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Embodied Cognitive Reserve in Later Life: Education, Lifelong Learning, and Family-Based Social Support as Predictors of Mortality in the Midlife in the United States (MIDUS) Study

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Abstract

Objectives: This study examined whether education predicts mortality among older adults and whether lifelong learning and family-based social support moderate this association within an embodied cognitive reserve framework.

Methods: MIDUS 2 linked to 2016 National Death Index data were analyzed (N = 584; age ≥ 60). Cox proportional hazards models estimated mortality as a function of educational attainment (occupational education index), lifelong learning (PCA-derived factor score), and family-based social support (standardized composite). Interaction terms (education × lifelong learning; education × family support) were modeled to assess buffering effects on the education-mortality link, adjusting for age and sex.

Results: Higher education was associated with lower mortality risk (HR = 0.83, 95% CI [0.73, 0.94]). Lifelong learning strengthened this effect after adjusting for baseline functional limitations. Family-based social support showed a weaker moderating effect.

Conclusions: Findings support the embodied cognitive reserve framework, suggesting that lifelong learning enhances the survival benefits of education.

Keywords

education, lifelong learning, social support, cognitive reserve, mortality

Introduction

Global population aging has accelerated into a major public health challenge. Between 2015 and 2050, the proportion of people over 60 years old worldwide is projected to nearly double from 12% to 22% (World Health Organization, 2025a). In the United States, adults aged 65 and above made up 18% of the population in 2024, a share expected to reach 22% by 2040 (Vespa et al., 2020; U.S. Census Bureau, 2025). People are living longer than ever, but these added years are not always healthy or equitable (Permanyer et al., 2023; Pongiglione et al., 2015). Notably, good health and longevity in older age are not distributed equally across societies (World Health Organization, 2025b). For example, older adults of lower socioeconomic status experience higher rates of disability and face earlier mortality than their more advantaged peers (Steptoe & Zaninotto, 2020). These disparities highlight the need to understand how social and behavioral factors shape mortality risk among older adults, so that extended lifespans can be accompanied by improvements in health equity.

Educational attainment has long been recognized as a central social determinant of health and longevity in later life (Kaplan et al., 2015; Montez et al., 2024). A substantial body of population-based research demonstrates that individuals with higher levels of education experience lower mortality risk and longer life expectancy compared with their less educated counterparts (Baker et al., 2011; Mackenbach et al., 2016). These educational gradients in mortality persist across

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national contexts and historical periods, underscoring the enduring role of education in shaping health trajectories across adulthood (Stringhini et al., 2017).

From a life course perspective, however, education should not be understood as a fixed or uniform resource (Sperlich & Mutz, 2021). Life course epidemiology emphasizes that later-life health outcomes reflect the accumulation and interaction of exposures, resources, and constraints across the lifespan (Kuh et al., 2003). Theories of cumulative advantage further suggest that early-life resources such as education shape trajectories that may diverge over time depending on subsequent opportunities and contexts (Dannefer, 2003; Ferraro & Shippee, 2009). Consequently, educational attainment may influence survival not only through its initial accumulation but also through whether its associated resources continue to be activated and translated into adaptive responses in later life (O'Rand, 2009). This perspective implies that heterogeneity in later-life mortality reflects not only differences in educational attainment itself but also in how educational capital is enacted across the life course.

One key mechanism through which education may exert conditional rather than uniform effects in later life is lifelong learning. Beyond formal schooling, lifelong learning encompasses ongoing cognitive, motivational, and behavioral engagement in activities that promote intellectual stimulation and personal agency (Wang et al., 2025; Zheng, 2025). Prior research has shown that participation in mentally, socially, and physically engaging activities is associated with better cognitive functioning and reduced risk of adverse health outcomes in older adulthood (Field, 2006; Karp et al., 2006). More recent evidence further indicates that lifestyle activities in midlife contribute to cognitive reserve in later life, independent of educational attainment and occupational complexity (Chan et al., 2018). The concept of lifelong learning, however, has been defined and operationalized in different ways across the literature. Some studies adopt a narrower definition that emphasizes participation in formal or structured educational activities, such as adult education or training programs (e.g., Wang et al., 2025). In contrast, other approaches conceptualize lifelong learning more broadly as ongoing engagement in cognitively, socially, and behaviorally stimulating activities that extend beyond formal education settings. Although this broader view is not always labeled explicitly as lifelong learning, it is closely aligned with research on lifestyle engagement and cognitive health in aging populations (Fratiglioni et al., 2020; Livingston et al., 2020). In the present study, we adopt this broader, engagement-based conceptualization. This approach is motivated by both empirical and theoretical considerations. Empirical evidence suggests that diverse forms of everyday engagement, including cognitively, socially, and behaviorally active lifestyles, are associated with cognitive health and functional outcomes in later life (Livingston et al., 2020; Ngandu et al., 2015). From a theoretical perspective, this broader definition is consistent with cognitive reserve frameworks, which emphasize the role of ongoing engagement in supporting the activation and maintenance of cognitive resources in real-world contexts, rather than viewing these resources as accumulated solely through formal education (Stern et al., 2020). Accordingly, lifelong learning is conceptualized here as a dynamic process through which educationally derived cognitive capital is maintained and expressed across adulthood. Importantly, this conceptualization also informs our measurement strategy. By operationalizing lifelong learning using indicators of active coping and perceived agency, the present study captures the enacted and activation-oriented nature of lifelong learning, rather than restricting it to formal educational participation alone.

Taken together, these findings suggest that cognitive resources accumulated through education are not static endowments, but require continued engagement to be maintained and functionally expressed across adulthood (Hanushek et al., 2025). From this perspective, lifelong learning does not substitute for education nor operate as an independent protective factor; rather, it serves as a mechanism through which educationally derived cognitive capital is actively maintained, updated, and mobilized in later life (Parisi et al., 2012). In the absence of such engagement, educational advantages may become dormant or less consequential for health and survival, as higher levels of education are associated with reduced adult mortality only when they are accompanied by sustained cognitive and social engagement over the life course (Hummer & Hernandez, 2013; Lleras-Muney, 2005). Despite this theoretical relevance, relatively few studies have explicitly examined whether lifelong learning conditions the association between education and mortality in later life.

In addition to lifelong learning, close social relationships constitute another critical and analytically distinct pathway through which educational resources may be translated into health advantages. Social ties influence health through mechanisms of emotional regulation, stress buffering, and behavioral support (Seeman, 1996). Empirical work has consistently linked social integration and supportive relationships to better health and survival, suggesting that education operates within relational contexts rather than as an individual attribute in isolation (Berkman et al., 2000; Waite & Gallagher, 2001). Family and spousal relationships often become increasingly salient in older age, offering emotional support and facilitating the management of health-related challenges, particularly through encouragement of adaptive behaviors and regulation of stress (Wu et al., 2025).

Within this framework, family-based social support can be understood as a relational context that enables the translation of educational capital into concrete health-protective practices. The convoy model of social relations emphasizes that stable, emotionally meaningful ties provide enduring support across the life course (Antonucci et al., 2013; Kayonga et al., 2025; Park et al., 2025). In later life, such support may help individuals deploy educationally derived skills and knowledge more effectively by facilitating adherence to health-promoting behaviors, buffering psychosocial stressors, and sustaining motivation for self-care (Han et al., 2019; Ma et al., 2024). Thus, family-based social support represents a relational dimension of embodied cognitive reserve, shaping the conditions under which educational resources are enacted rather than functioning as a parallel or competing system of protection (Negi & Sattler, 2024). In this sense, family-based social support does not constitute cognitive reserve per se, but rather shapes the embodied conditions under which cognitive reserve is enacted. Supportive relational contexts may enable individuals to deploy educationally derived cognitive skills more effectively in managing stress, maintaining health behaviors, and adapting to age-related challenges (Rothon et al., 2012; Xu et al., 2022), thereby conditioning whether cognitive reserve is translated into survival advantages.

Despite strong evidence linking education, lifelong learning, and social relationships to health, existing research has rarely examined how these factors jointly shape mortality risk in later life. Recent studies continue to document robust associations between education and all-cause mortality across diverse settings (Balaj et al., 2024), while emerging work also indicates that engagement in cognitively stimulating activities, as a component of lifelong learning, is prospectively associated with mortality risk among older adults (Duan et al., 2025). In parallel, contemporary research demonstrates that social support processes remain meaningfully related to survival outcomes (Chen et al., 2021). However, these domains are still most often examined in relative isolation. Limited attention has been given to whether lifelong learning and family-based social support function as complementary conditions that activate, sustain, and translate educational resources into survival advantages in later life.

Using longitudinal data from the Midlife in the United States (MIDUS) Study, the present study examines whether education predicts mortality risk among adults aged 60 years and older and whether lifelong learning and family-based social support moderate this association. Grounded in life course and embodied cognitive reserve frameworks, educational attainment is conceptualized as a latent stock of cognitive capital accumulated earlier in life, whose influence on later-life survival depends on subsequent activation and enactment. We hypothesize that higher education will be associated with lower mortality risk, and that this association will be stronger among individuals who engage more actively in lifelong learning and who are embedded in supportive family relationships that facilitate the sustained mobilization of educational resources for health and stress regulation.

In the present study, we define embodied cognitive reserve as a minimal, testable process linking structural resources to survival through three stages: stock, activation, and translation/enactment. This formulation extends the concept of cognitive reserve from neurocognitive aging to broader psychosocial processes shaping survival. Education represents an accumulated stock of cognitive and self-regulatory capital acquired through formal and occupationally embedded learning. Lifelong learning captures later-life activation of this stock via continued goal-directed engagement, active coping, and perceived agency. Family-based social support represents the translation context that scaffolds whether activated resources are enacted in everyday stress regulation and health management. Critically, this formulation yields a falsifiable implication rather than a post hoc narrative. If education operates as a latent stock, its protective association with mortality should be stronger under higher activation (lifelong learning) and stronger translation capacity (family-based social support), consistent with an amplification prediction. A plausible competing compensation account, often invoked in the social support literature, would instead predict that support buffers low-education risk, thereby weakening the education gradient when support is high. By explicitly contrasting these predictions, the moderation tests in this study serve as discriminating evidence about how educational resources are carried forward and expressed in later-life survival.

Methods

Data

Data for this study were drawn from the Midlife in the United States (MIDUS) Study, a nationally representative longitudinal project designed to investigate behavioral, psychosocial, and biological processes across adulthood. Recognized for its methodological rigor and broad population coverage, MIDUS has been widely used in empirical research on aging, resilience, health trajectories, and mortality outcomes in the United States (Brim et al., 2004; Radler, 2014). The study employs standardized survey protocols and longitudinal follow-up procedures that allow researchers to examine associations between psychosocial exposures and long-term health outcomes across multiple waves of data collection.

The present analysis used data from the MIDUS 2 core survey, conducted between 2004 and 2006, together with linked mortality follow-up records through 2016. The MIDUS 2 wave provides detailed baseline information on demographic characteristics, educational attainment, psychosocial factors, and health-related indicators in midlife and later adulthood. Mortality follow-up data were obtained through linkage with the National Death Index, enabling objective ascertainment of survival status and timing of death. Survival time was calculated as the number of years from the MIDUS 2 interview to the year of death or to the end of follow-up for participants who remained alive, with surviving individuals treated as censored observations. All censored participants were assigned survival time through

2016, reflecting administrative censoring at the end of the observation period. As a result, survival times among censored participants exhibit limited variability. Baseline age and sex were included as covariates given their well-established associations with mortality risk in aging populations.

Sample Selection and Attrition

Participants were eligible if they were aged ≥60 years at MIDUS 2 and had valid information on age, sex, and mortality follow-up. Among 1,813 age-eligible MIDUS 2 respondents, 12 were excluded due to missing mortality follow-up and/or missing age or sex, leaving 1,801 participants for sample construction. We then applied sequential exclusions due to missing analytic variables. The largest reduction in sample size was attributable to missing information required to construct the occupational education index (n = 1,073). Because this index is derived from respondents' reported occupations, participants without valid occupational data, such as individuals who had never worked, were retired without available occupational histories, or were engaged in informal roles such as homemaking, could not be assigned an index value and were therefore excluded at this stage. Additional exclusions were applied for missing lifelong learning indicators required to compute the PCA-derived factor score (n = 117), the family support item (n = 4), and the spousal/partner support item among partnered respondents (n = 3), which was excluded to avoid within-partnered measurement heterogeneity (one-versus two-item scoring). In addition, 2 participants were excluded due to missing baseline functional limitation (activities of daily living; ADL). Although the number of cases was small, ADL was treated as a key covariate in subsequent models; therefore, these cases were excluded to ensure a consistent analytic sample across all model specifications. This yielded 602 respondents with complete covariate and moderator data. Prior to survival modeling, an additional 18 participants were excluded due to missing or non-positive survival time (time-to-event ≤ 0), yielding a final analytic sample of 584 older adults. Because the occupational education index and several PCA input indicators had nontrivial missingness, the final analytic sample was smaller than the original MIDUS cohort. However, comparisons between included and excluded participants, as shown in Table 2, indicated that excluded participants were significantly older and had significantly higher levels of functional limitation. Additional statistically significant differences were observed for lifelong learning and data availability indicators. By contrast, no statistically significant differences were found in the occupational education index or family-based social support. These results suggest that selection into the analytic sample was primarily associated with age, functional status, and data completeness rather than systematic differences in the primary constructs of interest. All Cox models were estimated using this fully observed analytic sample, and no additional case-wise deletion occurred at the modeling stage.

To ensure that all Cox models were estimated on an identical analytic sample, enabling direct comparisons across nested specifications, we applied a strict, consistent analytic sample. In addition to excluding cases with missing mortality status, age, sex, education, lifelong learning (PCA-derived factor score), or family-based social support measures, we also excluded participants missing baseline functional limitation (ADL). This decision was made to avoid sample inconsistency across models when functional limitation was introduced as an additional adjustment. We recognize that baseline functional limitation can be interpreted in two ways: as a potential confounder associated with both psychosocial exposures and subsequent mortality, and as a plausible intermediate condition through which accumulated resources are enacted in everyday functioning. Accordingly, we report models both without and with ADL adjustment and interpret changes in estimates as an explicit sensitivity check rather than as definitive causal partitioning.

Measures

Outcome Variable. The outcome of interest was all-cause mortality during the follow-up period. Mortality status was determined using linked National Death Index records, which provide verified information on death occurrence and timing. Participants were coded as deceased if a death record was identified and as censored if they were alive at the end of the observation period. Survival time was measured in years from the MIDUS 2 interview to the year of death or censoring. This operationalization of mortality outcomes follows standard practice in longitudinal epidemiological research.

Primary Predictor. Educational attainment was operationalized using the occupational education index available in MIDUS, which reflects the typical educational requirements associated with respondents' occupations. This index captures accumulated socioeconomic and cognitive resources across the life course, rather than relying solely on formal years of schooling or degree attainment. Compared with conventional measures, the occupational education index incorporates the educational requirements associated with individuals' occupations and reflects their position within the broader structure of occupational stratification across the life course (Hauser & Warren, 1997; Warren et al., 2002). This index has been widely used in prior research and provides a meaningful indicator of occupationally embedded educational demands and social stratification. In the context of the present study, this index is interpreted as a proxy for accumulated cognitive and skill-related resources derived from both formal education and occupational experiences. This approach is consistent with the present study's conceptualization of education as an accumulated and functionally expressed cognitive resource, rather than a static indicator based solely on formal attainment. The index was standardized (mean = 0, SD = 1) within the analytic sample to facilitate interpretation and comparability across models.

In the present study, the occupational education index was treated as a continuous variable and was used to represent respondents' relative educational positioning within the analytic sample. Consistent with its use in previous MIDUS-based research, higher values indicate occupations typically requiring higher levels of formal education. The index aligns with the literature linking educational attainment to mortality through mechanisms related to cognitive reserve and health behavior pathways, thereby serving as a theoretically appropriate operationalization of education in later life. We treat the occupational education index as a functionally oriented proxy for education-related resources across the life course rather than a direct substitute for formal educational attainment. Although its use reduced the analytic sample because valid occupational information was required, sensitivity analyses using an alternative operationalization of education based on self-reported education level (Table S1) yielded substantively consistent results, suggesting that the main findings were not driven by this specific operationalization.

In addition, for descriptive and visualization purposes, the occupational education index was categorized into tertiles based on its distribution within the analytic sample. This approach was adopted to facilitate interpretation of group differences and to illustrate graded patterns in survival outcomes without imposing externally defined cut points that may not align with the distribution of the index. It is important to note that these tertiles do not correspond directly to years of formal education, as the occupational education index reflects the typical educational requirements of occupations rather than respondents' reported years of schooling. Therefore, the tertile categorization should be interpreted as representing relative educational positioning within the analytic sample rather than absolute educational attainment levels. In this context, tertiles facilitate the interpretation of comparative differences in survival outcomes by illustrating the relative distribution of the occupational education index across the analytic sample, without implying equivalence to formal years of schooling. All inferential analyses were conducted using the continuous standardized occupational education index, and the tertile categorization was used solely for descriptive and graphical presentation. The use of tertiles is intended solely to aid interpretability and does not imply meaningful categorical distinctions in educational attainment.

Moderator Variables. Lifelong learning was operationalized using principal components analysis (PCA) applied to two MIDUS indicators: active coping (B1SACTIV) and sense of agency (B1SAGENC). These variables capture individuals' tendency to engage in goal-directed behavior when facing challenges and their perceived capacity to exert control over life circumstances. Both measures are derived from multi-item Likert-type scales in the MIDUS survey, with higher scores indicating greater endorsement of adaptive engagement and perceived control. When both indicators were available, the first principal component was extracted based on eigenvalues and factor loadings and was retained as a continuous PCA-derived factor score, with higher scores representing greater engagement in lifelong learning. In cases where only one indicator was available, the standardized (z-score) value of that indicator was used to preserve sample size while maintaining comparability across measures. Missingness occurred at the level of PCA input indicators, and no imputation was applied. Notably, these measures do not capture participation in specific cognitively, socially, or behaviorally engaging activities. The MIDUS dataset includes a range of activity-related items; however, these indicators are heterogeneous in content (e.g., cognitive, social, and behavioral domains), differ in measurement scales, and vary in temporal framing, and therefore do not readily form a unified or theoretically integrated construct of activity-based engagement within the scope of the present study. As such, a composite measure capturing participation in cognitively, socially, and behaviorally engaging activities could not be constructed in a conceptually coherent manner within the scope of the present study.

Accordingly, in the present study, lifelong learning is operationalized from an activation-oriented perspective, indexed by individuals' engagement disposition through active coping (B1SACTIV) and sense of agency (B1SAGENC). This approach complements activity-based perspectives by emphasizing the enactment of cognitive and motivational resources, rather than solely the frequency of participation in specific activities. Specifically, these indicators reflect individuals' behavioral and motivational orientation toward engaging with life demands, including the tendency to take action, plan, and exert control. In this framework, lifelong learning is conceptualized as an activation-oriented construct, representing the extent to which cognitive and motivational resources are enacted in later life rather than the frequency of participation in specific activities. Within this perspective, agency is treated as an indicator of the enactment of motivational and self-regulatory capacities in older adulthood rather than their developmental origin. Although educational attainment may contribute to the formation of such capacities earlier in life, the present operationalization focuses on how these capacities are expressed through ongoing engagement. Thus, the lifelong learning factor reflects the behavioral and motivational deployment of educational resources rather than a redundant proxy for education.

Family-based social support was constructed to reflect emotional and relational support within close interpersonal relationships. Perceived support from family members was assessed using a MIDUS item (B1SFAMSO), treated as a single-item indicator of perceived emotional support, capturing the extent to which respondents feel understood, cared for, and supported by their family. Responses are recorded on Likert-type scales, with higher values indicating greater perceived support. For respondents who reported having a spouse or long-term partner, a parallel item assessing perceived spousal or partner support (B1SPOSAF) was also included to capture relational resources within intimate partnerships. To reduce measurement nonequivalence across respondents with and without a spouse/partner, a composite support score was computed as the mean of available standardized items (family and spouse/partner when both were present; family only otherwise), rather than a sum that would mechanically differ by the number of observed items. This approach ensures comparability across respondents while minimizing bias due to differential item availability. All input indicators were standardized prior to aggregation, and the resulting composite variable was further standardized (z-score) for use in regression models. Respondents without a spouse or partner were retained in the analytic sample; for these individuals, the composite corresponds to the standardized family support item. Thus, relationship status was not used as an exclusion criterion. Although the measure relies on a limited number of indicators, it captures a core dimension of perceived emotional support that has been consistently linked to health outcomes and underlying physiological processes in prior research (Robles et al., 2014), which are themselves associated with long-term morbidity and mortality risk.

Baseline functional limitation (activities of daily living; ADL) was included as a sensitivity adjustment to address concerns about confounding and potential reverse causation, recognizing that baseline functional limitation (ADL) may also partly reflect the embodied enactment of resources in daily life.

Statistical Analysis

Cox proportional hazards models were used to estimate the association between education and all-cause mortality and to test moderation by lifelong learning and family-based social support. Survival time was defined as years from the MIDUS 2 interview to death or censoring in 2016. Models adjusted for baseline age and sex and were estimated sequentially: Model 1 included main effects; Model 2 added interaction terms (education × lifelong learning; education × family-based social support); and Model 3 further adjusted for baseline functional limitation (ADL) as a sensitivity specification. The Efron method was used to handle tied event times, and proportional hazards assumptions showed no substantive violations. All models were estimated on the same analytic sample to ensure comparability. Analyses were conducted in SPSS.

Results

Sample Characteristics

Table 1 presents the baseline characteristics of older adults aged 60 years and older included in the analytic sample (N = 584). Participants had a mean age of 66.23 years (SD = 5.25), and 50.5% were male. Over the follow-up period, 263 participants died and 321 remained alive at the end of observation. Descriptively, participants who died during the follow-up were older at baseline and had lower education scores compared with those who survived. Educational differences were also evident when education was categorized for descriptive purposes: a larger proportion of deaths occurred among individuals in the lowest education tertile, whereas participants in the highest education tertile were more likely to remain alive over the follow-up period. In contrast, levels of lifelong learning engagement and

Table 1. Baseline Characteristics of Older Adults Aged 60 Years and Older

Variable	Overall mean (SD) or %	Alive mean (SD) or %	Deceased mean (SD) or %
Age (years)	66.23 (5.25)	64.46 (4.05)	68.41 (5.71)
Male	296 (50.5%)	151 (46.7%)	145 (55.1%)
Education score (occupational education index)	0.00 (1.01)	0.13 (0.99)	−0.16 (1.02)
Education tertile			
Low	212 (36.3%)	92 (28.7%)	120 (45.6%)
Medium	185 (31.7%)	110 (34.2%)	75 (28.5%)
High	187 (32.0%)	119 (37.1%)	68 (25.9%)
Lifelong learning (PCA-derived factor score)	−0.15 (1.08)	−0.15 (1.09)	−0.14 (1.07)
Family-based social support (z)	0.05 (0.97)	0.09 (0.93)	0.01 (1.02)
Survival time (years)	15.93 (4.69)	18.94 (0.23)	12.23 (4.92)
Mortality status, *n* (%)	-	321 (55.0%)	263 (45.0%)

Note. Values are presented as mean (SD) for continuous variables and *n* (%) for categorical variables. Mortality status reflects deaths occurring during the follow-up period. Percentages in the Alive and Deceased columns are calculated within each mortality group, whereas percentages in the Overall column are based on the total analytic sample. Education tertiles were created based on sample-specific percentiles and are presented for descriptive and visualization purposes only. All inferential analyses treated education as a continuous variable.

family-based social support were similar between deceased and surviving participants. The mean survival time for the overall sample was 15.9 years (SD = 4.69), with substantially longer survival observed among participants who remained alive compared with those who died during the follow-up. The relatively small standard deviation in survival time among participants who remained alive reflects administrative censoring in 2016. Sensitivity analyses using an alternative educational indicator (education level; Table S1) yielded consistent patterns. Higher education was associated with lower mortality risk in both specifications, and the direction and statistical significance of other key predictors remained unchanged. The final analytic sample of 584 participants reflects exclusions primarily due to missing occupational education index, lifelong learning (PCA-derived factor score) input indicators, family support and spousal/partner support items, and baseline functional limitation (ADL), rather than differences in core sociodemographic characteristics.

Comparison of Included and Excluded Participants

Sample selection and attrition are summarized in Table 2. As shown in Table 2, included participants were significantly younger and more likely to be male than excluded participants. Included participants also exhibited significantly lower baseline functional limitation (ADL) and lower lifelong learning engagement. In contrast, no statistically significant differences were observed in education or family-based social support between included and excluded participants.

Cox Proportional Hazards Models

Table 3 presents the results of Cox proportional hazards models predicting all-cause mortality. In Cox proportional hazards models estimated among adults aged 60 years and older (strict, consistent sample, $N = 584$), higher education was associated with a lower risk of mortality in the main-effects model (Model 1: HR = 0.83, 95% CI [0.73, 0.94], $p = 0.004$), whereas lifelong learning and family-based social support were not independently associated with mortality (both $p > 0.10$). In the interaction model (Model 2), education remained protective (HR = 0.78, 95% CI [0.68, 0.90], $p < 0.001$) and the education × lifelong learning interaction was significant (HR = 0.88, 95% CI [0.78, 0.99], $p = 0.029$); the education × family-based social support interaction was also significant (HR = 0.87, 95% CI [0.75, 1.00], $p = 0.049$). In a sensitivity model additionally adjusting for baseline functional limitation (ADL) (Model 3), ADL limitation strongly predicted higher mortality risk (HR = 1.58, 95% CI [1.35, 1.86], $p < 0.001$), and education remained significantly protective (HR = 0.80, 95% CI [0.70, 0.92], $p = 0.002$). The education × lifelong learning interaction remained statistically significant (HR = 0.89, 95% CI [0.79, 1.00], $p = 0.043$), whereas the education × family-based social support interaction was attenuated and no longer statistically significant at conventional levels (HR = 0.88, 95% CI [0.76, 1.01], $p = 0.064$).

Sensitivity analyses using an alternative educational indicator (education level), as shown in Model 4, yielded consistent findings. Individuals in the lowest education group had a significantly higher mortality risk compared with those in the highest group (HR = 1.63, 95% CI [1.20, 2.22], $p <$

Table 2. Comparison of Included and Excluded Participants in the Analytic Sample

Variable	Included (N = 584)	Excluded (N = 1,217; edu n = 108)	Test statistic
Age (years), mean (SD)	66.22 (5.25)	70.46 (6.52)	$t = 13.02$***
Male, *n* (%)	296 (50.5%)	532 (43.7%)	$\chi^2 = 7.05$**
Education score (occupational education index), mean (SD)	0.00 (1.02)	0.02 (0.92)	$t = 0.17$
Education tertile (descriptive; based on available occupational education index)			
Low	212 (36.3%)	31 (28.7%)	
Medium	185 (31.7%)	43 (39.8%)	
High	187 (32.0%)	34 (31.5%)	
Lifelong learning (PCA-derived factor score), mean (SD)	−0.15 (1.08)	0.07 (0.95)	$t = 4.45$***
Family-based social support (z), mean (SD)	0.05 (0.97)	−0.03 (1.02)	$t = 1.56$
Baseline functional limitation (ADL), mean (SD)	1.79 (0.79)	2.29 (0.96)	$t = 11.24$***
Family-based social support item observed, *n* (%)	580 (99.3%)	960 (78.9%)	$\chi^2 = 164.38$***
Spousal/partner support item observed, *n* (%)	581 (99.5%)	965 (79.3%)	$\chi^2 = 171.62$***

Note. Education tertiles are reported for descriptive purposes only and are based on participants with non-missing occupational education index. In the excluded group, only a subset of participants ($n = 108$) had valid occupational information required to compute the index; therefore, tertile percentages for the excluded group are calculated using $n = 108$ as the denominator. These participants were retained in the tertile distribution for descriptive comparison only but were not included in any inferential analyses, as they were excluded from the final analytic sample for reasons unrelated to occupational data. All inferential analyses treated education as a continuous standardized variable. *P* values are based on t tests for continuous variables and chi-square tests for categorical variables. **$p < 0.01$; ***$p < 0.001$.

Table 3. Cox Proportional Hazards Models Predicting All-Cause Mortality Among Adults Aged 60 Years and Older (N = 584; Deaths = 263)

	Model 1		Model 2		Model 3	
Variable	HR	95% CI	HR	95% CI	HR	95% CI
Education (standardized occupational education index)	0.83**	[0.73, 0.94]	0.78***	[0.68, 0.90]	0.80**	[0.70, 0.92]
Lifelong learning (PCA-derived factor score)	1.00	[0.89, 1.12]	0.98	[0.87, 1.10]	1.00	[0.89, 1.12]
Family-based social support	0.90	[0.79, 1.03]	0.89	[0.78, 1.02]	0.97	[0.85, 1.11]
Age at baseline	1.11***	[1.08, 1.13]	1.11***	[1.08, 1.13]	1.10***	[1.08, 1.12]
Male (vs female)	1.36*	[1.07, 1.74]	1.36*	[1.06, 1.74]	1.64***	[1.27, 2.12]
Education × lifelong learning			0.88*	[0.78, 0.99]	0.89*	[0.79, 1.00]
Education × family-based social support			0.87*	[0.75, 1.00]	0.88	[0.76, 1.01]
Baseline functional limitation (ADL)					1.58***	[1.35, 1.86]

Note. Model 1 includes main effects of education, lifelong learning, and family-based social support adjusted for age and sex. Model 2 adds interaction terms (education × lifelong learning; education × family-based social support). Model 3 further adjusts for baseline functional limitation (ADL). All models were estimated on the same strict, consistent sample (N = 584). *$p < 0.05$, **$p < 0.01$, and ***$p < 0.001$.

0.01). The direction and statistical significance of other key predictors remained largely unchanged, indicating that the results are robust to different operationalizations of education.

Interaction Effects

Education × Lifelong Learning. Figure 1 illustrates the interaction between education and lifelong learning in predicting mortality risk. Greater educational attainment was associated with a more pronounced reduction in mortality risk under higher lifelong learning engagement, consistent with an amplification pattern. In contrast, the amplification of the association between education and survival was attenuated among individuals with lower lifelong learning engagement. This pattern indicates that the survival advantage associated with education was most evident when accompanied by ongoing cognitive and motivational engagement across later life. In simple-slope terms, the hazard ratio for a 1-SD increase in education was lower at high lifelong learning (+1 SD; HR = 0.69) than at low lifelong learning (−1 SD; HR = 0.89), indicating a stronger amplification of the association between education and survival under higher activation conditions. Simple slopes were computed as conditional hazard ratios for education from the interaction model, evaluated at ±1 SD of lifelong learning.

Education × Family-Based Social Support. Figure 2 depicts the interaction between education and family-based social support. Higher education was associated with lower mortality risk primarily among individuals reporting stronger family and spousal support. Among those with lower levels of family-based social support, the association between education and mortality was comparatively weaker. These findings are consistent with an amplification effect, whereby close relational support strengthens the translation of educational resources into survival advantages. In simple-slope terms, the hazard ratio for a 1-SD increase in education was lower at high family-based social support (+1 SD; HR = 0.68) than at low support (−1 SD; HR = 0.90). Notably, this moderation pattern was attenuated after additional adjustment for baseline functional limitation (ADL), indicating greater sensitivity of the translation pathway to baseline functioning.

Supplemental Figures S1 and S2 present the interaction patterns after additional adjustment for baseline functional limitation (ADL; Model 3), and Table 3 (Model 3) provides the full model estimates. The patterns are substantively similar to those observed in the primary models, indicating that the interaction effects are robust to baseline functional status, both graphically and in the fully adjusted model estimates.

Education and Survival Curves. Kaplan–Meier survival curves stratified by education level are presented in Figure 3. Participants in the highest education tertile exhibited consistently higher survival probabilities across the follow-up period compared with those in the lowest education tertile. Differences between education groups became more pronounced over time, providing descriptive support for the graded association between attainment and longevity. The difference in survival distributions between education groups was statistically significant (log-rank test, $p < 0.01$).

Discussion

Principal Findings

Using a national sample of older adults from the MIDUS Study, this study examined whether education predicts mortality risk in later life and whether lifelong learning and family-based social support moderate this association. Consistent with prior research documenting educational

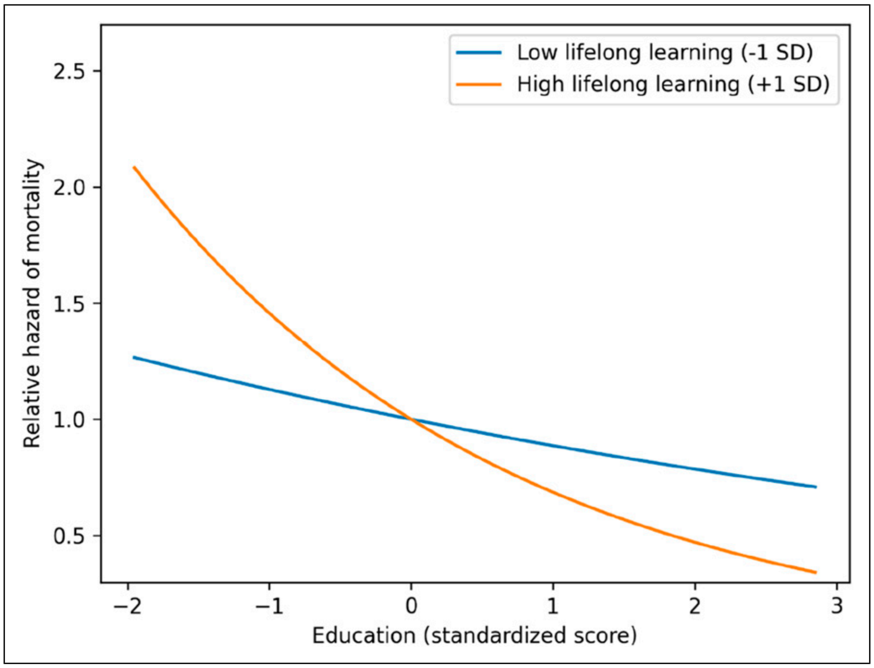

Figure 1. Interaction between education and lifelong learning engagement predicting mortality risk. Conditional hazard ratios for education were derived from Model 2 (without ADL adjustment) and evaluated at −1 SD (low) and +1 SD (high) from the mean of lifelong learning engagement

gradients in survival (Elo, 2009; Howe et al., 2023; Montez et al., 2011; Puka et al., 2022), higher education was associated with lower mortality risk. Importantly, this association was not uniform across individuals. The protective effect of education was stronger among individuals with higher lifelong learning engagement and, to a lesser extent, greater family-based social support, indicating an amplification pattern. The pattern indicates that the longevity

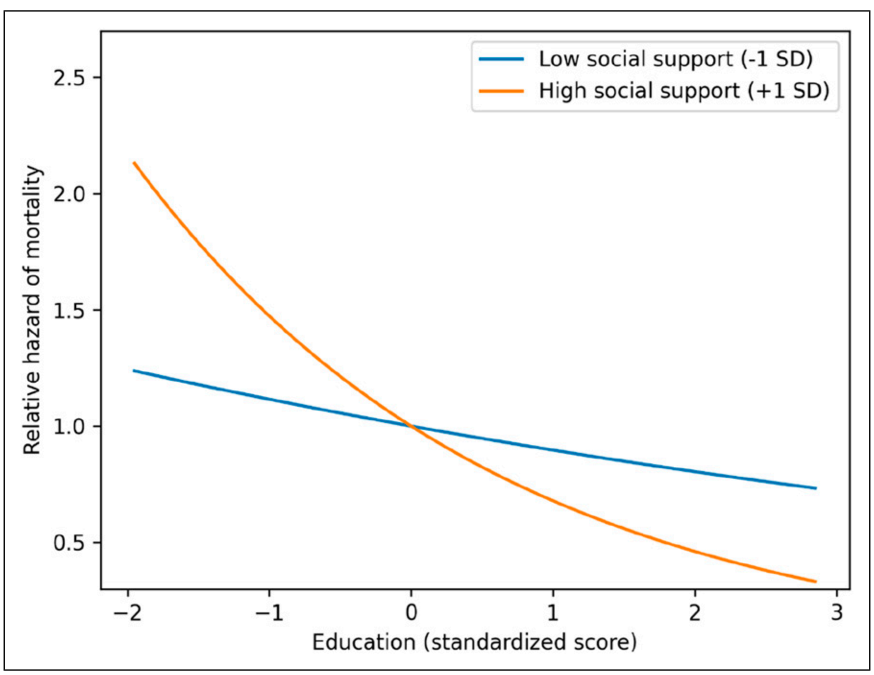

Figure 2. Interaction between education and family-based social support predicting mortality risk. Conditional hazard ratios for education were derived from Model 2 (without ADL adjustment) and evaluated at −1 SD (low) and +1 SD (high) from the mean of family-based social support

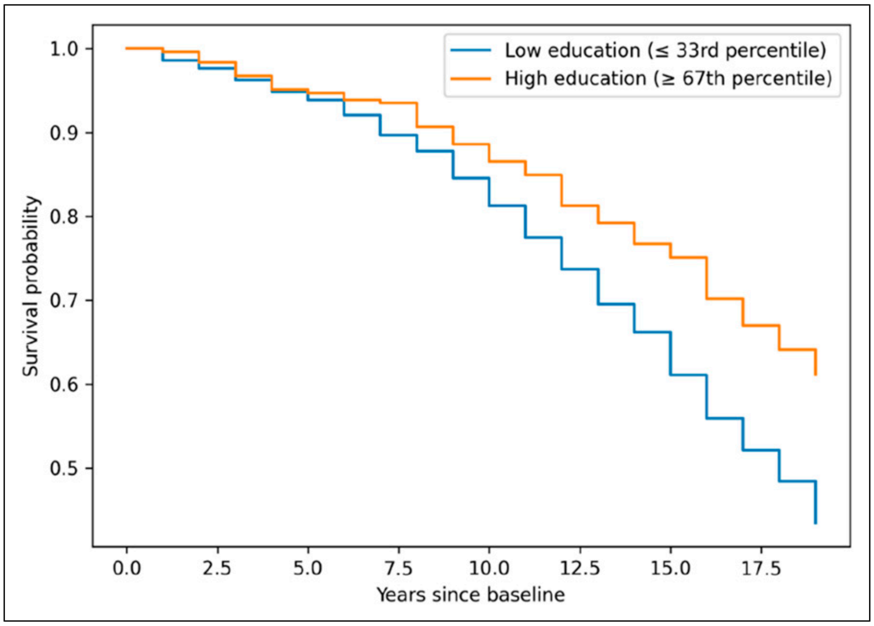

Figure 3. Kaplan–Meier survival curves stratified by education tertile. Education tertiles were created for descriptive purposes only. Survival curves illustrate graded differences in survival probability across education levels

benefits of education are most evident when educational resources remain activated and translated within supportive psychosocial contexts in later life. The consistency of findings across alternative operationalizations of education (Table S1) further indicates that these associations are robust, not dependent on the occupational education index, and unlikely to reflect a measurement artifact arising from sample selection.

Interpretation and Theoretical Implications

The observed association between education and mortality aligns with extensive evidence linking educational attainment to improved health and survival across adulthood. Education may influence health through multiple pathways, including cognitive reserve, health-related knowledge, and self-regulatory capacity (Mirowsky & Ross, 2015; Ross & Mirowsky, 2011). Our results extend this literature by indicating that educational attainment alone may not fully explain heterogeneity in later-life survival. Instead, the benefits of education appear to depend on later-life contexts in which educational resources are activated and enacted. Our use of life course and cumulative advantage perspectives is conceptual rather than causal. Education is therefore interpreted as an early-life stock of cognitive capital whose health benefits depend on later-life opportunities for activation rather than as a fixed determinant of survival. The robustness of findings across alternative operationalizations of education (Table S1) indicates that the observed association reflects a broader dimension of education-related resources rather than a specific measurement artifact.

The significant education × lifelong learning interaction supports an embodied cognitive reserve interpretation in which education represents an accumulated stock whose health benefits depend on later-life activation. Consistent with cognitive reserve theory, reserve is not a static product of early educational attainment but is reinforced through continued cognitive and motivational engagement across adulthood (Stern, 2012). In this study, lifelong learning reflects an activation-oriented form of sustained, goal-directed engagement, indexed by active coping and perceived agency, that may help maintain and deploy educational capital in everyday life. When lifelong learning engagement is higher, educational resources may be more consistently translated into adaptive health behaviors and self-regulatory processes, strengthening the protective association between education and mortality risk. Conversely, when such engagement is limited, educational advantages may remain comparatively dormant, resulting in a weaker association between education and survival.

Similarly, the interaction between education and family-based social support underscores the importance of close relational contexts for translating educational resources into health advantages. The education × family-based social support pattern is consistent with a complementary, amplifying account in which supportive family and spousal ties function as translation scaffolding that helps convert educational resources into stable, health-protective routines. In later life, relational support may facilitate the effective use of educational skills by promoting emotional regulation, buffering stress, and encouraging adherence to health-promoting behaviors, all of which are linked to lower mortality risk

(Holt-Lunstad et al., 2010; Uchino, 2006). Although a compensatory or substitution interpretation is plausible, whereby support offsets lower educational resources, our framework prioritizes translation capacity, namely, the conditions under which educational resources are enacted, rather than treating social support as a separate capital that replaces education. This theoretical choice motivates an a priori expectation of amplification rather than substitution and reinforces sociological perspectives that educational gradients in health are embedded within social and relational environments rather than operating as isolated individual attributes (Thoits, 2011). The attenuation of the education × family-based social support interaction after ADL adjustment should be interpreted cautiously. Baseline functional limitation may act as a confounder (health selection into psychosocial resources) and/or as an intermediate condition through which educational and relational resources are enacted in daily functioning. Thus, the ADL-adjusted specification is presented as a sensitivity check rather than a definitive causal partition.

Strengths and Limitations

Several strengths of this study warrant consideration. The use of a well-characterized national cohort with mortality follow-up strengthens confidence in the observed associations. Mortality outcomes were ascertained using the National Death Index, a widely used and reliable source for mortality ascertainment in U.S. population-based research (Cowper et al., 2002).

At the same time, several limitations should be acknowledged. First, the analytic sample was reduced due to missing data on specified analytic variables required for model estimation, which may limit the generalizability of the findings to the broader MIDUS population. As shown in Table 2, participants excluded from the analytic sample were characterized by older age and greater functional limitation. However, no statistically significant differences were observed in the occupational education index or family-based social support, suggesting that selection into the analytic sample was less likely to bias the primary associations of interest. Second, measures of lifelong learning and family-based social support relied on self-report and therefore may not fully capture the complexity and dynamic nature of the underlying cognitive engagement or relational processes across later life. Third, although longitudinal mortality follow-up was available, the observational design precludes causal inference. While we conducted sensitivity analyses adjusting for baseline functional limitation (ADL), residual confounding related to lifetime health selection processes or long-term socioeconomic conditions cannot be ruled out. Finally, family-based social support was operationalized using a mean-of-available-items approach to accommodate MIDUS skip patterns across respondents with and without a spouse or partner. Although this strategy avoids mechanical differences by relationship status, future research should examine measurement invariance and dyadic processes using richer relationship-specific modules.

Implications for Aging Research and Practice

These findings have important implications for research and practice aimed at promoting healthy aging. Policies focusing solely on early-life education may overlook opportunities to sustain health advantages in later life. Programs that encourage continued learning, engagement, and supportive family relationships may help extend the protective effects of education into older adulthood. Future research should further examine how educational resources interact with psychosocial contexts across diverse populations and life course stages to shape longevity.

Conclusions

This study demonstrates that higher educational attainment is associated with lower mortality risk in later life and that this association is conditionally expressed through psychosocial contexts. The moderating role of lifelong learning remained robust after adjustment for baseline functional limitation, whereas the moderation by family-based social support was attenuated in sensitivity analyses. These results indicate that educational advantages for survival are most consistently sustained through ongoing cognitive and motivational engagement, while relational support may play a more context-dependent role. Overall, the evidence supports the embodied cognitive reserve framework, indicating that the survival benefits of education depend on later-life activation and engagement. In particular, lifelong learning plays a critical role in translating early-life educational advantages into longevity.

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Ethical Considerations

This study used publicly available data from the Midlife in the United States (MIDUS) Study. Ethical approval and informed consent were obtained by the original MIDUS research team. The present study involved secondary analysis of de-identified data and therefore did not require additional institutional review board approval.

Consent to Participate

Not applicable (secondary analysis of publicly available data).

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Declaration of Conflicting Interests

The authors declare no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Data Availability Statement

The data that support the findings of this study are publicly available from the Midlife in the United States (MIDUS) Study via the Inter-university Consortium for Political and Social Research (ICPSR).

Supplemental Material

Supplemental material for this article is available online.

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