use from G1 to G2. Early school leavers comprised 26.1% of the G2 population (*Methods*). G2 offspring whose G1 parents belonged to more high-need groups were at elevated risk for early school leaving ($OR_{mothers}$ = 2.06 [2.03 to 2.08]; $OR_{fathers}$ = 1.83 [1.81 to 1.85]), and G2 early school leavers later belonged to more high-need groups (β = 0.329 [0.326 to 0.331]). Adjusting for G2 early school leaving reduced the intergenerational association in high-need group membership by approximately one-third (mothers: from β = 0.155 [0.153 to 0.158] to 0.110 [0.108 to 0.113]; fathers: from β = 0.120 [0.118 to 0.122] to 0.083 [0.080 to 0.085]; tests of differences in coefficients: zs = 18.62 and 15.23, ps < 0.001; Fig. 2 and *Methods*), indicating that completing secondary education disrupted the statistical transmission of risk for disadvantage. (See *SI Appendix*, Table S6 for an estimate of the degree of confounding that would be necessary to explain away the reduction in the association between G1 and G2 disadvantage attributable to G2 education.)

Within Families, Siblings who Obtained More Education Were at Reduced Risk for Later Health and Social Disadvantage. Second, we linked data between siblings in our index population ("Generation 2$_{sibs}$"; Fig. 1) and conducted a sibling fixed effects analysis to test whether siblings who obtained more education tended to experience fewer health and social problems compared with their cosiblings who obtained less education. This analysis controls for any influences on education and later-life disadvantage that are shared by siblings growing up in the same household.

Within the full G2 population, individuals who completed secondary education belonged to fewer high-need groups in later life (β = −0.329 [−0.331 to −0.326]). Within sibling groups, the association was attenuated but still significant. Consistent with the hypothesis that education reduces risk for disadvantage, the siblings who obtained more education belonged to fewer high-need groups in later life than their cosiblings who obtained less education (β = −0.205 [−0.210 to −0.199]; Fig. 4).

Education Disrupted the Transmission of Risk to the Next Generation. Third, we tested whether education disrupted the statistical transmission of risk for disadvantage from G2 to G3. G2 parents who

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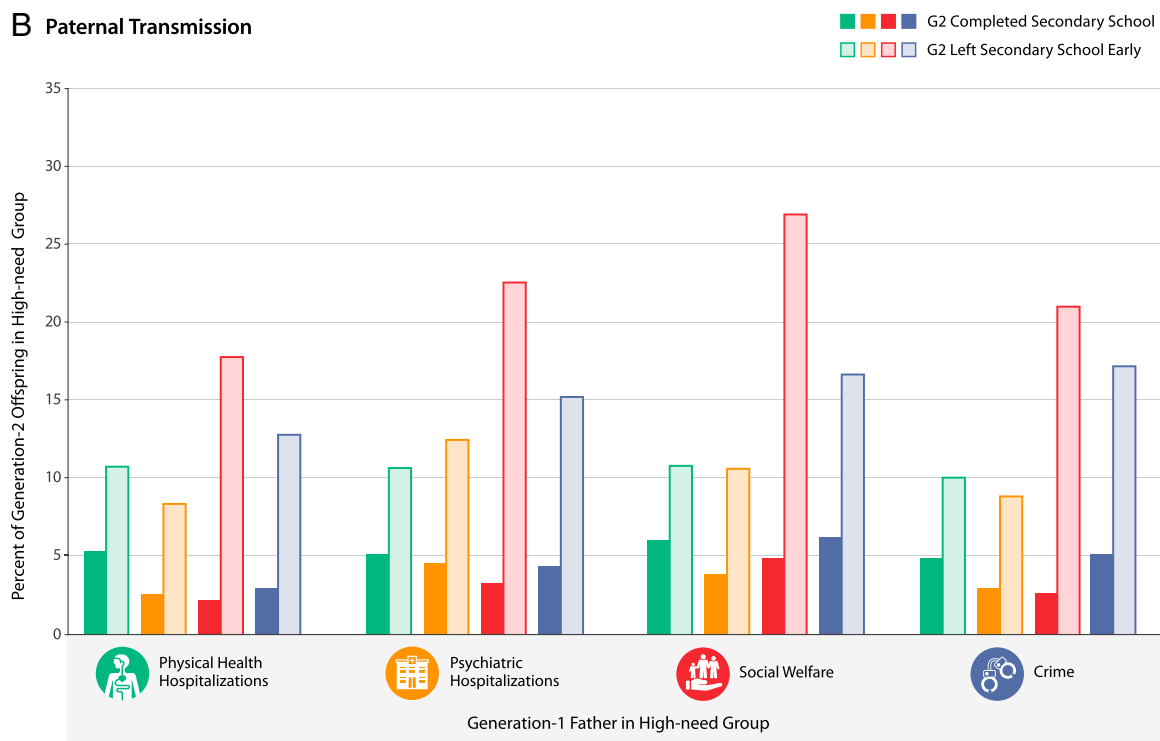
Fig. 2. The transmission and disruption of health and social disadvantage from G1 to G2. G1 parents who appeared as high-need users in each sector were more likely to have G2 offspring who appeared as high-need in all other sectors (*SI Appendix*, Table S3A); however, these associations were reduced when offspring completed secondary education (e.g., from $\beta = 0.155$ [0.153 to 0.158] to 0.110 [0.108 to 0.113] for maternal transmission and from $\beta = 0.120$ [0.118 to 0.122] to 0.083 [0.080 to 0.085] for paternal transmission of high-need group membership across multiple sectors). The G2 groups for maternal (*A*) and paternal (*B*) transmission are not independent, as some G2 offspring had both a G1 mother and father in the high-need group in a sector. Ns are provided in *SI Appendix, Supplementary Text*.
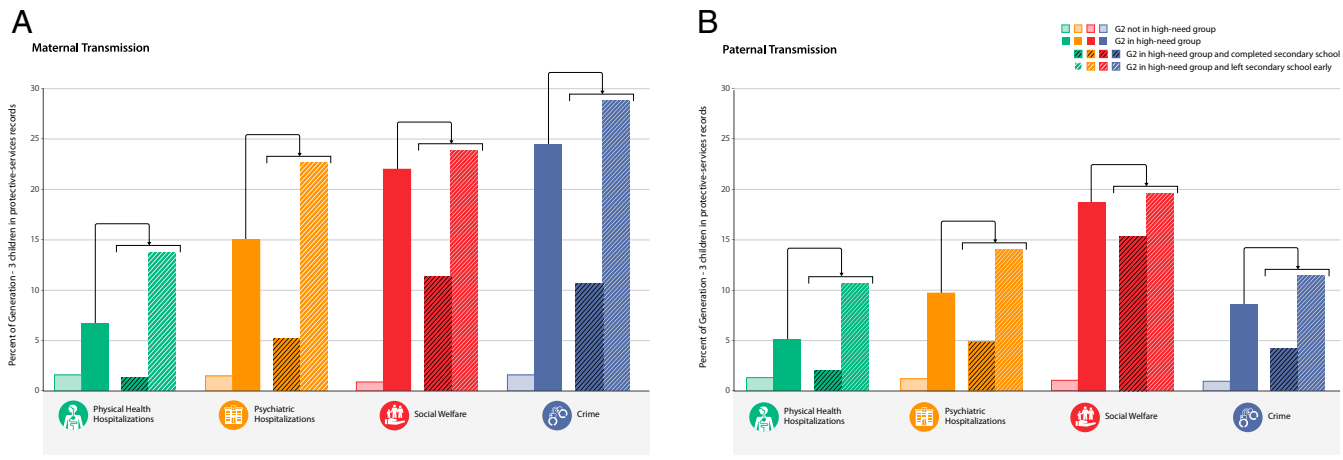
Fig. 3. The transmission and disruption of health and social disadvantage from G2 to G3. G2 parents who appeared as high-need users in each sector were more likely to have G3 children in protective services records; however, these associations were reduced when parents completed secondary education (e.g., from OR = 3.65 [3.51 to 3.79] to 3.16 [3.04 to 3.29] for maternal membership and from OR = 2.75 [2.64 to 2.87] to 2.34 [2.24 to 2.44] for paternal membership in multiple high-need groups; *SI Appendix*, Table S5). (*A* and *B*) Proportions of all G3 children in protective services records. To measure the intergenerational association while controlling for family size, we also estimated the proportions of G2 parents with at least one G3 child in protective services records; the pattern of associations was similar (*SI Appendix*, Table S10 *A* and *B*). The G3 groups for maternal (*A*) and paternal (*B*) transmission are not independent, as some G3 children had both a G2 mother and father in the high-need group in a sector. Ns are provided in *SI Appendix, Supplementary Text*.

completed secondary education were less likely to have children in protective services records (OR$_{mothers}$ = 0.20 [0.18 to 0.22]; OR$_{fathers}$ = 0.18 [0.16 to 0.19]). Furthermore, adjusting for G2 parents' education reduced the association between their high-need group membership and their children's appearance in protective services records (mothers: from OR = 3.65 [3.51 to 3.79] to 3.16 [3.04 to 3.29]; fathers: from OR = 2.75 [2.64 to 2.87] to 2.34 [2.24 to 2.44]; tests of differences in coefficients: zs = 14.61 and 13.67, ps < 0.001; *SI Appendix*, Table S6, Fig. 3, and *Methods*).

Transmission of Risk from G1 to G3 Was Partly Explained by G2 Disadvantage and Disrupted by G2 Educational Attainment. Continuity in disadvantage was evident between G2 adults and their G1 parents and between G2 adults and their G3 children. We integrated all three generations in one analysis to test whether 1) high-need group membership in G1 predicted protective services involvement in G3, 2) this association was explained by high-need group membership in G2, and 3) G2 education disrupted the association (*Methods*). G1 grandparents who were members of multiple high-need groups were more likely to have G3 grandchildren in protective services records, although the associations were smaller than the G2-to-G3 associations (OR$_{grandmothers}$ = 1.72 [1.67 to 1.78]; OR$_{grandfathers}$ = 1.63 [1.58 to 1.69]); Fig. 5 and *SI Appendix*, Table S7). Adjusting for G2 parents' high-need group membership reduced these associations, indicating that some of the transgenerational continuity in disadvantage was explained by G2 disadvantage (OR$_{grandmothers}$ = 1.39 [1.34 to 1.44]; OR$_{grandfathers}$ = 1.32 [1.28 to 1.37]; tests of differences in coefficients: zs = 37.53 and 35.23, ps < 0.001; Fig. 5 and *SI Appendix*, Table S7). Adjusting for G2 parents' education further reduced the G1-to-G3 associations (OR$_{grandmothers}$ = 1.29 [1.24 to 1.34]; OR$_{grandfathers}$ = 1.23 [1.19 to 1.28]; tests of differences in coefficients: zs = 10.41 and 8.72, ps < 0.001; Fig. 5 and *SI Appendix*, Tables S6 and S7), indicating that education disrupted the multigenerational statistical transmission of risk for health and social disadvantage.
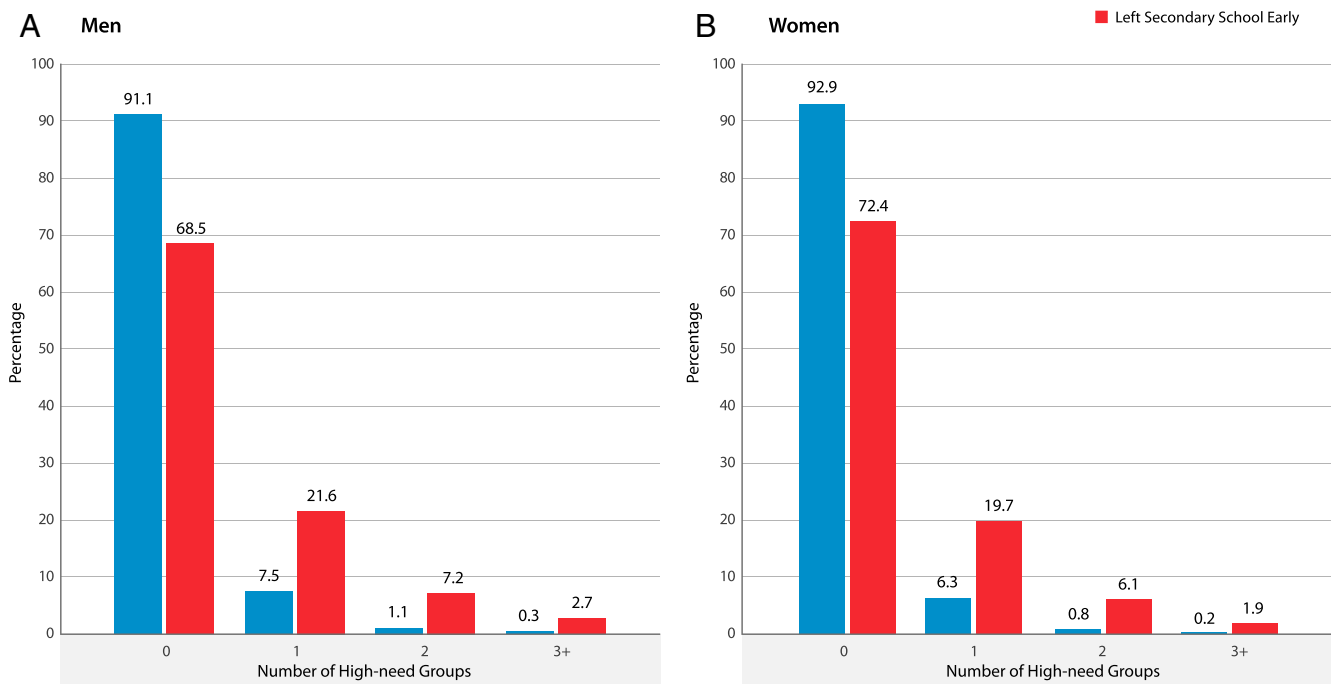
Discussion

Scientists and policymakers are calling for innovative approaches to interrupt the intergenerational cycle of disadvantage (11, 19, 20). Our analysis responds to this demand and yields two insights.

First, multiple health and social disadvantages concentrated, aggregated, and accumulated, within the same small segment of families, across three generations. G2 adults who relied disproportionately on multiple, different health and social services 1) tended to have parents who relied disproportionately on multiple, different health and social services and 2) tended to have children who evidenced the risk for disadvantage at an early age, through the appearance in protective services records. Furthermore, disadvantage in G2 helped explain the continuity in disadvantage between G1 and G3. Studies of the intergenerational transmission of disadvantage have largely focused on specific health and social disadvantages transmitted across two generations. By integrating information across multiple nationwide registers and three generations of citizens, we uncovered a high-priority segment of families.
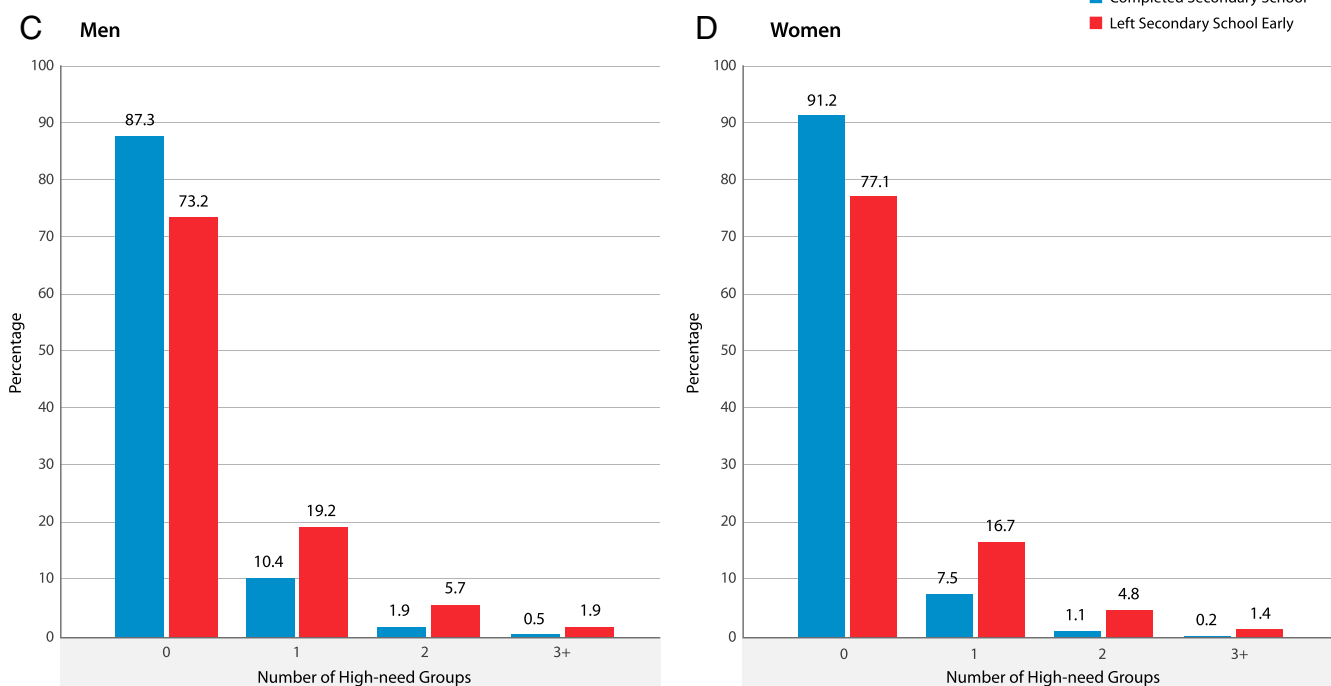
Second, education disrupted intergenerational continuity in health and social disadvantage: Associations between disadvantage across all three generations were reduced in families in which G2 completed secondary education. There is evidence that education can improve life chances (21–25), but causation remains controversial (26, 27). By linking data between siblings, we obtained quasiexperimental evidence that education mitigated risk for disadvantage in the study population. Interventions to improve educational outcomes for disadvantaged youth (e.g., refs. 14 and 28) might reduce the intergenerational persistence of health and social inequalities.

We acknowledge limitations. First, our results are specific to one nation and one welfare system. However, prior work has documented similar accumulation of services used in a small population segment in New Zealand (9, 10) and similar intergenerational associations in disadvantages between Denmark and countries with less extensive welfare systems, such as the United States (e.g., ref. 16). Second, although our definition of high-need groups based on a 5% cutoff was a practical way to capture concentration and identify a segment of families in need of intervention, such supports are also relevant for disadvantaged individuals and families who fall beneath the 5% cutoff (*SI Appendix*, Table S8). Third, results of our three-generation analysis may suffer from omitted variable bias, which arises when an association is reinforced by unobserved or omitted variables (e.g., contextual factors shared by G1 and G3), as well as selection bias arising from processes that lead some individuals to become parents or grandparents (29). Fourth, our

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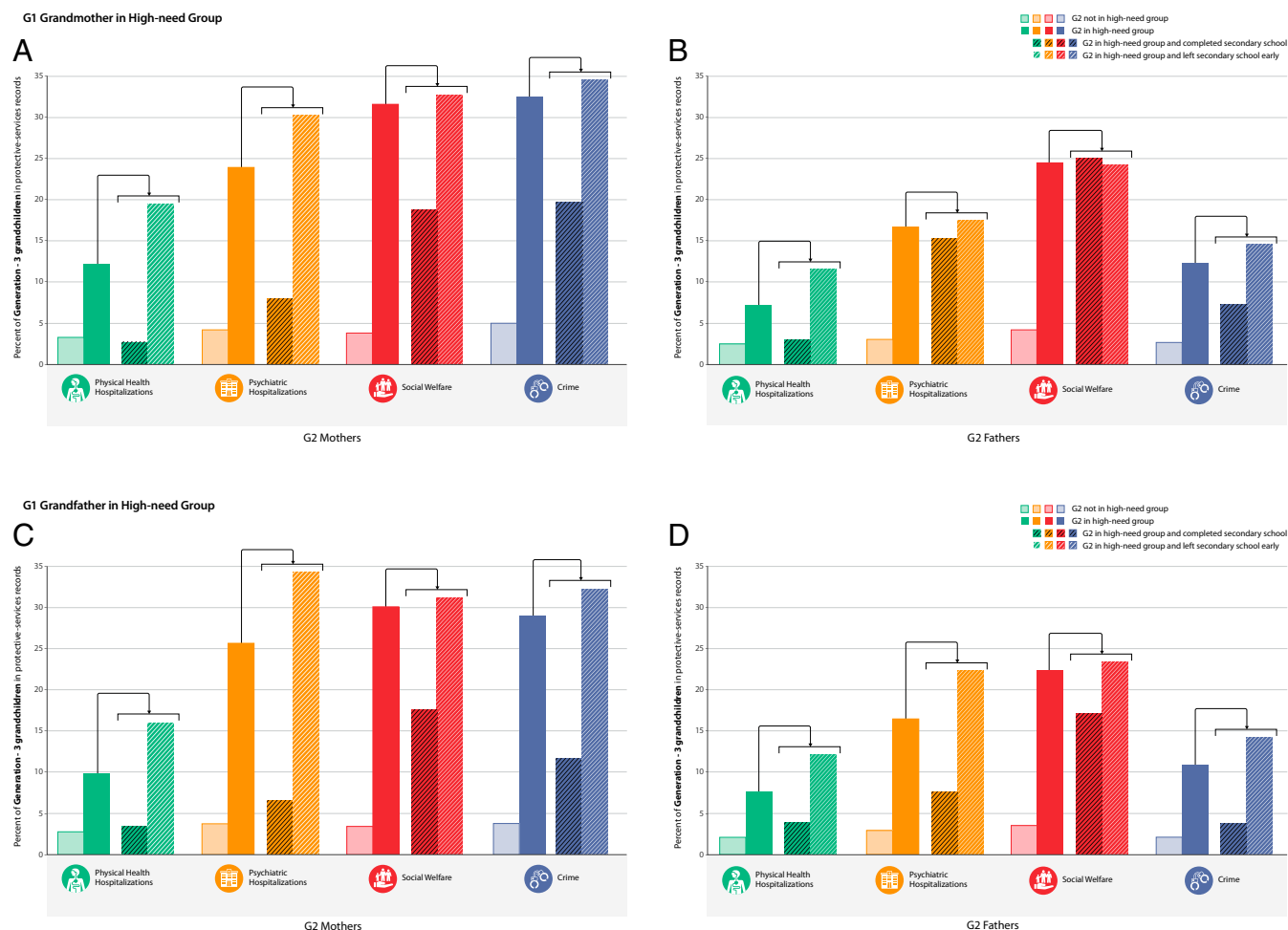Nationwide evidence that education disrupts the intergenerational transmission of disadvantage

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Generation 2: Complete Population

Completed Secondary School (blue)
Left Secondary School Early (red)

A   Men

B   Women

Generation 2: Discordant Full-Sibling Groups

Completed Secondary School (blue)
Left Secondary School Early (red)

C   Men

D   Women

Fig. 4. Adjusting for shared familial influences on the association between education and later-life disadvantage. Individuals who completed secondary education were less likely to be members of multiple high-need groups in later life. This association was evident within the full G2 study population (*A* and *B*; $\beta = -0.329$ [-0.331 to -0.326]) and within groups of full siblings discordant for secondary school completion (*C* and *D*; $\beta = -0.205$ [-0.210 to -0.199]). Discordant full-sibling groups were groups in which at least one sibling differed from their other siblings in their education level. Ns are provided in *SI Appendix, Supplementary Text*.

observational design cannot confirm that education plays a causal role in reducing risk for high-need service use. Although sibling fixed effects analyses enable rigorous control for shared familial risk factors, they cannot address all possible residual confounding.

Fifth, we focused our analysis on secondary school completion because it is a salient predictor of health, social, and economic outcomes (9, 30–32). However, the income gap between individuals with and without a university degree has widened (33), and changes in

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Fig. 5. The transmission and disruption of health and social disadvantage across three generations. The figure shows that 1) the association between G1 grandparents' high-need group membership and their G3 grandchildren's appearance in protective services records was partly explained by high-need group membership in G2 and 2) education in G2 helped disrupt this statistical association (see *SI Appendix*, Table S7 for statistical tests). (*A–D*) The proportion of G3 grandchildren of G1 grandparents in the high-need group in each sector who appeared in protective services records, as a function of G2 parents' high-need group membership and education. The G3 groups in the different panels are not independent, as some G3 grandchildren had both a G2 mother and father in the high-need group in a sector and/or both a G1 grandmother and grandfather in the high-need group in a sector. Ns are provided in *SI Appendix, Supplementary Text*.

labor force expectations are placing an increasing premium on higher levels of education and technical skills (34).

With these limitations in mind, several implications can be noted. First, our findings suggest the hypothesis that supporting the education potential of our most vulnerable citizens might reduce the intergenerational transmission of multiple disadvantages within a high-need segment of families. It is notable that even in Denmark, a country with free access to education and an extensive social safety net, early school leavers comprised one-quarter of our study population. In developed nations, the proportion of gross domestic product invested in education has been holding steady, or even rising (35), and global average years of schooling have increased (36). If these trends continue, individuals lacking education credentials may become increasingly isolated in a high-need segment of society. There is mounting evidence for the effectiveness of interventions to increase educational attainment among disadvantaged youth, but available interventions can go underutilized (37). Evaluation studies have shown the benefits of behavioral strategies to increase disadvantaged families' involvement with education programs [e.g., sending parents text messages about activities they can perform with their preliterate children (38) and informing parents about assignments their children have missed (39)]. Our

analysis reveals that families most in need of education-related supports come into contact with multiple public service systems at a very high rate. This suggests that coordinated service delivery programs already developed for families might incorporate strategies to increase their involvement with education. The present findings cannot, however, resolve the processes by which educational attainment disrupts the transmission of disadvantage. Direct mechanisms may include the acquisition of education credentials, which are important for employability and social capital. Involvement with education may also influence health and social outcomes indirectly, by promoting the development of capacities such as self-control. If so, then interventions targeting these capacities directly might also mitigate the transmission of disadvantage.

Second, in addition to education level and other individual-level factors, structural and social mechanisms might also help to explain the aggregation of multiple disadvantages within a high-need segment of families. Fragmented delivery of public services might result in individuals coming into contact with more sectors more frequently, with the implication that the system for delivering services should be reorganized. Although public services are better organized in Denmark than in countries such as the United States that lack public healthcare and social welfare systems, there are

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debates about how to best integrate these services so as to maximize public benefit while minimizing economic costs (40). In addition, the experience of coming into contact with a public service sector may increase one's likelihood of further involvement. For instance, individuals convicted of a crime may face stigma or difficulty securing work, leading them to receive social welfare benefits (41), and unemployment-related stress may increase their likelihood of experiencing health problems (42). If so, efforts to prevent the negative sequelae of individuals' initial interactions with public service sectors could help to reduce the aggregation of health and social disadvantage.

Third, inequality is a multidisciplinary problem. Different disciplines have typically studied the intergenerational transmission of different types of disadvantages: criminologists measure the transmission of crime; labor economists focus on the transmission of welfare dependence; and health scientists are concerned about the transmission of disability and disease. Our findings here [and previously in New Zealand (9, 10)] indicate that distinct fields may be identifying the same small segment of families. A key question is whether prevention and policy efforts to break up the cycle of disadvantage in one sphere will spill over to other spheres.

Lastly, our results highlight both the discovery value and ethical challenges that linked administrative data present for researchers and policymakers aiming to ameliorate disadvantage. Our ability to integrate information across multiple databases and within families enabled us to uncover a previously hidden, high-need segment of the population that extended across multiple generations. Existing linked registers in other nations offer the opportunity to test whether this multigenerational population segment replicates across countries with different education and social welfare systems. Although the United States does not yet have the same nationwide capacity to link across multiple administrative sectors, integrated electronic health information systems are becoming increasingly widespread at the regional and state levels, and researchers interested in health and social disparities are calling for increased efforts to integrate administrative data across sectors and within families (11, 19, 43, 44). These resources can also help to address the growing problem of nonresponse to national surveys, by providing a method for ascertaining objective indicators of disadvantage within the population (45). Developments in data digitization and linkage also, however, bring the potential for misuse. Linkage of multiple forms of information at the individual level increases the potential for identification, and this concern is especially relevant for disadvantaged populations who are often stigmatized. Scientists employing linked administrative data to study disadvantage have an increased responsibility to maintain the security and confidentiality of our most vulnerable citizens' data. With public trust and support in place, administrative data resources could significantly advance efforts to evaluate and eliminate health and social disparities (44, 46, 47).

Methods

Study Populations. We used population-level administrative data from Denmark. All Danish residents are assigned a unique personal number through the Danish Civil Registration System that identifies them in interactions with government and private institutions (48). These numbers enable the linkage of administrative databases at the individual level and within families.

Because the data for this study came from deidentified administrative registers that Statistics Denmark makes available for research purposes for approved institutions, institutional review board approval was not required to carry out the research. The research was conducted as part of Project #705830 approved by Statistics Denmark.

G2: Index Population. Our index population (G2) included all individuals who 1) were born in Denmark between 1974 and 1984, 2) were in the country for any period of time during the 2006 to 2016 observation period, and 3) had mothers and/or fathers with data to indicate whether or not public services were used, to enable intergenerational analyses ($n = 636,385$ [50.9% male]).

The population was 22 to 32 y of age at the start of the observation period (mean = 26.7) and was followed up to ages 32 to 42 (*SI Appendix*, Fig. S2A).

We also constructed a subpopulation that comprised all the full siblings from the G2 index population ("Generation 2_{sibs}"; $n = 347,076$; age at start of observation = 22 to 32 y [mean = 27.2]).

G1: Parents of the Index Population. G1 comprised the mothers and fathers of our index population. We observed G1 parents between 1984 and 1994, when the majority of parents were close in age to the age we observed their G2 offspring (birth years = 1907 to 1971; age at start of observation: mothers = 14 to 64 y [mean = 32.3], fathers = 13 to 77 y [mean = 34.9]; $N_{mothers} = 421,691$, $N_{fathers} = 397,609$) (*SI Appendix*, Fig. S2 *B* and *C*). There were fewer G1 mothers and fewer G1 fathers than G2 offspring because some G2 offspring were siblings from the same family.

G3: Children of the Index Population. G3 comprised the children of our index population (birth years = 1988 to 2016, age during 2006 to 2016 observation period: < 1 to 28 y [mean at end of period = 7.9], $n = 627,900$) (*SI Appendix*, Fig. S2D).

Health and Social Disadvantages. We collected information in Generations 1 and 2 about their contact with four public service sectors that signal health and social disadvantages. 1) Information about bed nights spent in public hospitals for physical health problems was recorded by hospitals and collected by the Danish Health Board. 2) Information about bed nights spent in psychiatric hospitals for mental health problems was recorded by hospitals and collected by the Danish Health Board. 3) Information about weeks spent on social welfare benefits was recorded by local governments and collected by Statistics Denmark (for G1) and the Labor Market Board (for G2). 4) Information about criminal convictions was recorded by Statistics Denmark (using information from the Criminal Justice System). We collected information about G2's contact with these sectors during 2006 to 2016 and about G1's contact during 1984 to 1994. This enabled us to observe the two generations' service use when they were as close in age as possible.

Childhood Protective Services Involvement. We collected information in G2 and G3 about Child Protective Services involvement (i.e., we measured whether the children of G2 appeared in protective services records). Information about protective services involvement was recorded by Danish local governments and collected by the Social Appeals Board. We collected information about whether 1) the child or family had received preventive services, 2) the child was in foster care, or 3) the child was involved in aftercare programs for individuals over age 18 who have aged out of foster care. This information was used to construct a measure of "any Child Protective Services involvement" at the G2 level. Of the 472,988 individuals in G2 who were parents, 1.34% had children who appeared in Child Protective Services records during the observation period.

Educational Attainment. Information about educational attainment in G2 was recorded by Statistics Denmark (using information from Danish schools). Educational attainment was coded as a binary variable to reflect whether individuals had received less than 12 y of education. We measured education in 2005 (just prior to the 2006 to 2016 observation period), when the G2 population was between 21 and 31 y of age. Early school leavers comprised 26.1% of the population.

Statistical Analysis.
Concentration, aggregation, and accumulation. We measured the concentration, aggregation, and accumulation of health and social disadvantages in the index population (G2). To measure concentration, we calculated Gini coefficients of inequality (17, 18) based on the cumulative distributions of events in each public service sector. We then operationally defined a high-need group in each sector as 5% of the population who accounted for the most disproportionate share of events in that sector. This 5% cut point was based on the sector with the lowest prevalence of use (psychiatric hospitalizations) and was applied in all sectors to allow comparisons across sectors. To measure aggregation, we used logistic regression to predict high-need group membership in one sector from high-need group membership in another sector, controlling for G2 birth year and sex. To measure accumulation, we added up (zero to four) the number of high-need groups to which each individual belonged and tested whether the distribution of high-need users across multiple sectors deviated from the expectation of a random distribution.
Intergenerational transmission. We tested whether risk for health and social disadvantage was transmitted across generations in three ways. First,

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we generated parallel high-need groups (top 5% of users in each sector) and a parallel measure of accumulation (zero to four high-need groups) in G1 parents and the G2 index population. Given the large age range of G1 parents, we specified G1's high-need group membership within age bands. We used logistic regression to test whether G1 parents' high-need group membership in each sector predicted G2 offspring's high-need group membership in each sector. We used linear regression to estimate the association between the number of high-need groups to which G1 parents belonged and the number of high-need groups to which their G2 offspring belonged. We estimated associations separately for mothers and fathers. Models controlled for sex (in G2 offspring) and birth year (in both generations).

Second, we used logistic regression to test whether 1) G2 parents' high-need group membership in each sector and 2) the number of high-need groups to which they belonged predicted their G3 children's appearance in Child Protective Services records. We estimated associations separately for mothers and fathers. Models controlled for G2 parents' birth year, number of G3 children, the proportion of children who were female, and birth year of the firstborn (to account for early parenthood).

Third, we integrated all three generations in a single analysis. We used logistic regression to test whether 1) G1 grandparents' high-need group membership in each sector and 2) the number of high-need groups to which they belonged predicted their G3 grandchildren's appearance in protective services records, before and after accounting for G2 parents' high-need group membership. We estimated associations separately for G1 grandmothers and grandfathers. We tested whether the coefficients from baseline and adjusted models significantly differed using the Karlson–Holm–Breen (KHB) method in Stata [(49, 50); see description of KHB method below]. Models controlled for birth year (in G1 and G2); sex (in G2); number of grandchildren; the proportion of grandchildren who were female; and birth year of the firstborn (in G3).

Impact of education. We tested if education disrupted the transmission of health and social disadvantage. First, we tested associations between high-need group membership in G1 parents and G2 offspring, adjusting for offspring education. We estimated associations separately for mothers and fathers. We tested whether the coefficients from baseline and adjusted models significantly differed using the KHB method (49, 50). Models controlled for sex (in G2 offspring) and birth year (in both generations).

Second, we used sibling fixed effects regression models in the G2 sibling subpopulation. These models tested whether siblings who achieved more education were at a reduced risk for later-life health and social disadvantage, controlling for any influences on education and disadvantage that were shared by siblings growing up in the same household. Models controlled for G2 sex and birth year.

Third, we tested associations between high-need group membership in G2 parents and protective services involvement in G3 children, adjusting for parents' education. We estimated associations separately for mothers and fathers. We tested whether the coefficients from baseline and adjusted models significantly differed using the KHB method (49, 50). Models controlled for G2 parents' birth year, number of G3 children, the proportion of children who were female, and birth year of the firstborn.

Fourth, we tested associations between high-need group membership in G1 grandparents and protective services involvement in G3 grandchildren, adjusting for G2 parents' education. Baseline models adjusted for G2 parents' high-need group membership; therefore, this analysis tested whether any remaining association between G1 and G3 was disrupted by G2 education. We estimated associations separately for G1 grandmothers and grandfathers. We tested whether the coefficients from baseline and adjusted models significantly differed using the KHB method (49, 50). Models

controlled for birth year (in G1 and G2); sex (in G2); number of grandchildren; the proportion of grandchildren who were female; and birth year of the firstborn (in G3).

KHB method. We tested whether associations differed significantly across nested models using the KHB method. This method is useful for testing differences in associations between all types of nested models but is particularly well suited for testing such differences between nested logit models, in which associations between the same variables are not directly comparable. The lack of comparability reflects that the error variance of each model, which goes into the estimation of the associations, results from the set of included variables, which differ between the two models. Therefore, the coefficients in the two nested models are not measured on the same scale. To facilitate comparability of the coefficients, the KHB method rescales the coefficients of the nested model using the error variance of the full model (49). For all tests of nested logit models, we therefore report both the original and the scaled coefficients (and associated confidence intervals).

Sensitivity analyses. We tested the robustness of our findings across two alternative specifications.

Period effects. We measured G1 parents' and G2 offspring's high-need group membership during different observation periods, which enabled us to assess both generations' public service use when they were close in age. However, historical changes in welfare state policies could impact estimates of service use obtained at different time periods. We therefore repeated tests of intergenerational associations after measuring G1 parents' service use between 2006 and 2016. We continued to observe intergenerational associations in high-need group membership (but associations for psychiatric hospitalizations, social welfare use, crime, and the number of high-need groups to which individuals belonged were smaller than those obtained when G1 parents' service use was assessed between 1984 and 1994 [*SI Appendix*, Table S3*B*]).

Death and outmigration. Individuals who died or traveled outside of Denmark during the observation period had reduced time during which they were eligible to appear in government records. To account for these differences in observation time, we reran tests of intergenerational associations after weighting the data based on time spent alive and in the country. Across two different weighting schemes, the estimates were very similar to those obtained using unweighted data (*SI Appendix*, Table S9 *A* and *B*).

High-need group cutoff. Our definition of high-need groups, based on a 5% cutoff, was based on the sector with the lowest prevalence of use (psychiatric hospitalizations) and was a practical way to capture concentration. However, the selection of any cut point is to some degree arbitrary. We tested the extent to which our selection of a 5% cutoff may have impacted results by respecifying high-need groups based on a 10% cutoff. Although some associations were modestly attenuated when using a 10% versus a 5% cutoff, the pattern of estimates and conclusions remained the same (*SI Appendix*, Table S8).

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