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Chronic loneliness and longitudinal changes in cognitive functioning

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Abstract

Background Loneliness is a worldwide concern with significant health implications that may be a significant risk factor for Alzheimer's disease and related dementias. In light of the importance of detecting early cognitive changes and risk factors influencing cognitive health, this study examined whether chronic loneliness predicted cognitive changes among young and middle-aged adults.

Methods This study utilizes data from a longitudinal measurement burst study spanning over two years, comprising three waves of data collection. A systematically recruited young to mid-life adult sample (25- 65 years) included 172 racially and economically diverse participants who provided information about loneliness for at least two consecutive waves. Chronic loneliness was defined based on the validated multi-item PROMIS Social Isolation scale. We assessed working memory, processing speed, and spatial memory in a measurement burst design using mobile cognitive assessments. Multilevel growth models were conducted to examine whether chronic loneliness was associated with changes in cognitive performance during the study period of up to two years.

Results Results revealed that chronic loneliness was not associated with baseline performance of working memory, processing speed, spatial memory or global cognitive performance, but chronic loneliness was associated with differential cognitive trajectories, specifically a lack of retest related improvement. There were no significant changes in cognitive performance for the chronic loneliness group across waves, whereas significant improvements were observed in those who were not chronically lonely.

Conclusions This study offers insights into the impact of chronic loneliness on cognitive changes in young and middle-aged adults, revealing that chronically lonely individuals did not exhibit the practice-related improvements that are commonly observed in longitudinal studies. Findings suggest the potential significance of identifying and addressing chronic loneliness promptly to prevent potential cognitive consequences of chronic loneliness.

Keywords Chronic loneliness, Cognition, Working memory, Processing speed, Spatial memory, Measurement burst design, Mobile cognitive assessment, Ecological momentary assessment

Background

Loneliness, defined as distressing and discomforting feelings arising from the perception of a mismatch between desired and actual social relationships in terms of quantity and quality (Peplau & Perlman, 1982), has been increasingly recognized as a global concern. Recent findings from a comprehensive meta-analysis encompassing 57 studies across 113 countries have underscored the pervasiveness of loneliness across various stages of adulthood [1]. A growing body of evidence consistently

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indicates that loneliness has adverse effects on mental health [2–4], physical well-being [4, 5], cardiovascular health [6, 7], and overall mortality [8].

Loneliness also has emerged as a significant risk factor for Alzheimer's disease and related dementias [9–13], a concern amplified by the expanding aging population, which imposes substantial socioeconomic costs on modern society [14]. Moreover, meta-analysis and systematic review studies have shown that higher loneliness is associated with compromised cognitive function in older adults [15, 16]. Recognizing the importance of identifying subtle cognitive changes and risk factors affecting cognitive function in the preclinical phase [17], our study aimed to investigate the impact of loneliness on longitudinal changes in cognitive function among young and middle-aged adults, with a specific focus on chronicity of loneliness.

Loneliness can be categorized using the de Jong Gierveld & Raadschelders typology [18], which considers both frequency and duration. Situational loneliness arises from stressful life events or environmental changes (e.g., divorce, relocation), whereas chronic loneliness is due to an individual's inability to establish satisfying social relationships or being restricted from social connections by their environment [19]. Transient or situational loneliness can evolve into chronic loneliness when unmet social connection needs persist [20].

According to the evolutionary theory of loneliness [21], feelings of loneliness are a natural and vital part of the human experience. Their evolutionary and adaptive function is to serve as a signal to motivate rebuilding or reestablishing social connections, thereby increasing chances of survival. This theory suggests that short-term feelings of loneliness may not necessarily harm one's health. However, when loneliness becomes chronic, it can lead to health problems due to associated psychological and physiological effects. Previous studies have supported the theoretical arguments of the evolutionary theory of loneliness, demonstrating links between chronic loneliness and adverse health outcomes such as frequent physician visits [22], risk of major depression [23], and mortality risk [24].

Chronic loneliness may affect neurocognitive health over the long term through various pathways. Loneliness has been linked to hypervigilance and self-preservation, potentially increasing cognitive load and reducing cognitive resources [25]. Drawing from Yaakov Stern's concept of cognitive reserve [26], which suggests that certain lifelong factors like education, social networks, and personality traits can protect against cognitive decline and Alzheimer's disease (AD), loneliness may work in the opposite direction. Unlike the protective effects of social engagement and strong social networks, chronic loneliness, characterized by persistent feelings of social isolation and a lack of meaningful social interactions, may lead to reduced cognitive engagement and stimulation. In these ways, chronic loneliness may reduce capacity to build cognitive reserves, increasing the risk for cognitive impairment [27]. Loneliness can also affect cognitive health via health-compromising behaviors (e.g., heavy drinking, substance use, smoking, physical inactivity, poor sleep) [5, 28–34] and physiological dysregulation (e.g., overactivation of the sympathetic-adrenal-medullary (SAM) axis and hypothalamic–pituitary–adrenal (HPA) axis) [35–39], all of which can adversely affect cognitive function. Given that chronic loneliness may significantly impact neurocognitive health through these mechanisms (cognitive reserve depletion, limited cognitive engagement, and the promotion of health-compromising behaviors and physiological dysregulation), the present study aimed to investigate whether and how chronic loneliness is related to cognitive performance over time, a necessary first step of understanding the impacts of chronic loneliness on neurocognitive health.

Current literature on chronic loneliness and cognitive functioning

To date, limited research has explored the effects of chronic loneliness on cognitive functioning and brain health. Zhong and colleagues [40] found negative associations between both transient and chronic loneliness and score on the Mini Mental State Examination (MMSE) at follow-up among Chinese older adults, with chronic loneliness showing a stronger impact. One of the limitations of this work was measuring global cognition with the MMSE, which is more accurately categorized as a mental status test rather than a comprehensive measure of global cognition. The cognitive impact of chronic loneliness has also been investigated using data from the Framingham Heart Study [41]. Results showed that cross-sectionally, persistent loneliness (compared to no loneliness) was associated with lower scores on the Victoria Stroop Test at baseline. Longitudinally, persistent loneliness (compared to no loneliness) was associated with a decrease in scores on the CERAD Word List Memory Test and the Victoria Stroop Test. Lastly, the relationship between loneliness duration and memory function among adults aged 50 and older has been examined with the US Health and Retirement Study (HRS) cohort [42]. Results revealed that longer loneliness duration correlated with lower memory function at baseline and a faster decline. In summary, the limited research on chronic loneliness and cognitive function suggests a potential negative impact of chronic loneliness.

Although this limited evidence suggests that chronic loneliness may be linked with cognitive decline, there are

aspects of this claim that require further examination. Those previous studies relied on single-item measures of loneliness for each wave. Zhong and colleagues [40] asked a single question about frequency of feeling lonely and dichotomized as not lonely ("never" and "seldom") and lonely ("sometimes", "often", and "always") each wave. Similarly, Yu and colleagues [42] employed a yes/no item ("Do you feel lonely?"). In Tao and colleagues' study [41] loneliness relating to cognitive functioning was assessed at two examination periods using a question from the Center for Epidemiologic Studies Depression Scale (CES-D), where participants indicated the frequency of feeling lonely during the past week. While these single-item measures offer simplicity, they may lack psychometric support, leading to potential reliability and validity issues [43, 44]. Directly asking about feeling lonely may result in underreporting due to the stigma associated with loneliness; multi-item measures indirectly assess feelings of deficits in social relationships, providing a more comprehensive understanding of loneliness [45, 46]. Moreover, the lengthy intervals (2–5 years) between successive measures of loneliness used to define chronic loneliness in prior studies are impractical in public health and clinical settings for identifying individuals who are chronically lonely and who may benefit from preventive interventions. Utilizing narrower time intervals between successive measures of loneliness and validated multi-item measures enables early detection. This is crucial for timely identification and intervention for individuals experiencing chronic loneliness in public health and clinical settings [47, 48].

Present study

Building upon the existing research, the present study further explores the relationship between chronic loneliness and changes in cognitive performance among young and middle-aged adults by utilizing a measurement burst design and assessments obtained in naturalistic settings. By using data from intensive cognitive ecological momentary assessment (EMA) conducted in daily life, our study aims to enhance the precision and reliability of measuring individual differences in cognitive function by reducing random measurement error within each wave [49, 50]. Further in contrast to two prior studies in which cognitive functioning was assessed at only two time points [40, 41], the current project uses three time points, more accurately enabling determination of a linear trajectory [51, 52].

Our study focuses on young and middle-aged adults, who are less likely to experience age-related neurological decline compared to older adults. Examining pre-symptomatic changes in cognitive functioning and identifying risk factors that contribute to cognitive variability during midlife is crucial for implementing targeted preventive strategies to delay or prevent cognitive decline in later life [48]. Furthermore, our study aims to mitigate the issue of reverse causality inherent in observational research by specifically targeting a young and generally healthy midlife sample. This approach seeks to reduce the likelihood of pre-existing brain damage or cognitive impairment – that are more common in older samples – influencing chronic loneliness within the parameters of our observational study. In the context of our study sample demographics, which investigates the association between chronic loneliness and cognitive changes over two years, we may not observe significant cognitive decline over time or even could expect slight retest-related improvements, a phenomenon that has been widely documented in longitudinal studies [53–55]. Recent studies have shown that retest effects can serve as valuable indicators for the detection of subtle cognitive changes and impairments [56, 57]. For instance, research has demonstrated that the reduction in practice effects is indicative of preclinical Alzheimer's disease (AD) [58]. Consequently, recognizing these nuanced aspects, we examine the relationship between chronic loneliness and cognitive changes in young to middle-aged adults.

Based on theoretical arguments regarding the hypervigilance of loneliness and its association with various potential behavioral and physiological mechanisms, as well as empirical evidence from prior studies [40–42] that highlight the detrimental effects of chronic loneliness, we hypothesized a negative relationship between chronic loneliness and rates of cognitive change. To test this hypothesis, we compared the slopes of cognitive change between individuals classified as chronically lonely and those who were not. We expected that individuals experiencing chronic loneliness would exhibit more negative rates of cognitive change compared to those who did not report chronic loneliness.

Methods

Sample

Data were drawn from the Effects of Stress on Cognitive Aging, Physiology and Emotion (ESCAPE) Project. Based on systematic probability sampling, participants were recruited from Bronx County, NY. Eligibility criteria included 25 – 65 years of age, being ambulatory, English fluency, free of visual impairment that would interfere with operating the study smartphone, and residency in Bronx County, NY. This study included 172 respondents who completed ambulatory assessment of cognitive functioning and provided information about loneliness and demographics over at least two consecutive waves, with complete data available for all predictors. The mean age of the sample was 46.8 years, with 32.6% men, and racial

distribution as follows: 26.7% White, 69.2% Black, 4.1% other races. Approximately 21% of the sample was Hispanic and 47% had a college degree or higher.

Procedures

The ESCAPE study is a longitudinal measurement burst study conducted over three years and spanning four bursts (i.e., waves). Ethical approval for this study was obtained from the Albert Einstein College of Medicine of Yeshiva University's review board (for additional details, refer to [59]). Informed consent was obtained from all participants prior to their involvement. During each wave, participants completed paper–pencil surveys assessing demographic and psychosocial characteristics. Following the paper–pencil surveys and a 2-day practice phase, eligible participants underwent a 14-day EMA burst, responding to smartphone "beeps" with surveys five times daily. Beeps were scheduled to sample the entire waking day, with quasi-random timing to ensure that participants could not anticipate the beeps; the average time between scheduled beeps was 2 h and 33 min. These EMA surveys included questions about recent experiences and were followed by EMA cognitive tasks, which are explained in more detail below. Participants also completed morning and bedtime surveys daily, but these were excluded from our study because these surveys did not include EMA cognitive tasks. Bursts were repeated every nine months and data from three waves were used in this study, covering 2 years of follow-up.

Measures

Loneliness

Loneliness was measured at the beginning of each wave in the paper–pencil survey, prior to the EMA burst assessments. We assessed loneliness using the 6-item Patient-Reported Outcomes Measurement Information System (PROMIS) Social Isolation scale. This PROMIS scale, characterized by high reliability (Cronbach's $\alpha = 0.91$), gauged feelings of avoidance, exclusion, disconnection, and being unknown to others. The PROMIS social isolation scale was shown to be closely resemble and correlated with those found in established loneliness measures [60], such the revised UCLA loneliness scale [61]. Participants responded to statements such as "I feel left out," rating them on a scale from 1 (Never) to 5 (Very often). Scores for the six items were adjusted according to PROMIS guidelines to a standardized scale based on the U.S. general population [62]. This adjustment resulted in scores ranging from 34.4 to 76.2.

Previous studies on chronic loneliness have typically defined chronic loneliness by relying on single questions, such as a 'Yes' response to a simple inquiry like 'do you feel lonely?' over two data collection points. In our study, we aimed to refine this approach by utilizing multiple items to construct a more comprehensive loneliness score for each wave of data. This allowed us to distinguish between individuals who experienced chronic loneliness, as opposed to those with occasional or moderate feelings of loneliness. To identify individuals consistently struggling with loneliness (not just average lonely), we categorized the distribution of loneliness scores into fifths for each wave. Those who consistently fell within the highest quintile for loneliness scores over two consecutive waves were classified as belonging to the chronic loneliness group (comprised 9.30% of the sample; $n = 16$). Although we acknowledge statistical concerns regarding dichotomization (e.g., [63]), we opted to dichotomize the chronic loneliness variable into chronically lonely vs. not chronically lonely without including a transient lonely group. This decision was made to maintain statistical power given the constraints of our small sample size.

EMA cognitive assessment

Cognitive performance was measured five times daily during the 14-day EMA burst within each wave and we calculated the summarized measures for each wave as follows.

Working memory A Flipback task was designed to assess working memory [50, 64]. As the task started, participants observed a series of three standard playing cards slide from one box on the right of the screen to the other box on the left of the screen. The two cards that were most recently shown were facedown prior to the move, and as the cards shifted positions, participants were asked to determine if the current target card matched the facedown test card, which they saw two trials back. Each assessment consisted of 12 trials, and for each assessment a throughput score (accuracy rate divided by median response time) was calculated. Individual person-mean throughput scores across assessments within each wave were calculated. The dependent variable was obtained by standardizing the person-mean throughput for each wave based on sample means and standard deviation of throughput at wave 1, with higher standardized scores indicating better performance.

Processing Speed The Symbol search task is a reliable and valid indicator of processing speed and visual attention, requiring participants to quickly compare images [50]. In this task, participants were presented with a row of three symbol pairs at the top of the screen and with two symbol pairs at the bottom. Participants were instructed to decide, as quickly as possible, which of the two pairs presented at the bottom were among the pairs at the top. These pairs were presented until participants

responded. Each EMA assessment featured 12 trials, with a throughput score (accuracy rate divided by median response time) calculated for each. The person-mean of the throughput scores for each individual across the assessments within a wave was calculated. The dependent variable was the standardized scores based on sample means and standard deviation of throughput at wave 1, with higher scores indicating better performance.

Spatial Memory Previous work has shown a Dot memory task to be a reliable and valid indicator of spatial working memory [50, 64]. Participants were tasked with memorizing the locations of three red dots presented on an empty 5×5 grid for three seconds before their removal. Following an eight-second distraction with different visual stimuli, participants were asked to recall the initial dot locations. Error scores were computed based on deviations from the correct locations. These error scores were calculated for each trial, involving the Euclidean distance of the incorrectly placed dot relative to the correct grid location. Participants completed two trials at each EMA assessment, and an error score was determined for each assessment. Subsequently, the person-mean of error scores across assessments within each wave was calculated. Standardized scores of the error score were derived for each wave, based on sample means and standard deviations of error scores at wave 1. Notably, the standardized scores were reversed, such that higher scores reflected better cognitive performance.

Global Cognitive Performance Additionally, a composite measure of global cognition was obtained by averaging the standardized scores from the three cognitive tests: Flipback, Symbol Search, and Dot Memory. This composite score provided an overall assessment of cognitive performance across multiple domains, including working memory, perceptual speed, visual attention, and spatial memory.

Covariates

We included the following covariates based on prior research [12, 65, 66] as potential confounders and predictors of the outcome.

Baseline Covariates Sociodemographic characteristics collected at baseline encompassed age (centered at the sample mean of wave 1), gender (women vs. men), race (White; Black; Others), ethnicity (Hispanic vs. not Hispanic), and education (less than college degree vs. college degree or higher).

Time-varying Covariates These were assessed via paper–pencil surveys at each wave. Physical function and health conditions were included as subjective health measures. Physical function was measured with a short version (10 items, Cronbach reliability $\alpha = 0.91$) of the PROMIS Physical Function scale. This measure assessed how much participants' health conditions limited their daily activities and level of difficulty with completing daily tasks. The sum of reversed item scores, centered at the sample mean, represented physical function, with higher values indicating better function. Health conditions were measured by querying participants about conditions like high blood pressure or chest pain, with the total number of endorsed conditions centered at the sample mean. Objective social isolation measures included marital status (married vs. not married) and living arrangement (living alone vs. living with others). Depressive symptoms were assessed with an 8-item short version of the PROMIS Depression scale (Cronbach's $\alpha = 0.93$), and the adjusted sum of scores was centered at the sample mean. Because there were multiple observations within births, we controlled for short term trends by including accumulated number of assessments for each wave.

Analytic approach

Multilevel growth models were tested in order to examine whether chronic loneliness was associated with changes in cognitive functioning during the study period of up to two years. Statistical analysis was performed using the lme function in the "nlme" R package. The model was a two-level multilevel model, with measurements of cognitive functioning at each wave (level 1) being nested within participants (level 2). Random effects included participant-specific intercepts and slope. Except for sociodemographic characteristics, all the covariates were obtained at each wave and treated as time-varying covariates in the analysis.

Supplementary analyses

We conducted four supplementary analyses. First, we additionally included social interaction and social support in analyses to examine whether the association of chronic loneliness and cognitive function was independent from other social indices. An individual's level of social interaction was calculated based on EMA measures. At each assessment, participants reported on their activities during the past five minutes. The social interaction variable represented the proportion of assessments participants selected "socializing" within each wave. Emotional, instrumental, and informational social support were measured in a paper–pencil survey with the

6-item PROMIS scale (α = 0.95 for emotional, α = 0.96 for instrumental, and α = 0.95 for informational, respectively). The sum of the six items for each social support category was centered at the sample mean. Higher scores indicated greater perceived social support.

Second, we examined whether changes in cognitive function across waves differed based on baseline loneliness. Participants at wave 1 were categorized into two groups: those in the highest quintile of loneliness and all others in the second group. This analysis aimed to determine if baseline loneliness predicts cognitive changes or if the persistence of loneliness is a crucial factor in predicting cognitive function across waves.

Third, we conducted additional analyses using tertiles and quartiles to define the chronic loneliness group at each wave to confirm that results were consistent when using other breakpoints and larger groupings. These supplementary analyses aimed to assess the robustness of our findings across different cutoff points.

Fourth, we examined the age interaction with chronic loneliness on cognitive changes to investigate possible age effects.

Results

Descriptive information

On average, participants provided data, which had no systematic missing values, on mobile cognitive tests in 60.4 EMAs (SD = 12.7) at wave 1, 62.3 EMAs (SD = 14.1) at wave 2, and 60.6 EMAs (SD = 15.1) at wave 3. Descriptive statistics for loneliness, cognitive performance, and all the covariates at wave 1 by chronic loneliness group are presented in Table 1. The mean level of loneliness of the chronic loneliness group (defined as individuals who consistently ranked in the highest quintile for loneliness scores for at least two consecutive waves) at wave 1 was 63.99 (sd = 6.96), and of the no-chronic-loneliness group was 48.31 (sd = 9.14). There were no significant differences in cognitive performance at wave 1 between the two groups ($ps > 0.05$). No significant differences were found between the two groups in age, gender, race, ethnicity, education, physical function, marital status, living arrangement, total number of sessions, and informational and instrumental social support ($ps > 0.05$). The chronic loneliness group, however, had significantly more health conditions ($F(1, 171) = 5.48$, $p = 0.02$), greater depressive symptoms ($F(1, 171) = 15.23$, $p < 0.001$), and lower emotional social support ($F(1, 171) = 4.86$, $p = 0.03$).

Table 1 Descriptive statistics for loneliness, cognitive performance, and covariates at wave 1 by chronic loneliness group (N = 172)

Variable	No chronic loneliness (*N* = 156)	Chronic loneliness (*N* = 16)	*p*
Loneliness, mean (SD)	48.31(9.14)	63.99(6.96)	**< .001**
Working Memory, mean (SD)	0.001(0.004)	0.002(0.004)	0.40
Processing Speed, mean (SD)	0.0004(0.0002)	0.0004(0.0002)	0.78
Spatial Memory, mean (SD)	1.75(0.93)	1.89(0.98)	0.57
Age, mean (SD)	46.78(11.01)	47.00(12.59)	0.94
Gender, % of Female	66.67%	75.00%	0.50
Race, % of			
White	25.64%	37.50%	0.15
Black	71.15%	50.00%	
Other	3.21%	12.50%	
Ethnicity, % of Hispanic	21.79%	18.75%	0.78
Education, % of College degree or more	50.00%	46.79%	0.81
Physical function, mean (SD)	51.35(9.83)	46.97(8.51)	0.09
Health condition, mean (SD)	3.21(2.46)	4.75(2.98)	**0.02**
Marital status, % of Married	31.41%	37.50%	0.62
Living arrangement, % of Living alone	26.92%	12.50%	0.21
Depression, mean (SD)	52.07(9.10)	61.31(8.04)	**< .001**
Total number of sessions	59.90(13.09)	64.75(6.15)	0.15
Emotional support, mean (SD)	51.53(8.92)	46.23(11.44)	**0.03**
Informational support, mean (SD)	54.52(9.69)	50.99(12.02)	0.18
Instrumental support, mean (SD)	51.40(8.91)	51.18(9.56)	0.92
Socializing, mean (SD)	0.10(0.10)	0.08(0.06)	0.31

**p < .05, **p < .01, ***p < .001*

Results from multilevel growth models on chronic loneliness and cognitive changes

Results from multilevel growth models are summarized in Table 2.

Global Cognitive Performance

A composite measure of global cognition was obtained by averaging the standardized scores from the three cognitive tests. Multilevel growth models showed that, on average, global cognitive performance significantly increased across a 2-year period ($b=0.22$, $p<0.001$). There was no significant difference in cognitive performance at baseline between the chronic loneliness group and the no chronic loneliness group ($b=0.17$, $p>0.05$). However, chronic loneliness moderated the rates of change ($b=-0.17$, $p=0.009$) in cognitive performance. According to a simple slope test, only those defined as not chronically lonely showed significant improvements in global cognitive performance ($b=0.22$, $p<0.001$); those classified as chronically lonely did not ($b=0.05$, $p>0.05$). These slopes are depicted in Fig. 1.

Working memory

Results showed that working memory performance significantly increased across waves ($b=0.41$, $p<0.001$), after controlling for all the other covariates. There was no significant association with chronic loneliness and cognitive performances at baseline ($b=0.49$, $p>0.05$). Chronic loneliness was associated with the rates of change ($b=-0.25$, $p=0.008$). A simple slope test confirmed that the not chronically- lonely group showed significant increases in working memory performance ($b=0.41$, $p<0.001$), but the chronic loneliness group did not show significant changes ($b=0.16$, $p>0.05$). These results are depicted in Fig. 2.

Processing speed

Results from multilevel growth modeling showed that, on average, processing speed performance significantly improved over two years ($b=0.17$, $p<0.001$), after controlling for all the covariates. Chronic loneliness was not significantly associated with cognitive performance at baseline ($b=0.21$, $p>0.05$), but it was marginally related to the rates of change in cognitive performances ($b=-0.17$, $p=0.05$). A simple slope test showed that

Table 2 *Results from multilevel growth models for chronic loneliness and cognition (N = 172)*

	Global cognitive performance		Working memory		Processing speed		Spatial memory	
Predictors	**Estimates**	**CI**	**Estimates**	**CI**	**Estimates**	**CI**	**Estimates**	**CI**
Fixed effects								
Intercept	−0.47*	−0.89 – −0.05	−0.71**	−1.23 – 0.19	−0.59*	−1.14 – 0.04	−0.17	−0.73 – 0.39
Wave	0.22***	0.18 – 0.25	0.41***	0.36 – 0.46	0.17***	0.12 – 0.22	0.07**	0.01 – 0.13
Chronic loneliness (ref: not chronic loneliness)	0.17	−0.25 – 0.59	0.49	−0.04 – 1.02	0.21	−0.34 – 0.76	−0.19	−0.76 – 0.38
Wave X Chronic loneliness	−0.17**	−0.29 – −0.04	−0.25**	−0.43 – −0.07	−0.17^{+}	−0.34 – 0.00	−0.10	−0.29 – 0.10
Age	−0.03***	−0.04 – −0.02	−0.05***	−0.06 – −0.03	−0.04***	−0.05 – −0.02	−0.01^{+}	−0.03 – 0.00
Gender (ref: Women)	−0.18	−0.43 – 0.06	−0.28^{+}	−0.57 – 0.01	0.06	−0.26 – 0.37	−0.28^{+}	−0.58 – 0.03
Education (ref: Less than college degree)	0.27*	0.04 – 0.51	−0.07	−0.34 – 0.20	0.35*	0.05 – 0.66	0.53***	0.23 – 0.82
Race – Black (ref: White)	−0.10	−0.45 – 0.24	0.04	−0.36 – 0.44	−0.08	−0.52 – 0.37	−0.29	−0.72 – 0.14
Race – Others (ref: White)	0.09	−0.57 – 0.74	0.16	−0.60 – 0.92	−0.11	−0.95 – 0.73	0.16	−0.66 – 0.98
Ethnicity – Hispanic (ref: Hispanic)	−0.02	0.39 – 0.35	−0.02	−0.46 – 0.41	0.11	−0.36 – 0.59	−0.22	−0.69 – 0.24
Physical functioning	0.00	−0.01 – 0.01	0.01	−0.00 – 0.01	0.00	−0.01 – 0.01	−0.00	−0.01 – 0.01
Health condition	0.00	−0.01- 0.02	0.01	−0.02 – 0.03	0.01	−0.02 – 0.03	0.01	−0.02 – 0.03
Marital Status (ref: Not married)	0.05	−0.10 – 0.20	0.10	−0.10 – 0.30	−0.05	−0.25 – 0.15	0.17	−0.06 – 0.39
Living arrangement (ref: Living with others)	0.14*	0.03 – 0.25	0.09	−0.07 – 0.25	0.04	−0.11 – 0.19	0.20	0.02 – 0.37
Depressive symptoms	0.00^{+}	−0.00 – 0.01	0.00	−0.00 – 0.01	0.00	−0.00 – 0.01	0.00	−0.00 – 0.01
Total number of sessions	0.00***	0.00 – 0.01	0.01***	0.00 – 0.01	0.00*	0.00 – 0.01	0.00*	0.00 – 0.01

Global Cognitive Performance: a composite measure of global cognition was obtained by averaging the standardized scores from the three cognitive tests

*$p<.05$

**$p<.01$

***$p<.001$

$^{+}$ $p<.10$

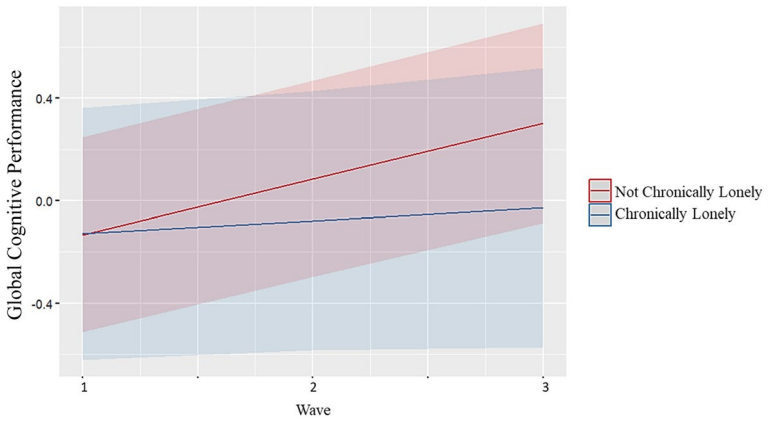

Fig. 1 Predicted changes in global cognitive performance across waves based on chronic loneliness (N = 172)

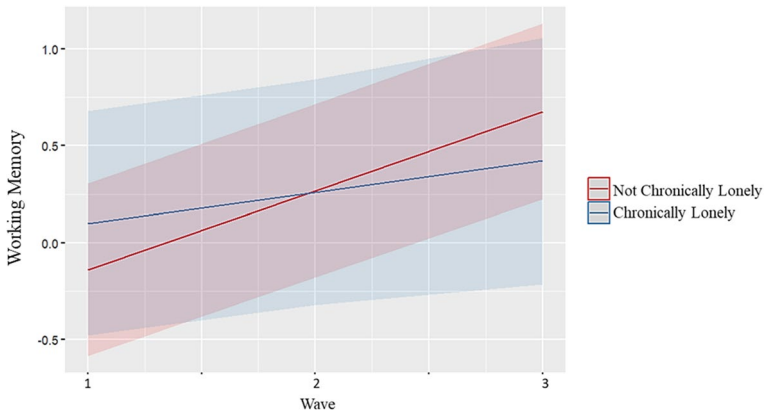

Fig. 2 Predicted changes in working memory performance across waves based on chronic loneliness (N = 172)

the not chronically lonely group demonstrated significant increases in processing speed performance across two years ($b = 0.17$, $p < 0.001$), but the chronic loneliness group did not significantly improve ($b = 0.00$, $p > 0.05$), which is shown in Fig. 3.

Spatial memory

Results showed that spatial memory performance significantly improved across bursts ($b = 0.07$, $p = 0.017$), after controlling for all the covariates. Chronic loneliness was not significantly associated with cognitive performance at baseline ($b = -0.19$, $p > 0.05$) or with the rates of change in cognitive performance ($b = -0.10$, $p > 0.05$).

Supplementary analyses

The main findings remained virtually unchanged after controlling for two additional indices of social relationships (social interaction and perceived social support) in the first set of supplementary analysis, except for results for Symbol search (Supplementary Table 1). After including social interaction and social support, the association between chronic loneliness and changes in Symbol search performance became significant (having been marginally significant in the main analyses). In the second set of supplementary analyses, we examined whether baseline loneliness was associated with changes in cognitive performance across waves. Results demonstrated no significant associations of baseline loneliness with baseline cognitive functioning (Global Cognitive Performance $b = 0.05$, $p > 0.05$; Working Memory $b = 0.35$, $p > 0.05$; Processing Speed $b = 0.18$, $p > 0.05$; Spatial Memory $b = -0.36$, $p > 0.05$) or the rate of change in cognitive functioning (Global Cognitive Performance $b = 0.02$, $p > 0.05$; Working Memory $b = -0.06$, $p > 0.05$; Processing Speed $b = -0.17$, $p > 0.05$; Spatial Memory $b = 0.13$, $p > 0.05$) (Supplementary Table 2). In the third set of supplementary analyses using tertile- and quartile-based chronic loneliness group, consistent patterns were found in these analyses, with the interactions between wave and chronic loneliness being significant for the working

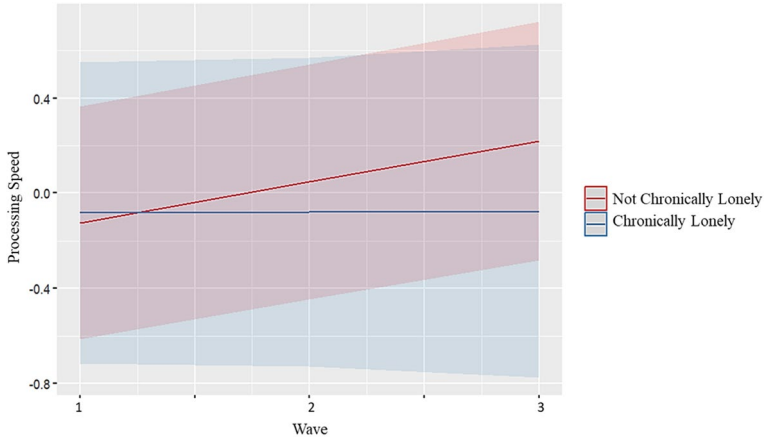

Fig. 3 Predicted changes in processing speed performance across waves based on chronic loneliness (N = 172)

memory tests (Supplementary Tables 3&4). Simple slope tests revealed that individuals classified as chronically lonely based on quartiles ($N=22$) and tertiles ($N=33$) showed significant but less improvement in working memory compared to the not chronically lonely group over the study period. These analyses demonstrate that the group differences in the rate of cognitive changes are consistent, with the chronically lonely group showing less improvement. Lastly, we tested for potential interaction by age and observed that age did not interact significantly with any cognitive performance indicator (Supplementary Table 5).

Discussion

This research aimed to investigate the association of chronic loneliness with changes in cognitive performance among young and middle-aged adults, utilizing ecologically valid and sensitive measures of cognition. Two key findings from the present study are discussed below.

Main analyses revealed that chronic loneliness was associated with a lack of change in cognitive performance over time, controlling for sociodemographic factors, subjective health indicators (physical functioning and health condition), objective measures of social isolation (marital status and living arrangement), depressive symptoms, and total number of sessions. These findings support our hypothesis and are consistent with previous research indicating a negative association between chronic loneliness and the rate of change in cognitive functioning [40–42]. Furthermore, supplementary analyses indicated that baseline loneliness was not linked to changes in cognitive functioning, highlighting the importance of persistent loneliness (and the need to operationalize "chronicity") for cognitive functioning in healthy young and middle-aged adults.

Despite the consistency in our main findings with previous research, our study also revealed unique insights. We observed an overall improvement in cognitive performance across waves, particularly among those who were not defined as chronically lonely. Given that our sample consisted of young and middle-aged adults, who still retain some degree of cognitive plasticity, it is possible that participants in our study experienced genuine cognitive improvement. Previous research has demonstrated that interventions like cognitive training, exercise, and brain games can enhance cognitive functioning in this population [67, 68]. Importantly, however, our study observed improvement without any intentional intervention, suggesting the presence of practice effects. Our findings indicate a discrepancy between groups in terms of less improvement in chronically lonely individuals across waves versus significant improvements observed in those who were not chronically lonely. Interestingly, this pattern resembles individuals with Alzheimer's disease (AD) biomarker positivity. Aschenbrenner and colleagues [69] revealed that cognitively normal individuals with AD biomarkers did not exhibit any practice-related gains in cognitive performance over time, unlike biomarker-negative individuals, suggesting that the gains associated with practice were "overshadowed" by the decline attributable to AD pathology. Similarly, Hassenstab and colleagues [58] found that those in the preclinical stage of AD did not show improvement over time, which suggests that lack of retest effects may serve as an early AD marker. Our findings align with these studies, suggesting a similarity between chronically lonely individuals and those in the preclinical stage of AD and the individuals with AD biomarkers. The negative impact of chronic loneliness on cognitive functioning may outweigh what are otherwise expected benefits of repeated testing. If our study were conducted with older adults, both chronically lonely and

non-lonely individuals might show cognitive declines over time due to normal aging; however, the decline might be more pronounced among chronically lonely individuals, as previous research has suggested, even though practice effects were not considered [40].

We did not find associations between chronic loneliness and baseline cognitive functioning, which helps rule out the possibility of reverse causality. Although the correlational nature of our study prevents us from establishing causal relationships, a lack of difference in baseline cognitive performance based on chronic loneliness during midlife – a period when age-related neurological decline is less common – indicates that cognitive impairment is less likely to be a direct cause of chronic loneliness. It suggests that chronic loneliness may be a risk factor for cognitive changes, rather than the other way around.

Moreover, young and midlife adults may not have accumulated sufficient duration of loneliness to manifest significant cognitive impacts at baseline. However, over time, as loneliness persists, its impact on cognitive function may become more detectable. Baseline differences in cognitive function linked with chronic loneliness observed in previous studies of older adults, with average ages of 76 and 64 years respectively [40, 41], likely reflect the cumulative effects of long-term loneliness experienced over years or decades prior to the study period, although specific information about loneliness history was not available.

Within our study, using sensitive cognitive measures, we observed chronic loneliness-related differences in subtle, small within-person changes in cognitive performance over a two-year period. These subtle differences in changes, while not significant enough to create noticeable baseline differences at this stage of life, suggest the beginning of a trajectory that could lead to more pronounced cognitive decline later in life. By focusing on younger and midlife adults, our study captured these early, subtle changes that may precede more significant cognitive decline. This approach underscores the potential importance of addressing loneliness early in life to mitigate its potential cumulative effects on cognitive health over the long term.

An absence of association between chronic loneliness and baseline cognition may also indicate that the effect of chronic loneliness is specific to the reduced ability to benefit from practice or retest, which cannot be evident at baseline. The finding that the chronically lonely group did not show the expected practice effects over time suggests that chronic loneliness may have a unique impact on an individual's cognitive abilities in response to repeated testing or practice. This sensitivity to the effects of chronic loneliness could potentially explain the lack of association between chronic loneliness and baseline cognition, as the differences may only become apparent when considering the patterns of cognitive change over time. These findings highlight the importance of further research to explore the specific mechanisms through which chronic loneliness may influence cognitive functioning, particularly in relation to practice effects and the ability to benefit from repeated testing.

Limitations and future directions

This study has several limitations, opening avenues for future research. Firstly, the loneliness questionnaire used at each wave lacked a specified time frame by design. Participants were asked to answer questions regarding how they feel about their relationships without explicit instructions about the time frame. This issue of not specifying the time frame of loneliness measured is quite common in the current literature, even in studies using well-known loneliness scales such as the revised UCLA Loneliness scale [65, 70]. This ambiguity may lead to participants' varying interpretations of loneliness duration, perceiving it to reference a few days, weeks, or even longer, potentially resulting in variations in the levels of chronicity or severity of loneliness, even among individuals in the chronic loneliness group in our study. To address this issue, future studies could benefit from including a clear time frame instruction in loneliness questions.

The current study cannot fully unpack the cognitive trajectories of individuals who experienced chronic loneliness as compared to those who did not. We observed that chronically lonely individuals displayed stagnant cognitive performance over time (a flat trend), whereas those who were not chronically lonely demonstrated some improvement. Although the lack of retest effects was demonstrated to be associated with AD biomarker positivity by Aschenbrenner and colleagues [69], our results as well as those from Hassenstab's study [58], showing less improvement among preclinical AD older adults, cannot definitively determine the underlying cause of differences in cognitive trajectories. The disparity in retest effects among chronically lonely individuals could be attributed to two possible factors: Either chronically lonely individuals have a lower ability to benefit from repeated testing, indicating an inability to learn from repeated exposure, or they do benefit from repeated testing, but this benefit is offset by an underlying latent cognitive decline. To address this uncertainty, future studies should include AD/ADRD biomarkers and employ methodologies that can distinctly separate retest/learning effects from longer-term decline processes. Regardless, our study demonstrates that the dynamic

aspects of cognitive performance related to retest gains are indeed sensitive to chronic loneliness.

Compared to previous studies on chronic loneliness and cognitive functioning that include over 2000 participants [40–42], the present research was conducted with a relatively small sample size due to the nature of intensive longitudinal study design; we thus chose not to create and separate the transient loneliness (being lonely at either wave) and no loneliness groups to maintain statistical power. However, having only 16 chronically lonely individuals in the study remains a limitation. We acknowledge that this small sample size requires careful interpretation of the findings and that replication in future studies is necessary. Moreover, previous studies have shown inconsistencies regarding the strength of transient loneliness effects, ranging from significant but less strong than chronic loneliness [40], to somewhat significant depending on duration [42] and even no significance [41]. Thus, it is worth examining the effect of transient loneliness on cognitive functioning with a larger sample, still using an EMA design, if feasible.

Another notable limitation of the present research is the lack of information on participants' prior experiences of loneliness, including the specific duration, intensity, and frequency of their loneliness before the study period. The variability in participants' histories regarding loneliness may have diluted the observable impact of chronic loneliness at baseline but could have become more pronounced over the study interval as loneliness was measured longitudinally. Future research incorporating comprehensive assessments of participants' lifelong loneliness experiences could provide deeper insights into the cumulative effects on cognitive health observed in older adulthood.

Importantly, our study was conducted using data collected prior to the COVID-19 pandemic, omitting potential pandemic-related loneliness impacts. A considerable number of participants in our study reported "never" experiencing loneliness on all of the six loneliness items (18% at burst 1, 26% at burst 2, 24% at burst 3). Replicating this finding in future research with a focus on collecting data during and after the pandemic would provide a reflection of more current circumstances and the potential changes in loneliness prevalence and levels.

Conclusion

Despite its limitations, the current study provides valuable insights into the impact of chronic loneliness on cognitive changes in healthy young and middle-aged adults, revealing that chronic loneliness predicts presymptomatic changes in cognitive function. Chronic loneliness has been identified as a significant risk factor for dementia, indicating its potential as an early indicator of emerging disease. By identifying the impact of chronic loneliness on cognitive changes within a shorter time frame, our findings highlight the importance of accurately predicting pre-symptomatic changes in both loneliness and cognitive functioning on an individual level [47]. The negative impacts of chronic loneliness on cognitive changes observed in the present study call for future research to investigate potential mechanisms through which chronic loneliness may affect neurocognitive health. These mechanisms include cognitive reserve depletion, limited cognitive engagement, health-compromising behaviors, and physiological dysregulation. The current dataset is not well-suited for examining these mechanisms, which will be a focus of our future work. In addition, our hope is that this and future research in this domain will prompt the development of targeted strategies to reduce loneliness and prevent it from becoming a chronic condition. Taking proactive measures to combat chronic loneliness during midlife may lead to more effective strategies in preserving cognitive function throughout the lifespan.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12889-025-22313-2.

Supplementary Material 1

Authors' contributions

JK and MS conceptualized the theoretical model and research questions. JK conducted the data analysis and led the writing of the manuscript. LM, JG, DA, and MS reviewed the manuscript, contributed to the writing of the manuscript, and made critical revisions of the manuscript for intellectual content.

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Data availability

The dataset from ESCAPE study is subject to the following licenses/restrictions: Interested collaborators are asked to complete a concept proposal form (details for potential project, paper, or abstract) to be reviewed and forwarded to the ESCAPE team for consideration (escapeosf@gmail.com). For additional information on data sharing requests for the ESCAPE study, see https://osf.io/4ctdv/.

Declarations

Ethics approval and consent to participate

The Albert Einstein College of Medicine of Yeshiva University ethical review board approved the ESCAPE study protocol.

Competing interests

The authors declare no competing interests.

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