Acta Psychologica 233 (2023) 103844

Contents lists available at ScienceDirect

Acta Psychologica

journal homepage: www.elsevier.com/locate/actpsy

Early- to late-life environmental factors and late-life global cognition in septuagenarian and octogenarians: The SONIC study

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A R T I C L E I N F O

Classification codes:
2800 Developmental Psychology
2860 Gerontology

Keywords:
Cognitive function
Cognitive plasticity
Cognitive reserve
Environmental complexity
Work complexity

A B S T R A C T

This study aimed to evaluate cognitively stimulating environments throughout life and to examine direct and indirect associations between these environments and late-life cognition. Early-life education, three domains of work complexity (data, people, and things) based on the longest-held occupation, and engagement in late-life leisure activities (LAs) were assessed. A structural equation model was developed using cross-sectional data of 1721 Japanese older adults in 70 ± 1 and 80 ± 1 years. The model confirmed significant direct effects of work complexity with data and late-life LAs on late-life cognitive performance. The associations of education and work complexity with late-life cognition were mediated through the subsequent environment(s). However, the total effects of work complexity with people and things on late-life cognition were insignificant. The findings suggest that cognitively stimulating activities in adulthood and beyond may lead to individual differences in late-life global cognition. In addition, antecedent complex environments might make subsequent life environments more cognitively stimulating. The results are discussed from the perspectives of cognitive plasticity and environmental complexity.

1. Introduction

This study examines the roles of life environment across one's life course—such as early-life education, mid-life work experience, and engagement in late-life leisure activity (late-life LA)—in late-life global cognition. These life environments have been frequently examined as psychosocial factors related to cognitive aging (Fratiglioni et al., 2020; Mangialasche et al., 2012). However, few studies have simultaneously modeled multiple life environments from past to present. Specifically, little research has considered the relationships among life environments. Therefore, this study takes such relationships into account and uses a simultaneous model to examine whether life environments from early to late life are directly or indirectly linked to late-life global cognition. This will lead to an understanding of intellectual development from a life-span perspective and the roles of environmental factors in late-life cognition.

1.1. *Cognitive plasticity*

Plasticity in life-span developmental psychology means that a person's development, for example, speed and timing of cognitive development, can change depending on his or her life conditions and experiences (Baltes, 1987). Concerning cognitive plasticity in later life, while cognitive abilities decline with age on average (Hilborn et al.,

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https://doi.org/10.1016/j.actpsy.2023.103844
Received 29 July 2022; Received in revised form 6 January 2023; Accepted 20 January 2023

2009; Myerson et al., 2010; Salthouse & Meinz, 1995), the finding that individual differences in late-life cognition increase (Christensen et al., 1994, 2010; Hilborn et al., 2009; Laplume et al., 2022; Morse, 1993) suggests that cognition has the characteristics of plasticity beyond adulthood. If constraints in adulthood, regardless of childhood circumstances, influence cognitive development, then the range of plasticity is likely to persist into adulthood.

1.2. Two perspectives explain individual differences in late-life cognition

Cognitive malleability has gained prominence in identifying the factors and mechanisms that preserve cognitive abilities in old age. Studies have examined cognitively stimulating activities or stimulating lifestyles mainly based on two points of view.

One is the neuropsychological perspective, including the hypotheses of brain maintenance (Nyberg et al., 2012), cognitive reserve (Scarmeas & Stern, 2003; Stern, 2009), and compensation (Cabeza, 2002; Reuter-Lorenz & Park, 2010). All three assume different mechanisms in the relationship between neural resources and cognitive demands, but all that intellectual stimulation allows humans to accumulate sufficient neural resources to perform cognitive tasks in old age (Cabeza et al., 2018; Stern et al., 2019).

The other is the behavioral perspective. Schooler (1984) proposed the theory of the psychological mechanism in which environmental complexity affects various subsequent psychological functions. In this idea, the complexity of an individual's environment depends on the characteristics of the stimuli or load. A complex environment can be defined as stimuli that require complex judgments and responses to ambiguity and uncertainty. In such cognitively stimulating environments, individuals are motivated to enhance their cognitive abilities and generalize their established cognitive processes to other different situations. Kohn and Schooler (1983) conducted a research project named "Work and Personality" and found that one aspect of occupational self-direction affects various aspects of subsequent behavior, including intellectual flexibility. The environmental complexity theory was also supported by other findings within the same projects (Schooler et al., 1999, 2004).

These two perspectives overlap, and both presume that older individuals who are cognitive-intact have been exposed to cognitively stimulating environments in the past. On the contrary, the cognitive plasticity perspective requires clarifying at what point in life stage exposure to intellectual stimulation is associated with individual differences in cognitive function in old age. The neuropsychological perspective emphasizes the importance of the extent of exposure to such environments throughout life (Cabeza et al., 2018; Stern et al., 2019). In addition, the environmental complexity theory suggests that the life environment indirectly influences outcomes, as cognitively demanding prior life stage conditions may result in such subsequent life stage conditions and then influence outcomes (Schooler, 1984). However, whether the influence of subsequent life environment remains is unclear, regardless of the conditions of the prior life stage. Furthermore, little work has been done to determine the mediating associations of early- and mid-life environments with late-life cognition.

1.3. Cognitively stimulating environments throughout life

This study focused on early-life education, mid-life work experiences, and engagement in late-life LAs as life environments that may cause individual differences in late-life cognition.

1.3.1. Early-life education

Education is a protective factor against cognitive decline. While results are inconsistent with the association between educational level and age-related changes in cognitive abilities (Seblova et al., 2020), longer education has been reported to be strongly related to a higher level of cognition (Opdebeeck et al., 2016; Seblova et al., 2020; Valenzuela & Sachdev, 2006b). For example, Wilson et al. (2009) indicated that people with 8 years of school education had significantly lower global cognition than those with ≥12 years of school education. This agrees with the findings that the frequency of dementia has substantially decreased from the 1980s to the 2010s in Europe and the United States (Wolters et al., 2020). This could be due to an increase in the education level of these countries.

1.3.2. Mid-life work experiences

Studies examining whether these differences in long-term occupational life are associated with individual differences in cognitive function in old age have received increasing attention with the increase in studies of cognitive reserve. Occupational indexes differ depending on the research. Most early studies related to cognitive reserve before the 2000s have used occupational classifications or occupational classes in their assessments (Valenzuela & Sachdev, 2006a, 2006b, 2007). More and more have considered the primary activities that workers are required to do their work. Many of these studies evaluated occupations in terms of their level of complexity.

Work complexity refers to the degree to which workers must make complex decisions to perform their work in relation to data, people, and things (United States Department of Labor, 1991). Scores on work complexity describe the degrees of complexity in judgments that workers exercise during the performance of their duties. The scores were defined by the U.S. Department of Labor based on the premise that every job requires a worker to function, to some degree, with three domains: data, people, and things (see the details: https://occupationalinfo.org/appendxb_1.html). First, "data" divides jobs into seven levels of complexity in terms of information processing. The complexity of data is high when decisions must be made integral using words, numbers, symbols, ideas, or concepts. Second, the complexity in "people" has nine levels, in which jobs that require following instructions or orders have low complexity, and jobs that require negotiating or mentoring have high complexity. Third, "things" have eight levels of complexity: jobs that involve no judgment about the movement or selection of objects, tools, or materials are of low complexity; whereas jobs that involve planning the sequence of operations based on the capabilities of machines or characteristics of materials are of high complexity.

Although results differ depending on outcomes, a review paper by Then et al. (2014) summarized the protective effects of high occupational complexity with data and people at risk of cognitive decline and dementia. Studies using the Mini-Mental States Examination (MMSE) indicated that the greater the work complexity with data or people, the higher the cognitive performance (Andel et al., 2007; Andel et al., 2015).

The effect of work complexity with things remains inconsistent. Some studies have shown positive relationships between levels of work complexity with things and cognitive health, including risk of vascular dementia (Kröger et al., 2008) and MMSE scores (Correa Ribeiro et al., 2013). However, others found no relationship between these (Andel et al., 2007; Andel et al., 2015; Dekhtyar et al., 2015; Dekhtyar et al., 2016; Finkel et al., 2009; Ishioka et al., 2015). Furthermore, Lane et al. (2017) observed a negative association between levels of work complexity with things and cognitive performance.

Such inconsistent findings could be due to the low reliability and validity of scores on things. In their early study, Cain and Green (1983) reported that the reliability of work complexity with things was lower than that of data. Kröger et al. (2008) also mentioned the difficulty of evaluating occupations in terms of things because the domain covers several tasks, from the movement, such as acupuncturists who do not directly use tools, to the operation of small tools such as kitchen knives and large machines such as cranes. In summary, studies have suggested that occupation plays a role in cognitive decline, although results vary by outcome or dimension of work complexity.

1.3.3. Late-life LA

Engagement in late-life LAs is a typical component of the life environment after retirement. LAs can be defined as activities one spends time doing outside work and household chores (Verghese et al., 2006). Unlike work and childcare, which are obligatory activities, LAs allow for a great deal of choice according to individual preferences and conditions. In reviews of longitudinal studies (Hertzog et al., 2008; Yates et al., 2016), most of the studies confirmed the protective effects of late-life LAs on cognitive impairment and dementia.

The ways to evaluate and categorize various LAs to examine their relationship to cognitive function vary by study. A method focuses on specific LAs and asks about the frequency of the activity and the experience of doing it (Christensen et al., 1996; Fabrigoule et al., 1995). Methods have been used to categorize activities based on similarities, such as physical activity and hobbies, and verify the relationship between cognitive function and each category (Dodge et al., 2008; Helzner et al., 2007; Kozono et al., 2016). Some studies have also evaluated variations in late-life LAs (Ihle et al., 2015; Kinjo & Shimizu, 2018; Sala et al., 2019).

Hertzog et al. (2008) proposed the cognitive-enrichment hypothesis, which suggests that a physically and intellectually active lifestyle promotes healthy cognitive aging. Physical, social, and cognitive activities, each of which may independently affect cognition, may also interact with each other. According to Hertzog et al. (2008) review, many observational studies have treated activity as one-dimensional. Therefore, based on this hypothesis, the current study focuses not on types of activities but on a diversity of activities in later life, including multiple activities.

1.3.4. Studies that include multiple life environments throughout a lifetime

Three main types of models include the life environments of different life stages: separate models (Foubert-Samier et al., 2012; Ihle et al., 2018; Wang et al., 2017), simultaneous models (Andel et al., 2015; Andel et al., 2016; Richards & Sacker, 2003; Wang et al., 2017), and composite factor models (Lavrencic et al., 2018; Wang et al., 2017). Studies classified as simultaneous model studies have contained different life environments across the life-span. Richards and Sacker (2003) assessed cognitive abilities at 53 years as the outcomes and showed a strong internal path from educational attainment to occupation, whereas independent paths from childhood cognition and educational attainment to the cognitive abilities were stronger than those from the occupation. By contrast, Wang et al. (2017) showed, using a simultaneous model, that only the late-life factor remained significantly associated with a reduced risk of dementia after including factors of early life and adulthood. Andel et al. (2015) also found that work complexity with data and people and engagement in cognitive or social LAs were independently related to cognition. In addition, when engagement in late-life LAs was above the average, the effects of work complexity were weaker. Furthermore, Andel et al. (2016) suggested the importance of LA engagement in those who have retired from less complex occupations. Therefore, based on the results of Andel et al. (2015), Andel et al. (2016) and Wang et al. (2017), it can be assumed that cognitive plasticity remains in adulthood and beyond. Life circumstances in close temporal proximity may influence late-life cognition.

1.4. The current study

This study examined two main objectives: (1) whether the life environment from early to late life is directly associated with individual differences in cognitive function in old age and (2) whether subsequent life circumstances mediate the effect of education on late-life cognition. By examining the relationships among life environments using a structural equation model, we expect to deepen the interpretation of the plasticity of intellectual development and environmental complexity.

2. Methods

2.1. Participants

The study data consisted of two cohorts of Japanese older adults by age range: 69–71 years and 79–81 years. The data used were from the Septuagenarians, Octogenarians, Nonagenarians Investigation with Centenarians (SONIC) study. The project aimed to explore the factors that contribute to healthy longevity, focusing on psychological, medical, and oral health. We used baseline data from groups aged 70 and 80 years in the SONIC study.

2.2. Procedure

Participants were recruited from the municipalities' residential basic books from the four survey areas: Itami City and Asago City in Hyogo, and Itabashi ward and Nishitama county in Tokyo. Venue surveys were conducted in each of the study areas. Details of the survey design were reported by Gondo et al. (2016).

The 70- and 80-year-olds were enrolled for each initial survey in 2010 and 2011, respectively. Self-administered questionnaires were distributed to ask about participants' demographic information, longest-held job, psychosocial variables, medical conditions, dental conditions, diet, and lifestyle. Cognitive assessments and interviews were conducted at the survey venue. A total of 1000 volunteers participated in the 70-year-olds survey and 973 in the 80-year-olds survey (participation rates, 23.2 % and 16.3 %, respectively).

This study was conducted in accordance with the guidelines laid in the Declaration of Helsinki. The study was approved by the Institutional Review Board of Osaka University Graduate School of Medicine, Dentistry and Human Sciences and the Tokyo Metropolitan Institute of Gerontology (approval nos. 266, 22041, 22018, and H31-E2). All study participants were informed of the purpose of the study and the protection of their personal information and gave written informed consent before participating in the study.

2.3. Measures

2.3.1. Global cognition

The Japanese version of the Montreal Cognitive Assessment (MoCA-J) (Fujiwara et al., 2010) was administered. The MoCA is a valid instrument for screening for mild cognitive impairment (Nasreddine et al., 2005) and for assessing global cognition in older adults (Sala et al., 2020). The total MoCA-J score ranges from 0 to 30, with higher scores indicating higher cognitive function.

2.3.2. Late-life LA

For the late-life stage, participants were asked to answer yes/no to questions regarding their engagement in 158 activities in the past year (Kozono et al., 2016). These activities were organized into 12 leisure categories according to types of activities, such as physical activities, games, and so on. Scores for each category were summed. Moreover, these categories were used to perform a confirmatory factor analysis of one latent factor model using AMOS 28 software. A latent factor model consisting of the following eight observed leisure categories was extracted using confirmatory factor analysis: (1) physical activities, (2) games, (3) personal social activities, (4) public social activities, (5) developmental activities, (6) hobbies, (7) use of technology, and (8) traveling. The following four activities were excluded from the model, as the factor loadings were <0.30: watching TV and/or listening to the radio, repairing and/or assembling, religious activities, and rest and or relaxation. The goodness of fit statistics indicated that the model was reasonable, χ^2 [9] $= 6.904$, $p = 0.647$; comparative fit index $= 1.000$; goodness of fit $= 0.999$; adjusted goodness of fit index $= 0.996$; root mean square error of approximation $= 0.00$. Higher values for the latent factor score indicate greater diversity of activities.

2.3.3. Mid-life work experiences

For the mid-life stage, we retrospectively evaluated the work complexity with three dimensions of data, people, and things based on the information about the occupations in which the participants worked the longest in their lives. The respondents answered a questionnaire about the occupations in which they worked the longest: starting age, ending age, job title, industry, size of employment at the company/office, and whether they were involved in management tasks. Semi-structured interviews about the details of their longest job task were conducted at the survey venue.

Psychosocial factors at work can vary by occupation, work environment, and individual. The work complexity scores for each dimension are composed of three indicators: (a) job title-based scores, (b) content-based scores, and (c) effort-based scores (Ishioka et al., 2015). For (a) the job title-based scores, researchers determined the participants' longest job titles based on the questionnaire and the interview. Nagamatsu et al. (2009) classified job titles into 188 job categories (e.g., rice retailers and fish store owners are classified into the retail store owner category) and estimated the Japanese version of the Dictionary of Occupational Titles (DOT) scores from the U.S. DOT scores (Cain & Treiman, 1981). The participants' longest job titles for this study were categorized corresponding to the 188 job categories, and work complexity scores of data, people, and things by Nagamatsu et al. (2009) were applied. The job titles that fell into the same job category have the same values for the job title-based scores. For (b) the content-based work complexity score, semi-structured interviews were conducted based on the questionnaire, asking for details of the main job content in which they were involved, regardless of their job titles. Trained interviewers evaluated the level of content-based work complexity based on the scale defined by the U.S. Department of Labor (Appendix A): complexity of work with data (0–6), people (0–8), and things (0–7), indicating that the higher the scores, the greater the complexities. The content-based job complexity scores can have different values for participants with the same job category. Lastly, for (c) the effort-based score, participants were asked to rate on a 5-point scale from "not at all (1)" to "very much (5)" the degree to which specialized knowledge and skills were necessary or the degree to which judgment was required under the situation in each of the three dimensions (Appendix B). The effort-based job complexity scores can take different values for participants with the same content-based job complexity scores. Ultimately, all scores were converted to Z scores, and they were summed to the dimensions of data, people, and things. Higher values correlated with more complex work in each dimension.

2.3.4. Early-life education

For the early-life stage, education level was used to classify the participants into the following three groups: (1) less than high school, (2) high school, and (3) college/postgraduate.

2.3.5. Control variables

Age, sex, and childhood abilities were included as control variables. Language and arithmetic abilities during elementary school were each evaluated on a three-point scale, namely, (1) below average, (2) average, and (3) above average (Dekhtyar et al., 2016).

2.4. Data analysis

Respondents with missing values for variables used in the model were excluded ($N = 252$). With their exclusion, our analytical sample was based on 1721 participants. First, descriptive information and correlational coefficients between all study variables were presented. Then, a structural equation model was formed. Fig. 1 shows a conceptual model consisting of all variables. The variables childhood ability and work complexity contain two and three variables, respectively, but are not shown in the figure for simplicity. Solid lines show the paths of interest in this study. The dashed lines show the paths from the control variables to the variables of interest. The goodness of fit statistics indicated that the model was reasonable, χ^2 [78] = 411.564, p = 0.000; comparative fit index = 0.955; goodness of fit = 0.973; adjusted goodness of fit index = 0.947; root mean square error of approximation = 0.50. Indirect (mediating) relationships among environmental factors from early to late life were also examined using 5000 bootstraps. IBM SPSS Statistics for Windows, version 28 and AMOS 28 (IBM Corp., Armonk, NY, USA) were used for all statistical analyses. Values of $p <$

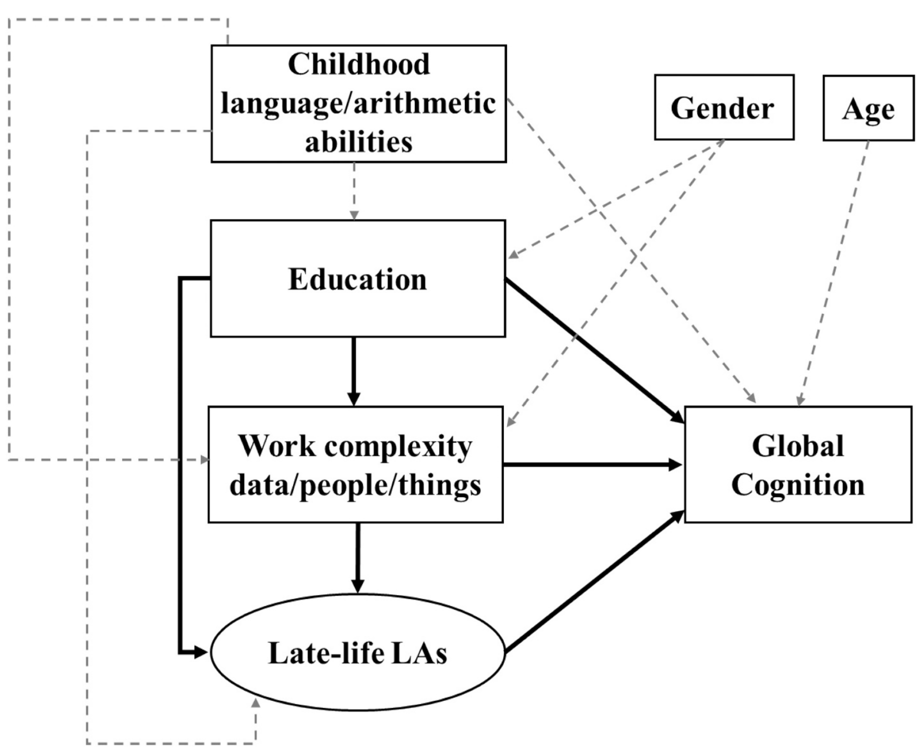

Fig. 1. Conceptual model containing all variables used.
Note. The rectangle named childhood abilities contains two variables: language and arithmetic abilities. The rectangle named work complexity contains three variables: work complexity data, people, and things. But these variables are not shown for simplicity. The oval named late-life LAs refers to a latent score consisting of eight observed leisure categories. Solid lines show the paths of interest in this study. The dashed lines show the paths from the control variables to the variables of interest.

0.05 were considered significant.

3. Results

3.1. Descriptive statistics and bivariate analyses

Table 1 shows the descriptive results of the study variables. Table 2 presents the results of correlational coefficients among the variables. The results showed that MoCA-J correlated significantly with all variables except work complexity with things and sex (late-life LAs: $r = 0.302$, $p < 0.001$; work complexity with data: $r = 0.264$, $p < 0.001$; work complexity with people: $r = 0.217$, $p < 0.001$; work complexity with things: $r = 0.005$, *ns*; education: $r = 0.235$, $p < 0.001$; childhood language ability: $r = 0.306$, $p < 0.001$; childhood arithmetic ability: $r = 0.325$, $p < 0.001$; age: $r = -0.252$, $p < 0.001$; sex: $r = 0.035$, *ns*). Among life environments, work complexities with data and people positively correlated with education ($r = 0.477$, $p < 0.001$; $r = 0.450$, $p < 0.001$, respectively), whereas work complexity with things slightly negatively correlated with education ($r = -0.067$, $p < 0.001$). Late-life LAs significantly correlated with education ($r = 0.321$, $p < 0.001$) and work complexities with data ($r = 0.343$, $p < 0.001$) and people ($r = 0.311$, $p < 0.001$) but not with work complexity with things ($r = 0.041$, *ns*).

3.2. Direct paths from education, work complexity, and late-life LAs to MoCA-J (Fig. 2)

Fig. 2 only indicates the variables of interests. The numerical values in the figure show standardized coefficients. Significant pathways from late-life LAs ($\beta = 0.125$, $p < 0.001$) and work complexity with data ($\beta = 0.145$, $p < 0.001$) to MoCA-J were observed. The path from education was marginally associated with a higher score in the MoCA-J ($\beta = 0.044$, $p = 0.085$). Work complexity with people ($\beta = -0.055$, $p = 0.144$) and things ($\beta = -0.033$, $p = 0.136$) were not significantly directly related to the outcome. Two pathways from childhood abilities to the outcome were significant (not shown in Fig. 2: childhood language ability: $\beta = 0.138$, $p < 0.001$; childhood arithmetic ability: $\beta = 0.142$, $p < 0.001$).

3.3. Indirect paths to MoCA-J (Fig. 2b and c)

Four pathways from education were significant (Fig. 2b). The paths from education to work complexity with data ($\beta = 0.378$, $p < 0.001$) and people ($\beta = 0.362$, $p < 0.001$) were stronger than the path from education to late-life LAs ($\beta = 0.116$, $p < 0.001$). However, the path from education to work complexity with things was negative ($\beta = -0.086$, $p < 0.001$). On the other hand, the model (Fig. 2c) showed that the three variables of work were positively associated with late-life LAs (data: $\beta = 0.206$, $p < 0.001$; people: $\beta = 0.097$, $p = 0.02$; things: $\beta = 0.071$, $p = 0.004$).

Table 1
Results of the descriptive statistics ($N = 1721$).

	Mean	SD	Min	Max
MoCA-J	22.6	3.7	4.0	30.0
Late-life LAs	9.7	5.9	0.0	37.0
Work complexity (data)	0.0	2.6	−5.0	4.9
Work complexity (people)	0.0	2.4	−5.0	5.9
Work complexity (things)	0.0	2.1	−5.5	4.6
Education	2.0	0.8	1.0	3.0
Childhood language ability	2.3	0.6	1.0	3.0
Childhood arithmetic ability	2.2	0.7	1.0	3.0
Age (year)	75.0	5.0	69.0	82.0
Gender (women)	848 (49.3 %)			

Note: MoCA-J: the Japanese version of the Montreal Cognitive Assessment, Late-life LAs: the mean of the eight observed categories of late-life leisure activities, Work complexity: all three indicators were converted to Z scores, and they were summed for each dimension, Gender: number of women and percentage is shown in parentheses.

Bootstrapping analyses evaluated the four mediating associations (Table 3). The findings showed that the association between education and MoCA-J was mediated through the three variables of work complexity and late-life LAs ($\beta = 0.066$, $p < 0.001$). The total effect was significant ($\beta = 0.110$, $p < 0.001$). For each domain of work complexity, mediation was also found for late-life LAs and MoCA-J (data: $\beta = 0.026$, $p < 0.001$; people: $\beta = 0.012$, $p = 0.014$, things: $\beta = 0.009$, $p < 0.004$). The total effect of work complexity with data was significant ($\beta = 0.171$, $p < 0.001$). However, those of work complexity with people and things were insignificant (people: $\beta = -0.043$, $p = 0.249$, things: $\beta = -0.024$, $p = 0.262$).

4. Discussion

The direct and indirect effects of the life environment, including early-life education, mid-life work experiences, and late-life LAs, on late-life global cognition were examined using the structural equation model. Results showed that for older adults composed of septuagenarians and octogenarians, work complexity with data and late-life LAs had significant direct effects on global cognition. Additionally, the relationships between antecedent life environments and late-life cognition were mediated through the subsequent life environments.

4.1. Direct effects of life environment on late-life global cognition

Many studies have reported that the effect of early-life factors, especially education, on the level of cognitive function was robust (Seblova et al., 2020). Using a path model, Richards and Sacker (2003) showed that strong effects of education on the cognitive abilities in the 50s were stronger than the effect of occupation. In our study data, a positive relationship was found with education, but only marginally. Rather, even after controlling for education and other demographics, the environment of adulthood and beyond, such as high complexity of work with data and diverse LAs, were significantly associated with better global cognition in old age. This suggests that features of developmental plasticity may emerge even in adulthood and beyond, as shown by Andel et al. (2015), Andel et al. (2016) and Wang et al. (2017). Regardless of childhood factors, environments in adulthood may lead to individual differences in cognitive function in later life.

Our results indicated that independent of late-life LAs, older individuals who had worked with more complex data in their longest jobs had higher cognitive function. In jobs with high data complexity, one must analyze various types of data to solve problems, research, develop, and create. From a neuropsychological perspective, exposure to such stimulation in adulthood may provide sufficient neural resources to perform cognitive tasks in old age. For work complexity with people and things, the direct effects on the outcome were insignificant in the analytical model. Andel et al. (2015) showed that the effects of work complexity, especially work complexity with people, were weaker, especially if their participation in social activities was higher than the average. In other words, the association between work complexity with people and cognition was moderated by leisure activity. This current research focused on the mediating associations; however, moderating variables should also be considered to examine work complexity's direct effects in more detail.

4.2. Indirect effects of life environment on late-life global cognition

According to the environmental complexity theory (Schooler, 1984), antecedent complex environments lead to complex environments in subsequent life environments. In the present findings, the theory was largely supported by the observation that all pathways from antecedent environments to subsequent environments were positive and significant, except for the only path from education to work complexity with things. First, for the paths from education to mid-life work experience, the higher the education, the more complex the jobs with data and people.

Table 2
Correlations among variables ($N = 1721$).

		1	2	3	4	5	6	7	8	9
1	MoCA-J	–								
2	Late-life LAs	**0.302****	–							
3	Work complexity (data)	**0.264****	**0.343****	–						
4	Work complexity (people)	**0.217****	**0.311****	**0.814****	–					
5	Work complexity (things)	0.005	0.041	**0.115****	0.003	–				
6	Education	**0.235****	**0.321****	**0.477****	**0.450****	**−0.067****	–			
7	Childhood language ability	**0.306****	**0.301****	**0.264****	**0.248****	**−0.061***	**0.317****	–		
8	Childhood arithmetic ability	**0.325****	**0.294****	**0.305****	**0.271****	0.006	**0.309****	**0.580****	–	
9	Age (year)	**−0.252****	**−0.171****	**−0.062****	**−0.066****	**−0.092****	**−0.055***	−0.031	**−0.079****	–
10	Gender (−1: men, 1: women)	0.035	0.014	**−0.428****	**−0.389****	**−0.236****	**−0.084****	0.039	−0.043	−0.015

Note: The correlations significant at $p < 0.05$ level are in bold. **$p < 0.01$, *$p < 0.05$, MoCA-J: the Japanese version of the Montreal Cognitive Assessment, Late-life LAs: a latent score consisting of eight observed leisure categories, Gender: the values −1 for male and 1 for female were assigned.

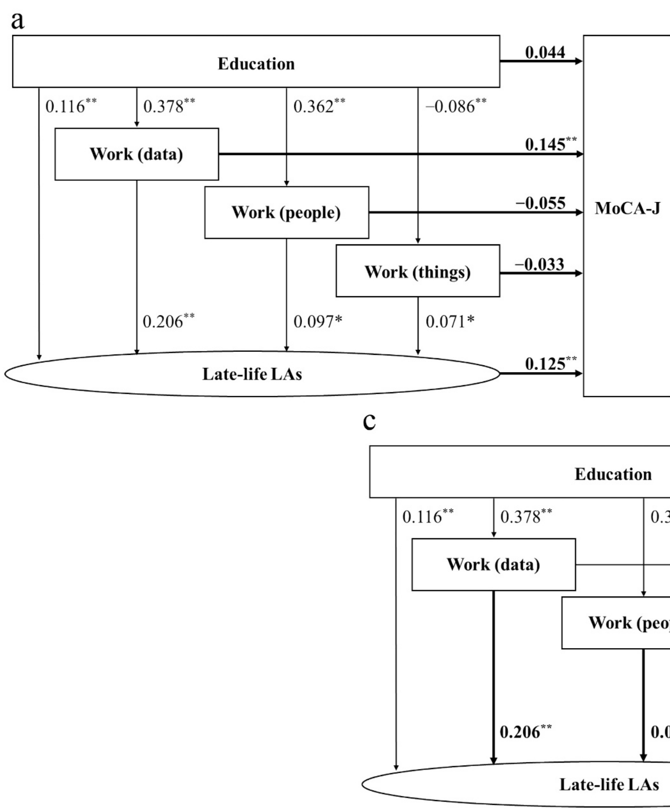

Fig. 2. a. The direct paths from education, work complexity with data, people, and things, and late-life LAs to MoCA-J.
b. The paths from education to work complexity with data, people, and things, and late-life LAs.
c. The paths from work complexity with data, people, and things to late-life LAs.
Note: This figure only indicates the variables of interests. **$p < 0.01$, *$p < 0.05$, MoCA-J: the Japanese version of the Montreal Cognitive Assessment, Late-life LAs: a latent score consisting of eight observed leisure categories.

Table 3
Indirect pathways to MoCA-J.

	Regression coefficients (CI)
Education → Work (data, people, things) → Late-life LAs	0.107 (0.084, 0.132)**
Education → Work (data, people, things) → Late-life LAs → MoCA-J	0.066 (0.043, 0.09)**
Work (data) → Late-life LAs → MoCA-J	0.026 (0.012, 0.045)**
Work (people) → Late-life LAs → MoCA-J	0.012 (0.002, 0.028)*
Work (things) → Late-life LAs → MoCA-J	0.009 (0.003, 0.018)*

Note: Regression coefficients are standardized regression coefficients. CI = 95 % confidence interval. **$p < 0.01$, *$p < 0.05$, MoCA-J: the Japanese version of the Montreal Cognitive Assessment, Late-life LAs: a latent score consisting of eight observed leisure categories.

Abstract thinking and deductive reasoning in higher education may have led to the accomplishment of jobs that required making decisions considering ambiguous situations and relationships. From a societal perspective, greater complexity with data and people is more likely to be found in specialist or administrative workers. Thus, it may be reasonable to assume that these relationships between education and mid-life work complexity are due to sociological factors. Additionally, regarding work complexity with things, practical rather than academic skills are required, and manipulation and hand movements should be trained according to actual machines, devices, and materials used. Therefore, work complexity with things was not greatly related to the educational background. Rather, a negative correlation was found between education and complexity with things, as management positions are considered less complex with things.

Second, a weak but positive relationship for the path from education to late-life LAs was found. Compared with job choices, LAs can be influenced by personal interests and preferences. It is thought that the more highly educated people are, the more curious they are to engage in diverse LAs at older ages. A qualitative examination of education and late-life LAs may reveal more details about the mechanisms of the pathway from education to late-life LAs.

Third, interestingly, all mediating pathways from the three domains of mid-life work complexity to late-life LAs were positive and significant. Hence, the higher the complexity of work with data, people, or things, the more diverse the late-life LAs. Unlike the results of previous studies (Andel et al., 2007; Correa Ribeiro et al., 2013; Finkel et al., 2009; Kröger et al., 2008; Lane et al., 2017), no direct and total effects of work complexity with people and things on late-life cognition were found. However, our findings suggest that mid-life work complexity, including all dimensions, can promote a more active lifestyle in a subsequent life stage. In other words, regardless of the domains, the experience of working with a high degree of complexity, such as that involved in managing uncertainty, encouraged them to engage in diverse activities outside work. Concerns have been raised about the validity of work complexity score on things (Cain & Green, 1983; Kröger et al., 2008). Although there are areas for improvement, our results provide some support for the construct validity of work complexity with things.

4.3. Study limitations

This study has four limitations. First, because of the cross-sectional nature of the data, the possibility of reverse causation cannot be ruled out. That is, the higher the global cognitive function, the more diverse the activities may be (Schooler et al., 1999). This causality should be clarified in future longitudinal studies. Additionally, we only examined the level of cognition. Results on the association between educational level and age-related changes in cognitive abilities are inconsistent (Seblova et al., 2020). Clouston et al. (2020) used several databases for replication and demonstrated that education was associated with a delayed onset of accelerated declines in episodic memory, where they did not replicate the finding that the rate of the accelerated cognitive decline was faster in more educated individuals. In summary, the use of longitudinal data allows us to examine the relationships between life environment and cognitive decline as well as the cognition level.

Second, all participants were healthy enough to take part in the venue survey by themselves. Therefore, the results should be interpreted with caution, especially when applying these to individuals with lower functioning. Third, we assessed diversity as an evaluation of late-life LAs. LAs, like work experiences, could be examined by measuring the content of activities, such as physical, social, and cognitive activities (Wang et al., 2017), to examine which activities are associated with cognitive function. Moreover, social interaction or social isolation in later life has been reported to be moderately related to late-life cognitive function (Evans et al., 2019; Kuiper et al., 2015). Late-life LAs and social interaction can be comprehensively assessed.

Lastly, this study used only education as the early-life environment related to late-life cognition. However, the effects of early-life activities (e.g., music, art, sports, language learning) other than education on cognitive health have been indicated. Crane et al. (2022) and Morris et al. (2021) assessed a variety of enriching early-life activities during adolescence and revealed the positive associations between early-life activities and late-life cognition and subcortical functioning. In addition, it was found that the negative effects of adverse childhood experiences (e.g., abuse, parental divorce) on cognitive health in young and middle-aged adults (Hawkins et al., 2021; Ji & Wang, 2018). Therefore, it is necessary to evaluate enriching and adverse early-life experiences from perspectives other than educational background and to consider the long-term effects. The life course during adulthood and beyond is also becoming more diverse. Other life domains, such as housework, mid-life LAs, and late-life work experience, also need to be evaluated. The assessment method also should be taken into account when considering diverse life environments. To scrutinize the environmental complexity theory, there is a need to use a more consistent definition and operationalization of the life environments across life stages.

5. Conclusions and contributions

This study indicated older adults with a high level of work complexity with data and various late-life LAs might have a higher level of late-life cognition. Furthermore, older adults with work complexity with data, people, or things might have a lifestyle with more diverse activities in later life. These results may support environmental complexity because such individuals may be motivated to perform various activities in later life, which cognitive decline might be suppressed. Cognitively stimulating lifestyles are formed throughout life and can lead to improved cognitive health.

Funding

This study was supported in part by grants-in-aid from the Ministry of Education, Culture, Sports, Science, and Technology of Japan (Y.G.: 18K18456, 17H02633, and Y.I.: 19K14390).

Declaration of competing interest

All authors acknowledge there are no competing interests with the publication of this article. All authors have agreed to the published version of the manuscript.

Data availability

Data will be made available on request.

Acknowledgments

We would like to thank the participants and team members for taking part in the SONIC study. In addition, we gratefully thank Acta Psychologica, the reviewers, and the Special Issue Guest Editor for their helpful input and feedback on the content of this manuscript.

Appendix A. Levels of the content-based work complexity

Data	People	Things
6 Synthesizing	8 Mentoring	7 Setting Up
5 Coordinating	7 Negotiating	6 Precision Working
4 Analyzing	6 Instructing	5 Operating-Controlling
3 Compiling	5 Supervising	4 Driving-Operating
2 Computing	4 Diverting	3 Manipulating
1 Copying	3 Persuading	2 Tending
0 Comparing	2 Speaking-Signalling	1 Feeding-Offbearing

(*continued on next page*)

(*continued*)

Data	People	Things
	1 Serving 0 Taking Instructions-Helping	0 Handling

Note: Interviewers evaluated the participants' work complexity based on their specific duties. See the details: https://occupationalinfo.org/appendxb_1.html

Appendix B. Statements for the effort-based work complexity

For each of the three dimensions of work in which you worked the longest, which degree of specialized knowledge and skills was necessary or which degree of judgment was required in a given situation?

1 (Data) Writing, reading or analyzing.
2 (People) Interacting with people, such as customers, supervisors, coworkers, subordinates, etc.
3 (Things) Use your hands, tools, or machinery, or perform repairs.

Response options range from "not at all (1)" to "very much (5)."

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