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RESEARCH ARTICLE

Dynamic neurocognitive adaptation in aging: Development and validation of a new scale

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Abstract

INTRODUCTION: Forty-five percent of Alzheimer's disease (AD) cases may have been preventable through protective factors. Reserve, resilience, and resistance share common neurocognitive adaptive processes, acting through protective mechanisms. In this article we propose the development and validation of a new scale, called dynamic Neurocognitive Adaptation, developed in this direction.

METHODS: We included 815 participants (50% women; 65+ years inclusive of age), divided into two subsamples for exploratory and confirmatory factor analysis. Our initial scale was composed of 30 items, investigating seven dimensions, explored by a 5-point Likert scale reflecting the frequency of activities, for seven time windows.

RESULTS: Our final scale had 20 items divided among four dimensions: physical, cognitive, creative, and social. There were no issues related to multi-collinearity or non-collinearity. Kaiser–Meyer–Olkin (KMO) = 0.80 and Bartlett's test of sphericity indicated all values $\leq$0.01; Cronbach's alpha = 0.83.

DISCUSSION: We have validated a reliable, novel, easy to complete, and comprehensive scale to assess lifetime behaviors, which can be applied in research on AD risk reduction, mild cognitive impairment, and in clinical practice.

KEYWORDS
activities, adaptation, dynamic, neurocognitive, prevention, reserve, resilience, resistance, validation, well-being

Highlights

- Reserve, resistance, and resilience share similar adaptive mechanisms.
- Dynamic Neurocognitive Adaptation is a new scale to assess lifetime protective factors.
- Dynamic Neurocognitive Adaptation is a reliable, novel, and easy to complete scale.
- This approach can characterize specific life stages that are ripe for risk-reduction interventions.
- Our scale can be used to personalize health recommendations in aging.

1 | BACKGROUND

The World Health Organization (WHO) defines healthy aging as the composite of all the physical and mental capacities that an individual can draw on at any point in time. Good and healthy aging is a process of developing and maintaining the functional ability that enables well-being in older age.[1]

The plasticity of the human brain and the adaptability of our neurocognitive system are the bases of our success as a species, and has helped us to expand our life expectancy at birth from age 47.3 in 1900 to 78.7 in 2010.[2] This increase in longevity, however, brings an increase in risk for neurocognitive frailty, the most significant threat to successful aging in our society,[3] with more than 6 million Americans currently living with Alzheimer's disease (AD). By 2050, this number is projected to rise to nearly 13 million.[4] Fortunately, 45% of current AD cases may have been preventable.[5]

Physical, cognitive, and social activities may prevent or slow age-associated neurodegeneration and cognitive decline.[6] The concept of *reserve* is based on considerable heterogeneity in the severity of symptoms and speed of deterioration in patients with AD. That is, even in the presence of Alzheimer's neuropathology, many patients maintain their cognitive abilities.

The concept of reserve has a dualistic view, divided into two branches. First, *brain reserve*, mostly based on the physical/structural characteristics of the brain, acts as a protective factor against the expression of pathology. This *physical* factor was initially focused on measures such as size of the head,[7,8] or brain,[9] and the size and number of neurons and synapses,[10] and later extended to include cerebral blood flow,[11] cortical thickness,[12] white matter tract integrity,[13] hyperintensities,[14] and amyloid presence.[15] The second branch is called *cognitive reserve*, and it refers to individual cognitive features and achievements. Cognitive reserve was initially based on years of education[16] and intelligence quotient (IQ),[17] and subsequently has also included leisure activities.[18,19] Nevertheless, IQ and educational attainment are considered reliable proxies for cognitive reserve.[20]

On the other hand, adaptation is the adjustment of organisms to their environment to improve their chances to survive and improve their well-being. Humans are plastic organisms, exposed to a complex, plastic environment, changing dynamically through time. When people are exposed to an enriched environment—which we could establish as based on physical, cognitive, creative, and social dimensions—they are exposed to more complexity, thereby increasing their brain plasticity and their chances of better adaptation to aging.

Physical activity is an example of exposure to complexity, and it can alleviate symptoms of neurodegenerative diseases and delay pathological progression,[21] confirming a close connection between exercise and the immune system.[22] Involvement in these activities is correlated with an improvement in musculoskeletal health and function, preventing cognitive decline, and reducing symptoms of depression and anxiety.[23,24]

Our term "dynamic" points out the need to consider *time* in the adaptation process, to better understand sensitive windows in adaptation, based on the complexity of the environment and adaptation to this complexity.

RESEARCH IN CONTEXT

1. **Systematic review**: The authors reviewed the literature using traditional (e.g., PubMed) sources and meeting abstracts and presentations. Although the concepts of reserve and resilience are generally shared by the neuroscientific community, their common adaptative mechanisms are less explored. These aspects were appropriately investigated.
2. **Interpretation**: These findings led to a reliable, novel, easy to complete, and comprehensive means of assessing lifetime adaptive behaviors, which can be applied in research in Alzheimer's disease (AD) risk reduction and in clinical practice. The dynamic Neurocognitive Adaptation (dNA) is a simple and cost-effective measure that could be used to personalize health recommendations in aging.
3. **Future directions**: In this article, we propose a framework for the involvement in different activities as protective factors against neurodegeneration. Further research using this tool may characterize specific life stages that are ripe for risk-reduction interventions and may identify individual differences that explain discrepancies between intervention studies, exploring its correlation with neuropsychological and neuroimaging measures.

Although it is understandable to observe a decline in the frequency of physically demanding activities with age, it should be possible to observe a coincident increase in cognitive, social, or creative activities. This maintenance is consistent with our dynamic view of the cognitive dimension, compared to the more static application of years of education. This kind of resistance is a form of adaptation to aging and it should be correlated with better neuropsychological measures, compared to low/lesser adaptation of people who discontinued involvement in such activities, which should be correlated with worse neuropsychological results.

The focus of this report is the development and validation of the *dynamic Neurocognitive Adaptation (dNA) scale*, a new instrument for the assessment of *dynamic adaptation* across the life course. This scale assesses behavioral dynamic adaptation to the environment across the lifespan, offering a method for understanding adaptation, reserve, and resistance as well as for clinically assessing weakness and prescribing specific lifestyle interventions.

2 | METHODS

2.1 | Participants

Ethical approval was obtained from the institutional review board (IRB) of the Cleveland Clinic (IRB #22310) and informed consent for publication was obtained from the study participants. The total sample included 815 participants (50% women), minimum age 65 years. Two subsamples were included: one used for an initial exploratory factor analysis (EFA; $N = 405$), and a second for subsequent cross-validation ($N = 410$), performed via confirmatory factor analysis (CFA). The sample size was determined according to convention[25] and verified experimentally. Data collection utilized survey measures administered via Qualtrics. To exclude duplication and ensure validity, Qualtrics checks every IP address and uses unique and sophisticated digital fingerprinting technology. All invitations to participate take the form of emails where the subjects are invited, informing them that the survey is for research purposes only, how long the survey is expected to take, and that participants may unsubscribe at any time. Validity and reliability are checked by Qualtrics, also replacing respondents who finish in less than 1/2 the median survey completion length. All subjects needed to be 65 years of age or older, fluent English speakers, and U.S. residents. All enrolled study participants provided demographic information, including age in years, sex, gender identity, level of educational attainment, marital status, and number of children and grandchildren. Participants were excluded if they reported age less than 65 years, living outside the United States, or not being fluent in English.

2.2 | Measures

As suggested and described in[26] there were several steps anticipated and that accompanied the development of the scale, including focus groups (we had focus groups in person and remotely), with whom we shared the construct idea, proposing items, dimensions, factors, being aware of time and reliability needs for an old population. We also used a pilot with 20 elderly subjects. These subjects filled in the scale and one of the authors (F.C.) had a meeting and sharing time with the subjects in which critiques and suggestions from all the participants were collected and taken into consideration for the scale development.

In its initial form the scale had 30 items, which aimed to assess the complexity of the environment and the level of commitment to different types of activities throughout the lifetime, in seven dimensions: physical, cognitive, creative, emotional, social, travel, and sleep/dreaming. Because the scale is intended for an aging population, we designed the questionnaire to maintain a balance between length and internal consistency. Each item used a 5-point Likert scale reflecting the frequency of activities: 0 = Never; 1 = Once a year or less; 2 = Several times a year; 3 = Several times a month; and 4 = Every day/almost every day. A total score for this scale was calculated by summing all items, in each dimension. There were no reverse items. Each dimension was assessed separately for seven decades across the life course: childhood (0–10 years); adolescence (11–20 years); youth (21–30 years); adulthood (31–40 years); middle age (41–50 years); senior age (50– 64 years); old age (65+ years). Items are introduced with the statement, "The following questions ask about your involvement in…". Each question instructed participants to identify the best answer. For example, "How often did you read, or do you currently read books/e-books/audiobooks?" represents a typical item.

2.3 | Data modeling and statistical analysis

2.3.1 | Summary of data modeling procedures

Analyses were performed by two different authors (G.d.F. and F.C.) using standard software packages (Stata Statistical Software, version. 18.0; StataCorp., College Station, TX, USA; and SPSS, version 23). We divided the data randomly into two groups: an evaluation sample ($n = 405$) and a validation sample ($n = 410$).

Sociodemographic data including age, sex, marital status, and education level were collected. Sociodemographic variables between the EFA and CFA groups were compared using Student's *t*-test or the chi-square ($\chi 2$) test and their significance (Table 1). We performed a principal component analysis (PCA) and EFA, in parallel on the evaluation sample, which served as the basis for CFA modeling in the validation sample. The EFA is an important precursor of CFA,[26] in which the factors are extracted from the data without specifying the number and pattern of loadings between the observed variables and the latent factor variables. In contrast, CFA specifies the number, meaning, associations, and pattern of free parameters in the factor loading matrix before a researcher analyzes the data.[25] The EFA was used to examine the underlying factor structure and to identify true latent domains that explained common variance among the activity items rather than simply summarized the maximum amount of observed variance, as is done in PCA.[26] That is, we used the EFA to identify and distinguish between key constructs in our dNA scale. We used descriptive analyses (means and standard deviations SDs) for continuous variables and counts and percentages for categorical variables to characterize the study sample.

2.3.2 | PCA and EFA

We performed a PCA with raw data permutation to determine the number of components across items.[25] We examined the PCA factor loadings and retained all factors with eigenvalues >1. Before performing EFA, we assessed the adequacy of the sample size through the Kaiser–Meyer–Olkin (KMO[27]) test. Furthermore, we used the Bartlett's test of sphericity, separately for all seven time windows, to test the homogeneity of variances.[27] We extracted the initial factors via two stages: (1) defining the number of initial factors, and (2) rotating the factors to improve interpretation. We calculated Cronbach's alpha (α) to assess internal consistency, using a threshold of >0.8 to be considered acceptable.[28] Next, we estimated EFAs, separately for each time window, using maximum-likelihood extraction and direct oblique rotation with Kaiser normalization. The EFA was conducted on the pooled Pearson correlation matrix of all imputed data sets, in particular Pearson correlations have been recommended as appropriate for use when ordinal variables have five or more response categories and are normally distributed. Loadings were scrutinized to determine if any items failed to load substantially on the appropriate latent factor, and to determine whether loadings were consistent across the seven time

TABLE 1 Sociodemographic characteristics between groups EFA and CFA ($N = 815$).

	Total sample EFA ($N = 405$)	Total sample CFA ($N = 410$)	$t/\chi 2$	p-value
Age, mean (SD)	72.15 (5.35)	72.80 (5.35)	1.71	0.08
Sex, n (%)				
Male	198 (48.89%)	204 (49.76%)	0.24	0.80
Female	205 (50.62%)	204 (49.76%)		
Missing	2 (0.49%)	2 (0.49%)		
Age, years				
Min: 65	Max: 90	Max: 89		
Marital status, n (%)				
Single	101 (24.94%)	113 (27.29%)	6.59	<0.001
Currently married	197 (48.64%)	204 (49.64%)		
Unmarried	99 (24.44%)	66 (16.06%)		
Missing	8 (1.98%)	27 (6.57%)		
Education level, n (%)				
High school graduate	78 (19.26%)	78 (18.98%)	0.23	0.81
Some college	101 (24.94%)	115 (27.98%)		
Associate degree	58 (14.32%)	56 (13.63%)		
Bachelor's degree	109 (26.21%)	91 (22.14%)		
Master's degree	43 (10.62%)	54 (13.14%)		
Doctorate or professional degree	16 (3.95%)	16 (3.89%)		

windows. We examined item consistency to identify unduly high correlations ($r \geq 0.80$) suggesting multicollinearity, or low correlations ($r < 0.30$) indicating insufficient common variance for stable multi-item factors.

2.3.3 | CFA

After the EFA we collected an additional subsample of 410 new participants (same inclusion criteria of the EFA; 50% women). We used a structural equation modeling (SEM) approach to perform CFA with a maximum likelihood estimation method, to evaluate the fit of the hypothesized factor structure based on the results of the EFA. The CFA permitted direct comparison of alternative models of relationships among constructs, critical for establishing construct validity. The CFA estimated the relationships between latent constructs, corrected for measurement error.[26] Cross-loadings between items and non-target factors are assumed to be exactly zero. Measures of model fit included chi-square (χ^2; p value > 0.05), root mean square error of approximation (RMSEA; cutoff ≤ 0.06), the normed fit index (NFI), the comparative fit index (CFI; cutoff ≥ 0.90), the Tucker-Lewis index (TLI; cutoff ≥ 0.95), and standardized root mean square residual (SRMR; cutoff ≤ 0.08). We also evaluated the coefficient of determination (CD), which explains how much variability of one factor is caused by its relationship to another factor.[29]

3 | RESULTS

Mean participant age was 72.15 (SD = 5.35; see Table 1 for demographic information). The full item pool used to develop the scale is available in Table S1. The Pearson correlation matrix was assessed for multi-collinearity ($r < 0.95$) and non-collinearity ($r < 0.3$), and two items (Items 22 and 23) were subsequently removed. Bartlett's test of sphericity was performed in all the seven time windows, demonstrating a rejection of null hypothesis for this test, showing that all values are <0.01, meeting the necessary requirements (the variables in the correlation matrix are not orthogonal). Sampling adequacy based on the KMO measure was at a superior level (overall KMO = 0.80). Parallel analysis showed that four of five factor solutions appeared viable. Upon performing the EFA analysis, a four-factor solution emerged: physical, cognitive, creative, and social. Two factors were suppressed: traveling and the sleep/dreaming dimension; the emotional and social factors were combined in the social factor (Table 2). Iteratively running the EFA based on item removal criteria led to the retention of 20 items, with a further 8 items being removed due to low factor loading (Table 2). Most items loaded strongly or moderately strongly, with few loadings less than 0.30. However, a total of 10 items (<0.30)—6, 7, 20, 21, 26, 27, 28, 30 (and the mentioned 22 and 23) —were removed from our CFA according to[26]. Our reliability coefficient α was 0.83 (Table 3).

Our CFA in the validation sample showed that a 20-item, four-factor model was within the sufficient fit index ($N = 410$; $\chi 2 = 910.957$,

TABLE 2 CFA factor loading patterns of dNA scale ($N = 410$).

Constructs	Item	Child 0–10	Adolescent 11–20	Youth 21–30	Adult 31–40	Middle 41–50	Senior 51–64	Old 65+
Cognitive domain	1. [...] did someone tell/read stories to you, or do you currently tell/read stories to someone else?	0.51	0.48	0.42	0.37	0.41	0.40	0.36
	2. [...] did you read or do you currently read books/e-books/audiobooks?	0.52	0.59	0.61	0.58	0.56	0.50	0.45
	3. [...] did you read or do you currently read newspapers/magazines?	0.57	0.70	0.62	0.53	0.52	0.51	0.48
	4. [...] involved in challenging individual brain games (e.g., solitaire, crossword puzzles, Sudoku, etc.)?	0.78	0.73	0.82	0.79	0.78	0.77	0.70
	5. [...] involved in challenging social brain games (e.g., bridge, Mahjong, Scrabble etc.)?	0.76	0.78	0.77	0.78	0.74	0.72	0.68
Physical domain	6.[...] engaged in physically demanding sport activities?	0.75	0.80	0.80	0.73	0.66	0.64	0.77
	7. [...] were you or are you currently engaged in physically demanding work activities?	0.50	0.67	0.64	0.65	0.60	0.58	0.60
	8. [...] engaged in physically demanding hobbies?	0.67	0.67	0.69	0.69	0.74	0.68	0.47
	9[...] engaged in physically light activities (e.g. walking, hiking, swimming, yoga, Pilates, tai chi)?	0.63	0.66	0.64	0.65	0.63	0.62	0.60
Creative domain	10. [...] play a musical instrument(s)?	0.52	0.54	0.46	0.41	0.38	0.38	0.43
	11. [...] listen to music?	0.61	0.64	0.58	0.54	0.51	0.47	0.54
	12. [...] involved in creative/arts activities (e.g., acting, singing, dancing)?	0.68	0.65	0.58	0.56	0.51	0.51	0.59
	13. [...] visit a library/book-shop/online-book store?	0.57	0.56	0.53	0.57	0.55	0.50	0.48
	14. [...] visit/attend or do you currently visit/attend museums/concerts/theaters/movies?	0.36	0.35	0.40	0.52	0.50	0.44	0.52
	15. [...] write (e.g., stories/poetry/diary/letters/dreams)?	0.68	0.68	0.68	0.60	0.56	0.58	0.60
	16.[...] travel out of the state?	0.68	0.62	0.64	0.63	0.64	0.63	0.40
	17. [...] travel out of the country?	0.60	0.59	0.55	0.50	0.48	0.46	0.30
Social domain	18. [...] feel that you have people you are close to?	0.73	0.73	0.77	0.73	0.70	0.46	0.68
	19. [...] meet new people?	0.64	0.64	0.66	0.57	0.60	0.75	0.62
	20. [...] see/hear from your friends/family members?	0.79	0.81	0.75	0.81	0.74	0.43	0.70

TABLE 3 Cronbach's alpha for each factor/domain for both scales (30 items and final 20 items).

Model 1	Item no.	Initial Cronbach's alpha	Model 2	Item no.	Final Cronbach's alpha
Cognitive domain	7	0.63	Cognitive domain	5	0.76
Physical domain	4	0.68	Physical domain	4	0.73
Creative domain	6	0.76	Creative domain	8	0.80
Travel domain	4	0.45	Travel domain	-	-
Sleep/Dreams domain	2	0.23	Sleep/Dreams domain	-	-
Social domain	7	0.42	Social domain	3	0.76

TABLE 4 Scale-fitting coefficient.

	$\chi^{2/df}$	*p*	RMSEA	SRMR	CFI	TLI	CD
Childhood	381.404	<0.001	0.05	0.05	0.92	0.90	0.99
Adolescence	454.282	<0.001	0.06	0.05	0.90	0.88	0.99
Youth	559.282	<0.001	0.07	0.06	0.87	0.84	0.99
Adulthood	589.386	<0.001	0.08	0.06	0.84	0.81	0.98
Middle age	565.915	<0.001	0.07	0.06	0.83	0.80	0.98
Senior age	603.605	<0.001	0.08	0.06	0.80	0.77	0.98
Old age	582.976	<0.001	0.07	0.06	0.75	0.71	0.97

Abbreviations: CD, coefficient of determination; CFI, comparative fit index; RMSEA, root mean square error approximation; SRMR, standardized root mean square residual; TLI, Tucker Lewis index.

df = 170, $p < 0.001$, CFI = 0.90, TLI = 0.90, RMSEA = 0.07, CD = 0.99, and SRMR = 0.06) (Table 4). Seven structural equation models (SEM) were estimated according to the final selected model with the best RMSEA. All items that had a coefficient of >0.30 were retained. The results showed that five of seven items were retained in the first factor (cognitive domain), and four of four items were retained in the second factor (physical domain). In the third factor (creative domain), six factors were retained and two items on the travel domain were merged (Items 18 and 19; see Table 2). Finally, three of seven items were retained in the fourth factor (social domain). The final set of 20 items has a good model fit ($N = 410, \chi 2 = 381.404, df = 164, p < 0.001$; CFI = 0.92, TLI = 0.91, RMSEA = 0.05, and SRMR = 0.05). The factor loadings and factor correlations can be found in Table 2. The results of the model show that the cognitive domain is positively related to physical domain (coefficient of varioation [COV] = 0.65, $p = < 0.001$), to social domain (COV = 0.51 $p = < 0.001$), and to creative domain (COV = 0.77, $p = < 0.001$). The physical domain is positively related to creative domain (COV = 0.69, $p = < 0.001$) and to social domain (COV = 0.63, $p = < 0.001$). Finally, the social domain is positively related to creative domain (COV = 0.70, $p = < 0.001$). Moreover, in Figure 1 we plot the mean total scores with 95% confidence intervals (CIs), to show the general trend of this population, as discussed in the next section.

4 | DISCUSSION

Notions of brain resistance, maintenance, resilience, and reserve share some adaptive mechanisms, usually described during an aging pathological process (e.g., AD), although adaptive mechanisms act regardless of pathological mechanisms in action. Aging is a physiological process of life, although it is a primary risk factor for neurodegeneration. In other words, aging is a natural neurodegenerative process to which the individual adapts with different degrees of efficiency, which are in turn affected by genetic, biological, environmental factors, and their interactions.

In this article we proposed a new model pointing out the role of combined cognitive, physical, creative, and social activities, and highlighting the need for a dynamic approach, incorporating individual behavior over a more granular identification of time, or time windows, potentially able to explore sensitive time for interventions.

Reserve, resistance, resilience, maintenance, and neural scaffolding share and emphasize the adaptability and plasticity of the neurocognitive system. The idea of reserve refers to the level of "hardware" (e.g., synaptic density) or "software" (e.g., IQ, education) that an individual was able to reach prior to the onset of disease. Resistance is inferred from an observed absence or reduced neurodegeneration (*hardware*), relative to normative expectations, based on age, genetic vulnerability, or other individual differences.[30] According to the Collaboratory on Research Definitions for Reserve and Resilience in Cognitive Aging and Dementia, the term resilience is considered as a general term that subsumes any concept that relates to the capacity of the brain to maintain cognition and function with aging and disease. The idea of reserve is inferred from an observed level of cognitive (*software*) performance better than expected for a given brain (*hardware*) injury or neurodegeneration (amyloid beta [Aβ] plaques and hyperphosphorylated tau [p-tau] in the case of AD).[31,32]

The adaptive brain, or neurocognitive scaffolding,[3] suggests that a range of lifelong activities helps build or maintain brain tissue and/or network flexibility that may delay or compensate for structural brain changes of aging or in response to disease pathology. As Nyberg and colleagues[33] point out, maintaining an active brain, rather than compensating for changes, may be the key to successful memory aging. These perspectives and others, such as the *Adaptive Capacity Model*,[34] all posit that engagement in different kinds of activities is beneficial to brain aging and cognitive performance.

The *Lifetime of Experiences Questionnaire*[35] is one of the best current tools to explore individual involvement in leisure activities (cognitive, physical, and social). At the same time, it is rather complicated and long to complete, especially for the senior population, requiring ≈30 min. Moreover, the three time windows proposed by the authors are wide, including young adulthood: between 13 and 30 years; middle age: from 30 years to 65 years; and late life: 65 years of age or older. In addition, this questionnaire does not include the first stage of life (0–13 years old), a key stage for building the first individual approach to cognitive, physical, or social development, providing the base for the neurocognitive system to adapt—building the base for the *software development*.

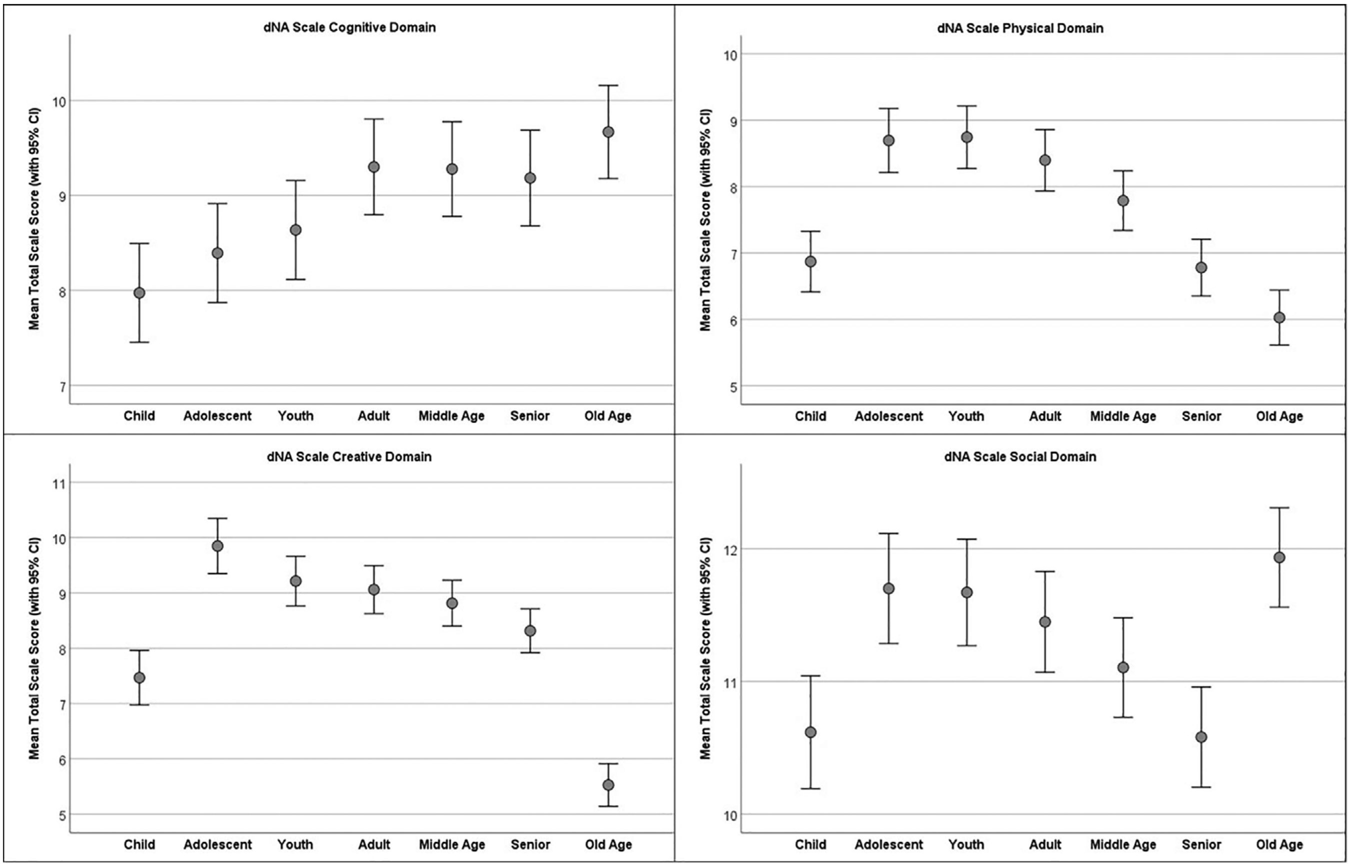

FIGURE 1 Plot of the mean total scores with 95% confidence interval (CIs).

In the realm of reserve, IQ and formal education have shown their role as protective factors, but they could act as correlational, causative, mediating, or facilitating factors in a more general dynamic adaptation to the environment. IQ and educational duration are positively correlated, which can be seen either that students with greater propensity for intelligence go on to complete more education or that a longer education increases intelligence.[36,37] People with higher levels of education are more likely to know the benefits of an active life, being more cognitively and physically active. At the same time, some studies have found no support for the hypothesis of education as a protective factor for brain pathology in the Alzheimer's Disease Neuroimaging Initiative (ADNI) cohort, questioning its accepted status as a reserve variable.[38]

We proposed to explore empirically a broader set of protective activities—beyond IQ and years of education—that might contribute to maintaining a younger neurocognitive system in a dynamic way, building resistance to AD pathology, such as amyloid aggregation and neuroinflammation. Our approach is based on brain imaging studies, which have shown that brain complexity naturally decreases during aging, and it is abnormally reduced during neurodegeneration, becoming "pathologically sub-critical." In a healthy and awake condition, the adult individual mind–brain system must be able to maintain a dynamic and complex level of criticality.[39,40] This dynamic criticality[41] gives the system the opportunity to be more flexible and adaptable to change. This can be seen as a paradox of the system, in which it needs "instability" to be more dynamically and "adaptively stable."[42] The brain is considered a system that exists near a critical dynamic zone between states of order and disorder.[39–42]

Neurocognitive adaptation could act through self-organization under normal conditions, showing transiently stable spatiotemporal configurations,[43] and this instability is maximal at a point where the global system is critically poised in a transition zone between order and chaos.[44] This criticality of a neural network is a measure of the variance in the network's intrinsic synchrony over time.[45] We believe that the exposure to a complex environment—explored by our scale—facilitates this state of criticality, making the neurocognitive system more ready, flexible, and prepared for changes, including aging, providing a better adaptative mechanism.

We developed a scale with a balance between length and reliability of information requested, especially since the scale is intended also for older adults. We created a scale with a rational number of items, a reasonable time to complete (≈15 min), and which explores a sufficient "complexity" of the environment in terms of dimensions, items, and time windows.

Another aspect emphasized in our approach is the emotion–cognition correlation, which should be considered and further investigated, since subjective memory complaints may correlate more strongly with mood states than with objective memory performance,[46] and late-life depression is a common emotional and mental disability in older adults.[47]

When we take into consideration our dimensions in a dynamic way (Figure 1), we observe an average trend of decrease in the physical and creative dimensions in our sample over time. On the other hand, we see an increase in the cognitive dimension and even a more surprising sudden increase in the social dimension, which decreases from childhood to senior stage, until it increases from senior to old age, reaching its highest point, higher than the adolescence stage, when the social dimension tends to be historically high.

We considered the creative dimension, sometimes underestimated in the traditional reserve approach, but the investigation of which could give some clues for helping people to cope with aging and its relative isolation and depression, aspects typical in older adults and amplified by the coronavirus disease 2019 (COVID-19) pandemic.[48]

Our approach underscores the vital component of time, exploring the dynamic aspect of adaptation through time. The dynamic consideration of time has been also raised in the functional neuroimaging field in terms of *dynamic* functional connectivity.[49] Dynamic spatiotemporal models better represent brain activities; however, both in behavioral and imaging studies there is a need for further research and long-term longitudinal studies to determine the effect of time, pathology, genetics, and environmental factors on (neurocognitive) adaptation.

The model for dynamic adaptation we present also has potential clinical and interventional value, as it may suggest personalized non-pharmacological interventions. This model has also value for a programmatic scientific approach in the investigation of the exposome[50] and its use in individual well-being.

Our study has limitations: we have used a "virtual sample"; most of the tool was developed and validated during the pandemic, using a sample collected by *Qualtrics*. Even though this approach allowed us to reach a great number of subjects in a relatively short time, with reliability controlled and checked by *Qualtrics*, it limited our ability to correlate scale results with other outcomes. We are currently using our scale in a regular recruitment process to examine the relationship of our scale with neuropsychological and neuroimaging outcomes. Another limitation is the retrospective approach; the ideal approach would be longitudinal. In our case, we have included people inclusive of age 65 years, to collect their behaviors based on their memory, which can give rise to some bias. Our study has also strengths: we proposed a novel, easy to complete, and comprehensive means of assessing lifetime adaptive behaviors, which can be applied in research on AD risk reduction, MCI, and in clinical practice. Further research using this tool may characterize specific life stages that are ripe for risk-reduction interventions and may identify individual differences that explain discrepancies between intervention studies. Finally, the dNA is a simple and cost-effective measure that could be used to personalize health recommendations in the context of AD or aging.

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CONFLICT OF INTEREST STATEMENT

All authors declare that they have no conflicts of interest. Author disclosures are available in the supporting information.

CONSENT STATEMENT

All human subjects provided written (electronic) informed consent.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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