



Review article

A systematic review of multivariate studies in cognitive aging: Introducing the concept of cognitive organization

E. Garcia-Cabello^a, A. Habich^e, Y. Molina^a, L. Perestelo-Pérez^{b,c,d}, J. Barroso^a, D. Ferreira^{a,e,*}

^a Departamento de Psicología, Facultad de Ciencias de la Salud, Universidad Fernando Pessoa-Canarias, Islas Canarias, Spain

^b Evaluation Unit (SESCS), Canary Islands Health Service (SCS), Tenerife, Canary Islands, Spain

^c Network for Research on Chronicity, Primary Care and Health Promotion (RICAPPS), Madrid, Spain

^d The Spanish Network of Agencies for Health Technology Assessment and Services of the National Health System (RedETS), Madrid, Spain

^e Division of Clinical Geriatrics, Center for Alzheimer Research, Department of Neurobiology, Care Sciences, and Society, Karolinska Institutet, Stockholm, Sweden

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ABSTRACT

Despite ample research on cognitive aging, it is still largely unknown whether cognition is organized in a distinct manner, with different cognitive domains and subcomponents interrelating with each other. It is also unknown whether this cognitive organization is stable or changes with increasing age. Following the PRISMA guidelines statement, we conducted a systematic review of multivariate studies of cognitive aging with the aim to identify a potential cognitive organization in healthy aging. We consulted Embase, PsycInfo and Medline electronic databases from 2000 to October 2025. The methodological quality of the included studies was analysed using CASP tools and a narrative synthesis of the selected articles was performed. We screened 1518 references and a total of 14 research articles met selection criteria and were included. We found convergent findings across studies suggesting a cognitive organization of four factors: memory, language, executive functions, and processing speed. This cognitive organization was rather consistent across studies, cohorts, and methodologies. A fifth factor for visuospatial abilities was identified in several studies. Some studies reported that processing speed may influence age-related changes in the direct performance of other cognitive domains. However, the current evidence did not allow concluding on the effect of age in this cognitive organization. Therefore, it is yet to be clarified whether this cognitive organization remains invariant throughout age. Advancing in our understanding of cognitive aging can result in a more accurate and personalized clinical assessment and intervention in people at risk of cognitive impairment.

1. Introduction

Psychological processes, specifically, cognitive abilities, refer to functional properties of the individuals that are not directly observed although are inferred from behaviour (Sivan and Benton, 1999). Traditionally, cognitive abilities have been classified into receptive functions, memory and learning, thinking, and expressive functions, and have been examined through neuropsychological assessment (Lezak et al., 2012). In the field of aging, cognitive abilities have been widely studied. Most of the research has focused on a specific cognitive test or variable such as attention, memory, language, processing speed, or executive functions. Studies assess how each of these tests or variables change over time or compare them across age groups using univariate methods for data analysis (Ferreira et al., 2015; Harada et al., 2013;

Lachman, 2004; Oschwald et al., 2019; Salthouse, 2009; Schaie, 2005; Schroeder and Salthouse, 2004; Tisserand and Jolles, 2003; West, 2001). These univariate studies have made important contributions towards understanding cognitive aging, helping to characterize the effect of age on different cognitive domains and cognitive subcomponents. However, univariate methodological approaches assess cognitive functions in isolation. Such an approach contrasts with the network perspective (Ferguson, 2022), which postulates that different cognitive functions are interrelated with each other and, therefore, age-associated changes in some functions may affect other cognitive functions.

More recently, several studies have applied multivariate methods for investigating cognitive aging (Habeck et al., 2015; Hoogendam et al., 2014; Machado et al., 2018; Nielsen and Wilms, 2015; Viroli, 2012). These multivariate studies provide a more comprehensive

* Corresponding author at: Departamento de Psicología, Facultad de Ciencias de la Salud, Universidad Fernando Pessoa-Canarias, Islas Canarias, Spain.

E-mail address: daniel.ferreira.padilla@ki.se (D. Ferreira).

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understanding of how various factors interact and influence cognitive functions during aging. In this regard, age was found to be strongly associated with changes in brain structure, especially in cortical thickness of frontal and parietal regions, and with cognitive performance, particularly in executive functions, processing speed and visual memory (Machado et al., 2018). These results suggest that certain brain regions and cognitive functions are particularly vulnerable to the aging process in cognitively healthy adults (Habeck et al., 2015; Hoogendam et al., 2014; Machado et al., 2018; Nielsen and Wilms, 2015; Viroli, 2012). However, these studies are not exclusively limited to cognitive variables; they also incorporate demographic, clinical, and neuroanatomical variables in their analyses. Including only cognitive variables in multivariate analyses could provide valuable information on how cognitive domains and different cognitive subcomponents are organized and interrelate with each other, forming what could be called the “cognitive organization” in healthy aging. Furthermore, it is not known whether that cognitive organization is stable or changes across ages, perhaps supporting the hypothesis of increasing correlations between cognitive domains at older ages (Baltes et al., 1980; Hultür et al., 2015).

The current systematic review synthesizes multivariate studies on cognitive aging. We hypothesized that different multivariate studies would converge into identifying a specific “cognitive organization” across studies, and we assessed whether that organization would be stable or change across ages.

2. Method

The present systematic review was carried out following the guidelines and recommendations of the PRISMA 2020 statement (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) (Page et al., 2021).

2.1. Inclusion and exclusion criteria

Participants: We included studies that recruited participants who were cognitively healthy, where the cohort had an average age of 20 years or older, and with participants having or not having a pharmacological treatment. We excluded studies that reported data on participants who met criteria for mild cognitive impairment, dementia, had cerebrovascular pathology (e.g. stroke), history of brain injury, mental disorder, intellectual disability or any other disease, pathology or condition that influences cognitive performance, or reported substance abuse.

Outcomes: We included studies with broad neuropsychological evaluations that include more than two cognitive domains (e.g. attention, memory, language, executive functions, visuo-perceptive, visuo-spatial and/or visuoconstructive functions). We excluded studies that evaluated only one or two cognitive domains or that only applied instruments for screening limited to an estimate of global cognitive status.

Design of studies: We included studies published in either Spanish or English (checked at screening phase), that were cross-sectional or longitudinal, and that applied any multivariate methodology to cognitive data. We included studies that allowed analysing the interrelationship between multiple cognitive variables, in a hypothesis-free manner. The different methodologies included graph theory as well as methods that observed a structure or organization between variables (e.g. factor analysis, principal components analysis, analysis of latent structures and structural equations). Studies that observed the effect of age on the mentioned cognitive organization were also included. Confirmatory factor analysis based on hypothesis-driven cognitive organizations were excluded.

Studies that performed analysis on the subjects (profile or cluster analyses) were excluded, as our interest was on the cognitive variables. We only included primary studies while we excluded single case studies, systematic reviews, and meta-analyses.

2.2. Search strategy

The search was carried out from 2000 to October 13th, 2025 in three databases (Embase, PsycInfo and Medline). This was done in two phases. A first search was carried out on November 16th, 2022, and an updated search was carried out on October 13th, 2025. We did not search for unpublished/grey literature to address potential publication bias. The following terms were used individually and combined: “Cognitive Aging”, “Healthy Aging”, “Graph theor*”, Multivariate Analysis, Factor Analysis, Statistical, Principal Component Analysis (Search strategy can be found into [supplementary material](#)). As for Medical Subject Heading (MeSH) terms, we used “Cognitive Aging”, “Healthy Aging”, “Multivariate Analysis”, “Factor Analysis”, and “Principal Component Analysis” (please see [Supplementary Table 1](#) for a complete description of search strategy and hits for each database). The other terms were searched by title/abstract. No language restrictions were applied to limit the search, although language exclusion criteria were applied in the screening phase.

2.3. Study selection and data extraction

The electronic search results from the different databases were imported into Zotero and duplicates were removed. The screening process was conducted separately for the original search in 2022 and the update in 2025. Screening in the original search was performed by a single reviewer (EG-C), and all the selected articles were independently verified by a senior researcher with extensive experience in systematic reviews (DF), who confirmed their eligibility. Screening in the update was performed blindly and independently by two reviewers (EG-C and AH). Disagreements were resolved by a senior researcher (DF). Screenings were first carried out on titles and abstracts and, subsequently, on full text. Two reviewers independently extracted data from each included study using a standardized data extraction form in Microsoft Excel using the following variables: first author, year of publication, number of participants, mean age, SD and range, % de female, years of education (mean and SD), cognitive measures, type of methodological approach, and main results.

2.4. Risk of bias and quality assessment of the include studies

The evaluation of risk of bias and methodological quality of the selected studies was carried out using the Critical Appraisal Skills Program (CASP) tool from the Oxford Centre for Triple Value Healthcare ([Critical Appraisal Skills Programme, 2023](#)). This is a flexible tool that enables the analysis of internal and external validity, describing the main characteristics of the studies (objectives, method, results...) and determining the quality and biases of studies with heterogeneous designs.

For the current review, cohort sheets were used and completed according to the objectives and results of interest. Each sheet consisted of 12 questions divided into three sections (validity; precision and power of results; and external validity and consistency with previous evidence). These questions had multiple responses: Yes, No or Don't Know/Cant tell ([Table 1](#)). Quality assessment was undertaken by two independent reviewers (EG-C and AH) and possible discrepancies were solved by a senior researcher (DF).

2.5. Concepts and decision criteria

This study proposes the term “cognitive organization” as a concept that reflects how cognitive domains and cognitive subcomponents are organized and interrelate with each other. The cognitive organization was operationalized through the solutions or structures of factorial analysis, principal component analysis and structural equations models, as well as through the modular solution of graph theory analysis. Specifically, the cognitive organization was extracted at the level of

Table 1
Main characteristics of the included studies.

	Participants					Method	
	n	Age, mean (SD)	Age, range	Sex, % female	Years education, mean (SD)	Cognitive measures, n	Methodological approach
Blujus et al. (2025)	679	33.5 (1.7)	30–38	NR	12.7 (2.3)	15	FA
Finkel et al. (2005)	778	62.2 (9.2)	50–89	60.0	1.6 ^a	11	FA
Finkel et al. (2007)	806	NR	50–89	59.0	NR	11	PCA
Garcia-Cabello et al. (2021)	334	57.8 (11.2)	37–78	56.0	NR	47	GT
Hatahet and Seghier (2024) ^b	163 120	NR	18–34 60–89	57.0 55.0	> 12.0 ^c	14	FA
Hernández-Gamboa et al. (2023)	238	69.2 (5.1)	55–85	68.5	NR	14	FA
Hollinshead et al. (2022)	943	67.3 (11.1)	17–95	72.4	14.9 (3.0)	21	PCA
Krueger et al. (2009)	66	71.1 (8.1)	55–87	83.0	6.9 (3.6)	18	PCA
Leritz et al. (2016)	120	68.1 (9.6)	43–85	61.7	14.8 (2.7)	14	FA
Nevado et al. (2021)	7623	72.7 (9.0)	NR	66.0	16.0 (6.0)	12	GT
Oh et al. (2014)	83	74.4 (6.6)	60–96	63.9	17.0 (1.9)	17	PCA
Salthouse et al. (2015)	297	NR	20–79	54.0	16.3 (NR)	12	FA
Salthouse and Ferrer-Caja (2003) ^d	204	49.5 (5.9)	20–91	66.0	15.9 (2.5)	15	SEM
Salthouse and Ferrer-Caja (2003) ^e	259	51.4 (NR)	19–94	NR	NR	11	SEM
Salthouse and Ferrer-Caja (2003) ^f	206	53.3 (15.4)	18–84	NR	NR	12	SEM
Wright et al. (2021)	220	53.0 (9.0)	NR	55.0	14.5 (5.0)	16	GT

The table shows the main characteristics of the participants and method used in each study. ^a In the study by Finkel et al. (2005), educational level is reported instead of years of education, with the minimum being primary studies (score = 0) and the maximum being university studies (score = 4). ^b Hatahet and Seghier (2024) included two age groups - data in the table is reported for each age group separately (younger | older). ^c In the study by Hatahet and Seghier (2024), a minimum of 12 years of education was an inclusion criterion. In the study by Salthouse and Ferrer-Caja (2003), three cohorts are used (^{d,e,f}). NR refers to not reported. Abbreviations: FA = Factorial analysis; PCA = Principal component analysis; SEM = Structural Equations Model; GT = Graph theory.

structure effects instead of level effects. The studies included in this systematic review used different methodological approaches (see Table 2). Consequently, the decision criteria for identification of cognitive domains reported in each study and integration across studies were theoretical rather than based on cross-study consistency metrics. Assignment to cognitive domains representing the cognitive organization was based on the original nomenclature provided by the study authors supported by inspection of the cognitive variables contributing to each factor, component or module. This was carefully reviewed and mapping from studies to domains in this review were done by an expert judgement upon consensus agreement of two co-authors (EG-C and DF)

using standard principles of construct validity in neuropsychological assessment (Lezak et al., 2012).

3. Results

The two searches returned 2070 references in the three databases and 4 through review of reference lists and manual searches. After removing duplicates, 1518 references were screened by title and abstract and 215 preselected studies were assessed on full text for eligibility. Fourteen references finally met our selection criteria and were included in the present systematic review. Fig. 1 shows the flowchart of

Table 2
Evaluation of the quality of the studies with the CASP scale.

Questions	1	2	3	4	5a	5b	6a	6b	7	8	9	10	Total
Studios	1	2	3	4	5a	5b	6a	6b	7	8	9	10	Total
Blujus et al. (2025)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	12
Finkel et al. (2005)	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	CT	10
Finkel et al. (2007)	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	CT	10
Garcia-Cabello et al. (2021)	Y	Y	Y	Y	Y	Y	CT	CT	Y	Y	Y	CT	9
Hatahet and Seghier (2024)	Y	Y	Y	Y	N	N	CT	CT	Y	Y	Y	Y	8
Hernández-Gamboa et al. (2023)	Y	Y	Y	Y	Y	Y	CT	CT	Y	Y	Y	Y	10
Hollinshead et al. (2022)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	CT	11
Krueger et al. (2009)	Y	Y	Y	Y	N	N	N	N	Y	Y	CT	Y	7
Leritz et al. (2016)	Y	Y	Y	Y	Y	Y	N	N	Y	N	CT	CT	7
Nevado et al. (2021)	Y	Y	Y	Y	Y	Y	CT	CT	Y	Y	Y	Y	10
Oh et al. (2014)	Y	Y	Y	Y	Y	Y	N	N	Y	N	Y	CT	8
Salthouse et al. (2015)	Y	Y	Y	Y	N	N	N	N	Y	N	Y	CT	6
Salthouse and Ferrer-Caja (2003)	Y	Y	Y	Y	Y	Y	N	N	Y	N	Y	CT	8
Wright et al. (2021)	Y	Y	Y	Y	Y	Y	CT	CT	Y	Y	Y	S	10

The table reflects the quality of the studies evaluated using the “Critical Appraisal Skills Program (CASP)” scale. The scale consists of 12 multiple response questions scored as Yes (Y), No (N) or Cant tell (CT). The total score for each study is the sum of the yeses and a higher total score reflects a higher level of quality. Items scored as “No” or “Can’t tell” were scored as zero and, therefore, did not add up to the final quality score. The specific questions are: 1. Does the study focus on a clearly defined topic?; 2. Was the recruitment of the cohort carried out in an acceptable manner?; 3. Was the exposure measured appropriately to minimize potential bias?; 4. Were the measurement of results carried out accurately to reduce possible bias?; 5a. Have the authors identified the most relevant confounding factors?; 5b. Have the authors taken confounding factors into account in the design and/or analysis?; 6a. Was the follow-up of the participants sufficiently complete?; 6b. Was the follow-up of the participants long enough?; 7. Do you believe the results?; 8. Can the results be applied to the local population?; 9. Do the results of this study coincide with other available evidence?; 10. Does this study have implications in practice?

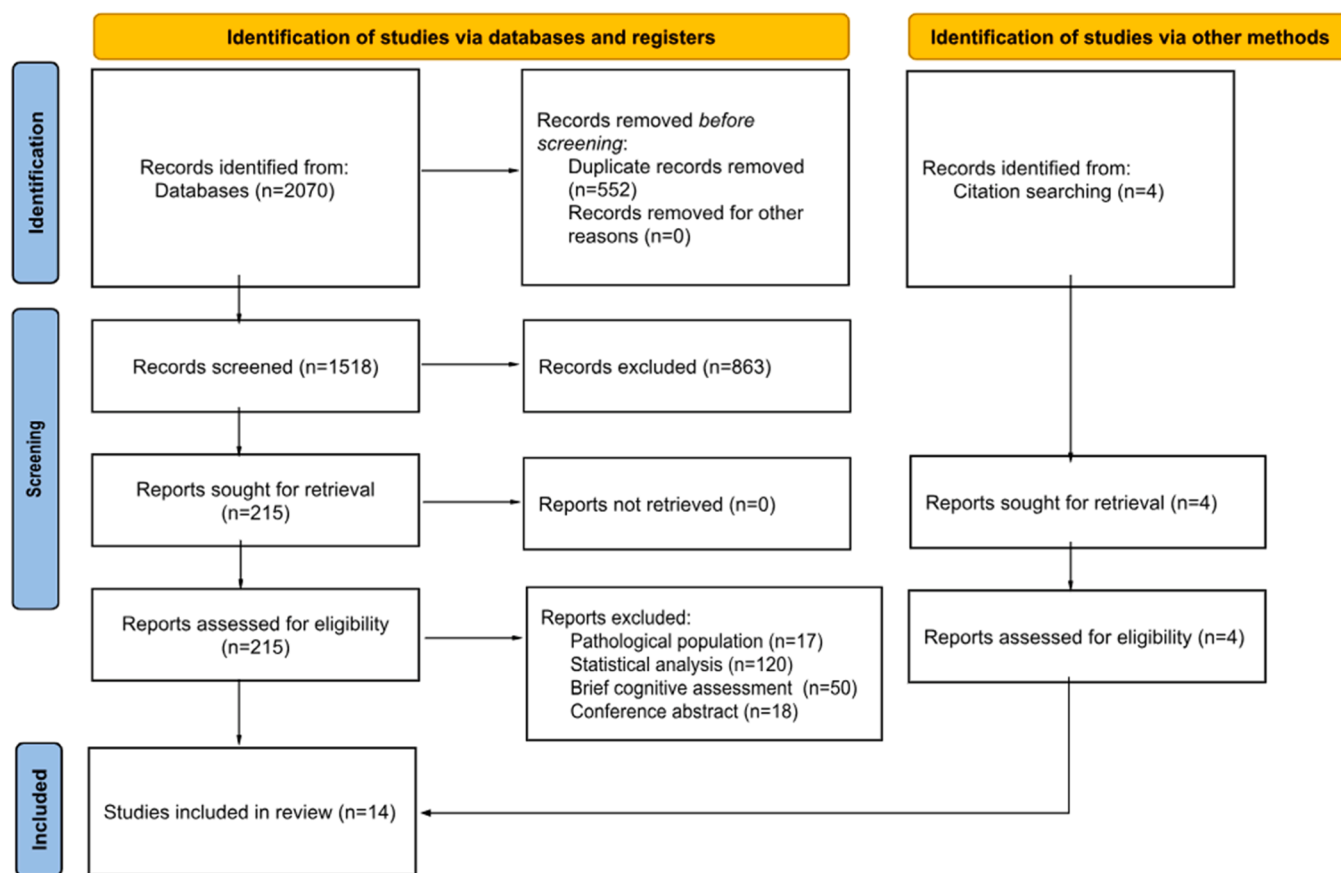


Fig. 1. Flow diagram of the included studies.

the study selection process.

3.1. Characteristics of the included studies

The main characteristics of the fourteen studies are shown in Table 2. Regarding the participants, this systematic review gathered a total sample of 13,139 subjects, with an average age of cohorts ranging between 23 years (Wright et al., 2021) and 74 years (Oh et al., 2014). The studies covered a wide range of ages, with the shortest age range being 8 years (Blujus et al., 2025) and the largest age range being 78 years (Hollinshead et al., 2022). Regarding sex distribution, most studies included around 60 % women, while one study reported up to 83 % women (Krueger et al., 2009). Most of the studies assessed education throughout years of education, with an average of 14 years across studies. Some studies assessed educational attainment instead (Finkel et al., 2005; Garcia-Cabello et al., 2021) or did not report any measures of education (Finkel et al., 2007; Hernández-Gamboa et al., 2023; Salthouse and Ferrer-Caja, 2003). All the studies recruited participants from the community except Nevado et al. (2021) and Wright et al. (2021), which recruited participants in clinical settings.

All the studies used numerous cognitive measures related to different cognitive domains. The average number of cognitive variables used was 16 measurements, with a minimum of 11 cognitive variables (Finkel et al., 2005, 2007; Salthouse and Ferrer-Caja, 2003) and a maximum of 47 cognitive variables (Garcia-Cabello et al., 2021). It should be noted that, among the cognitive measures included in the different studies, most are mainly related to verbal memory, processing speed, language, and executive functions. The most common methodology for analysis was factor analysis (Blujus et al., 2025; Finkel et al., 2005; Leritz et al., 2016; Hatahet and Seghier, 2024; Hernández-Gamboa et al., 2023; Salthouse et al., 2015), followed by principal component analysis

(Finkel et al., 2007; Hollinshead et al., 2022; Krueger et al., 2009; Oh et al., 2014) and graph theory (Garcia-Cabello et al., 2021; Nevado et al., 2021; Wright et al., 2021). Only one study used structural equation modelling (Salthouse and Ferrer-Caja, 2003).

3.2. Risk of bias and quality of included studies

All studies were scored as medium or medium-high methodological quality according to the CASP tool. Studies had a clearly defined topic and carried out an adequate recruitment and used measures that allow them to minimize possible biases and obtain plausible results that coincide with the evidence available (Blujus et al., 2025; Finkel et al., 2005, 2007; Garcia-Cabello et al., 2021; Hatahet and Seghier, 2024; Hernández-Gamboa et al., 2023; Hollinshead et al., 2022; Krueger et al., 2009; Leritz et al., 2016; Nevado et al., 2021; Oh et al., 2014; Salthouse et al., 2015; Salthouse and Ferrer-Caja, 2003; Wright et al., 2021). Furthermore, given their cross-sectional design, the studies did not follow-up the cohorts apart from the studies by Finkel et al. (2005), (2007) that had a longitudinal design. Some studies were scored to not adequately identify and control for possible confounding factors (Hatahet and Seghier, 2024; Krueger et al., 2009; Salthouse et al., 2015), compared to those that included sex, race, educational level, beta-amyloid deposits, or genetic or cerebrovascular factors as covariates (Blujus et al., 2025; Finkel et al., 2005, 2007; Leritz et al., 2016; Oh et al., 2014; Salthouse and Ferrer-Caja, 2003).

3.3. Qualitative analysis and synthesis

3.3.1. Cognitive organization

Several studies applied multivariate methodology as the main or secondary objective of the study (Blujus et al., 2025; Finkel et al., 2005,

2007; Garcia-Cabello et al., 2021; Hatahet and Seghier, 2024; Hernández-Gamboa et al., 2023; Hollinshead et al., 2022; Nevado et al., 2021; Salthouse et al., 2015; Salthouse and Ferrer-Caja, 2003; Wright et al., 2021). The remaining studies carried out this analysis with the purpose of reducing the dimensionality of their data for subsequent analyses (Krueger et al., 2009; Leritz et al., 2016; Oh et al., 2014).

Table 3 and Fig. 2 summarize the evidence in terms of the cognitive organization obtained in each of the studies. Table 3 includes a vote-counting approach to identify the most frequent number of factors identified, stratified by methodological approach. Regardless of the size of the samples, the methodological approach or the cognitive measures

Table 3
Synthesis of the most relevant results by methodological approach.

	Number of factors	Cognitive factors
FA - Factorial analysis		
Blujus et al. (2025)	4	Semantic Memory, Episodic Memory, Perceptual Reasoning, and Executive ^a
Finkel et al. (2005)	4	Language, Visuospatial, Verbal Memory, and Speed
Hatahet and Seghier (2024)	3	Semantic Memory, Episodic Memory, and Executive
Hernández-Gamboa et al. (2023)	4	Executive, Verbal Memory, Contextualized Memory, and Speed
Leritz et al. (2016)	3	Verbal Memory, Executive, and Language
Salthouse et al. (2015)	4	Verbal Memory, Language, Executive, and Speed
FA - vote counting		
PCA - Principal component analysis		
Finkel et al. (2007)	4	Language, Visuospatial, Verbal Memory, and Speed
Hollinshead et al. (2022)	4	Executive ^a , Verbal memory, Visuospatial, and Contextualized Memory
Krueger et al. (2009)	5	Verbal Memory, Language, Working Memory, Spatial, and Speed
Oh et al. (2014)	5	Verbal Memory, Visual Memory, Language, Working Memory, and Executive
PCA - vote counting		
GT - Graph theory		
Garcia-Cabello et al. (2021)	5	Verbal Memory, Visuospatial Memory ^b , Executive ^c , Processing Speed, and Procedural Memory
Nevado et al., (2021)	4	Executive, Language, Attention, and Memory
Wright et al. (2021) ^d	4	Verbal Memory, Executive, Language, and Visuospatial
GT - vote counting		
SEM - Structural equations model		
Salthouse and Ferrer-Caja (2003)	4	Verbal Memory, Visuospatial, Executive, and Speed

The table shows the number and names of the cognitive factors found in each study. Due to the variability of methodological approaches and reported metrics across studies, the synthesis was done theoretically using expert judgment through consensus agreement between two co-authors. The visuospatial factor includes both visuoperceptive, visuospatial and visuoconstructive components. Vote counting refers to the most frequent number of factors reported within each methodological approach. ^a The Executive factor was reported as Executive-Speed by both Blujus et al. (2025) and Hollinshead et al. (2022). Both studies included five and six tests, respectively, for executive functions that also tapped on processing speed/attention. ^b The Visuospatial Memory factor was reported as Visual-Visuospatial Memory by Garcia-Cabello et al. (2021). This factor included seven tests of visuospatial memory also tapping on visuoperceptive, visuospatial and visuoconstructive components. ^c The Executive factor was reported as Executive-Premotor by Garcia-Cabello et al. (2021). This factor included six tests of executive functions and two tests related to premotor functions. ^d In Wright et al. (2021), factors were not explicitly labelled; instead, they were described in terms of the cognitive components they comprised. The reported factors labels were agreed upon by two co-authors in this systematic review for the theoretical synthesis.

included, all the studies reflected the existence of a robust cognitive organization. With regards studies employing factor analysis, most studies reported a cognitive organization composed of four factors (Blujus et al., 2025; Finkel et al., 2005; Hernández-Gamboa et al., 2023; Salthouse et al., 2015). Nevertheless, two studies identified three factors (Hatahet and Seghier, 2024; Leritz et al., 2016). Studies using principal component analysis showed a cognitive organization characterized by four factors (Finkel et al., 2007; Hollinshead et al., 2022) or five factors (Krueger et al., 2009; Oh et al., 2014). With regard to graph theory, Nevado et al. (2021) and Wright et al. (2021) reported an organization of four factors, and Garcia-Cabello et al. (2021) reported a cognitive organization of five factors after controlling for the effect of age and cognitive reserve. Finally, Salthouse and Ferrer-Caja (2003) used structural equation modelling to analyse what cognitive organization best adjusted with age, showing that it was a hierarchical model of four first-order factors and a general second-order factor.

In summary, most studies reported a cognitive organization of four factors, whereas three studies reported an organization of five factors (Garcia-Cabello et al., 2021; Krueger et al., 2009; Oh et al., 2014) and two studies reported an organization of three factors (Hatahet and Seghier, 2024; Leritz et al., 2016).

Regarding the associations between different cognitive factors, Salthouse and Ferrer-Caja (2003) found that all cognitive factors were similarly associated with themselves, forming a general factor. Blujus et al. (2025) found moderate to strong correlations between all cognitive factors, except for a weak correlation between episodic memory and perceptual reasoning. Finally, Finkel et al. (2005) found a significant association between processing speed and other cognitive factors. Specifically, the processing speed factor was a main indicator of longitudinal change in visuospatial and verbal memory factors, while visuospatial and verbal memory factors were not main indicators of change in the processing speed factor (Finkel et al., 2007).

3.3.2. The effect of age on the cognitive organization

Two studies found differences in the cognitive organization in relation to the age (Garcia-Cabello et al., 2021; Wright et al., 2021). Specifically, both studies found that late middle age individuals were characterized by a modular organization of four factors, while older age individuals showed a modular organization of three factors. However, four studies observed that the cognitive organization did not vary when comparing groups of different ages (Finkel et al., 2005, 2007; Hatahet and Seghier, 2024; Salthouse and Ferrer-Caja, 2003) or when following a group over time in a longitudinal design (Finkel et al., 2005).

Interestingly, although the cognitive organization did not differ across age, these studies found an effect of age on the direct performance of the different cognitive factors. Salthouse et al. (2015) found a decline in general cognitive performance throughout age, with this decline being most notable around age 65. In relation to memory, several studies reported a negative association with age (Krueger et al., 2009; Leritz et al., 2016; Salthouse and Ferrer-Caja, 2003), characterized by a continuous and moderate decline over time (Finkel et al., 2005). Furthermore, Oh et al. (2014) found a negative correlation between age and performance in visual memory. Regarding processing speed, a negative association with age was reported in two studies (Krueger et al., 2009; Salthouse and Ferrer-Caja, 2003), characterized by a pronounced slowing with increasing age (Finkel et al., 2005). In relation to executive functions, Leritz et al. (2016) reported no significant associations between age and performance in working memory. Regarding language, Krueger et al. (2009) reported a negative association with age, while Leritz et al. (2016) could not confirm this result. Furthermore, a longitudinal study reported that language remained stable throughout age, although a modest decline was observed at age 65 (Finkel et al., 2005). It is possible that all these changes occur at the same pace across cognitive domains without affecting (Garcia-Cabello et al., 2021; Wright et al., 2021) or just minimally affecting the cognitive organization with increasing age (Finkel et al., 2005, 2007; Salthouse and Ferrer-Caja,

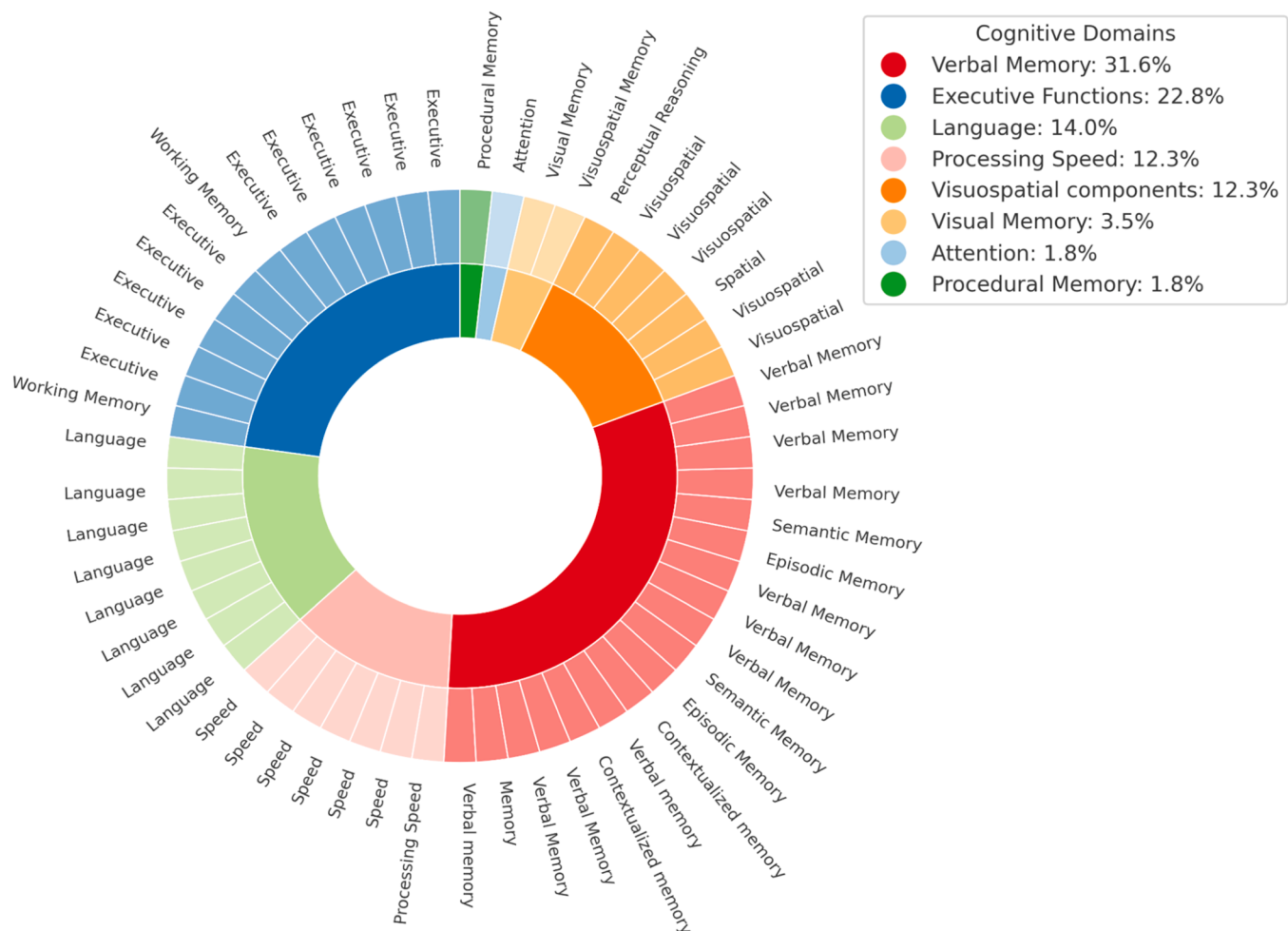


Fig. 2. Summary of cognitive factors. This figure synthesises the data reported across studies. Due to the variability of methodological approaches and reported metrics across studies, the synthesis was done theoretically. Firstly, using expert judgment through consensus agreement of two co-authors, we represented the reported cognitive domains into the outer ring of the figure. While we used the terminology and original labels provided by most of the studies, some labels were slightly modified for clarity, harmonization of terms and to facilitate theoretical assessment of cross-study consistency. The outer ring thus depicts the factors obtained by each individual study based on their original multivariate analysis (structure effects level). Secondly, we theoretically mapped the outer ring into broader cognitive factors represented in the inner ring. This was done in a manner that study-specific factors in the outer ring could be combined across studies with different methodologies. The legend reports the percentage of studies that reported each cognitive factor, ordered from highest to lowest representation.

2003).

4. Discussion

The main objective of this systematic review was to review the scientific evidence about a potential “cognitive organization” and assess whether that organization differs with age.

In general, regardless of the cohort, the age range, the cognitive tests used, or the analytical method used, we consistently identified a cognitive organization mainly made of four factors: verbal memory, language, executive functions, and processing speed. A fifth factor including visuospatial components was observed in several studies (Blujus et al., 2025; Finkel et al., 2005, 2007; Garcia-Cabello et al., 2021; Hollinshead et al., 2022; Krueger et al., 2009; Salhouse and Ferrer-Caja, 2003; Wright et al., 2021). The vote-counting approach showed that principal component analysis studies provided four to five factors (components), instead of four as indicated by the other three methodological approaches. The possibility to find four versus five factors may also be beyond methodological approach and be explained by a tendency to use a greater number of tests with verbal content or to assess cognitive domains traditionally related to the left hemisphere of the brain. The reason for the coherence of these factors across studies could

be related to differentiated neural network systems underpinning the different factors: prefrontal circuits for the executive factor (Alexander et al., 1986), medialtemporal circuits for the memory factor (Squire and Bayley, 2007), left-predominant fronto-temporal networks for the language factor (Zhang et al., 2014), right-predominant fronto-temporo-parietal networks for the visuospatial spatial factor (Nowrangi et al., 2014) and the integrity of the white matter of the brain for the processing speed factor (Kloppenborg et al., 2014). While we excluded confirmatory factor analysis based on hypothesis-driven cognitive organizations, it is worth noting that Gaynor et al. (2025) tested 12 a-priori defined organizations. The authors found that the four-factor model was the best-fitting model. This model was represented by episodic memory, executive function, language and attention. Furthermore, this four-factor model was similar across race/ethnicity groups. Other confirmatory factor analyses reported results on four (Rizio and Diaz, 2016; Siedlecki et al., 2012) or five (Mungas et al., 2014) factor solutions.

We also reviewed the associations between the different cognitive factors. We reported that [Blujus et al. \(2025\)](#) found moderate to strong correlations between all cognitive factors except for a weak correlation between episodic memory and perceptual reasoning. This weak correlation is consistent with classical models proposing partial interactions

between cognitive systems for verbal and visuospatial processing compared to other cognitive systems (Baddeley, 2000). Meanwhile, Finkel et al. (2005) and Garcia-Cabello et al. (2021) found a significant association between processing speed and all the other investigated cognitive factors. This result supports the hypothesis that processing speed may be an influential factor of age-related cognitive change (Salthouse, 1996). However, it should be noted that this significant association could also be explained by the role of global white-matter integrity in cognition (Madden et al., 2009). Therefore, a shared neurobiological substrate underlying cross-domain performance could be modifying these associations. Future research should control the effect of potential cross-domain factors when investigating the cognitive organization or test their possible mediating effect on the association between cognitive domains.

Regarding the effect of age on the “cognitive organization”, the literature addressing this question is limited and results are mixed. On the one hand, two studies found differences in the cognitive organization across age groups (Garcia-Cabello et al., 2021; Wright et al., 2021). On the other hand, three studies reported that the cognitive organization did not vary when comparing groups of different ages (Finkel et al., 2007; Hatahet and Seghier, 2024; Salthouse and Ferrer-Caja, 2003) or when investigating a population longitudinally over time (Finkel et al., 2005). This discrepancy could be related to the methodology (graph theory analysis in the first two studies), which may reflect a greater capacity of the technique to detect age effects on the dynamics of the cognitive organization, compared to that capacity of analytical methods employed in the other three studies. Specifically, both Garcia-Cabello et al. (2021) and Wright et al. (2021) found that the middle age group was characterized by a modular organization of four factors, while the older age group showed a modular organization of three factors. This result could reflect a dedifferentiation pattern in cognitive performance (Garrett, 1946). The term dedifferentiation refers to an age-related shift from a specialized (differentiated) cognitive organization towards a more interconnected and less specialized organization in later life (Baltes et al., 1980), possibly driven by age-related brain changes and compensatory mechanisms (Baltes and Lindenberger, 1997; Hult  r et al., 2015). In such framework, fluid intelligence has been suggested to decline with age whereas crystallized intelligence may remain stable or increase (Lindenberger, 2001). Consequently, it has been proposed that the age-related dedifferentiation may primarily affect fluid cognitive processes. Therefore, the changes in cognitive organization observed in later life and discussed in this paragraph may reflect increasing interdependence among fluid domains rather than a uniform loss of specialization across all cognitive domains. Garcia-Cabello et al. (2021) reported that this dedifferentiation was characterized by a stronger association of processing speed with other cognitive factors with increasing age. Similarly, Finkel et al. (2007) and Salthouse and Ferrer-Caja (2003) reported that processing speed contributed to the performance of other cognitive functions in their cohort.

The studies reporting that the “cognitive organization” may remain invariant with age used different methodological approaches and are relatively older (Finkel et al., 2005, 2007; Salthouse and Ferrer-Caja, 2003). The findings from these studies are in line with a review from 2006 that suggested that cognitive variables were organized into the same cognitive factors throughout life (Salthouse and Davis, 2006). However, while the effect of age on the “cognitive organization” has not been widely reported, numerous studies have indicated an effect of age on direct cognitive performance. Specifically, the negative effect of age on memory, executive functions, visuospatial functions, and processing speed is well established in the literature (Ferreira et al., 2015; Harada et al., 2013; Lachman, 2004; Oschwald et al., 2019; Schaie, 2005; Schroeder and Salthouse, 2004; Tisserand and Jolles, 2003; West, 2001). In the current study, we suggest that it is possible that all these direct changes occur at the same pace across cognitive domains without affecting or just minimally affecting the “cognitive organization” with increasing age. Hence, longitudinal studies using multivariate methods

should clarify whether the “cognitive organization” changes across ages. Some concrete examples of methodologies that could be tested in future work are multi-wave invariance to test if cognitive organization (a given factor solution) is consistent across different time points; assess longitudinal changes in graph modularity based on individual single-subject cognitive networks; or coupling loadings stability to network metrics.

The findings synthesized in this systematic review support the idea that cognition is organized in a rather stable and distinct cognitive manner, and that this cognitive organization may change slightly or not at all with increasing age. This review also highlights the advantages of multivariate methodologies when it comes to describing the associations or interrelationships across multiple variables, particularly in the complex context of cognitive aging. This approach and the learnings may have clinical implications. For example, the knowledge on cognitive organization may help clinicians interpret neuropsychological test results in the context of the entire cognitive profile. One clear aspect is the importance of processing speed when assessing performance in other cognitive tasks. We thus highlight the relevance of including neuropsychological protocols that comprehensively assess cognition through multiple cognitive domains and their subcomponents. Specifically, both for clinical and research purposes, the data from our review aligns with established principles of neuropsychological assessment that suggest the need to represent cognitive domains by at least two cognitive tasks (Lezak et al., 2012). This suggestion should be investigated systematically in the context of multivariate analysis on cognitive data, using cohorts that also represent ethnic minorities and people with low education. For example, since cognitive tasks are known to tap on multiple cognitive domains, in the context of multivariate analyses, some authors have suggested that only one task that includes at least three variables representing different cognitive processes may be sufficient (Hatahet and Seghier, 2024). Finally, we acknowledge that the field needs to continue delving into cognitive organization. Such an effort may help increase our current knowledge about compensatory mechanisms in cognitive aging, improve clinical interpretation and use of neuropsychological tests, and promote personalized programs for the promotion of healthy cognitive aging.

This study has some limitations. We provided a comprehensive narrative synthesis, which mostly relies on a qualitative descriptive analysis. A meta-analysis would have helped further identify the cognitive organization in a quantitative way. However, due to the lack of quantitative data in most of the primary studies covered, as well as the heterogeneity in the methodological approaches across studies, a meta-analysis could not be performed. The lack of quantitative data is likely because most of the included studies used a multivariate methodology to reduce the dimensionality of their cognitive variables, but not to explicitly investigate the cognitive organization. We hope that the current article will stimulate that future studies explicitly investigate the cognitive organization in aging. As studies with similar methodologies are published, a future prospect would include confirming our current findings with a quantitative approach. The different methodological approaches and metrics reported across studies also precluded us from identifying cognitive domains across studies using consistency metrics such as Tucker’s congruence. Instead, we synthesized the domains theoretically based on expert judgement upon consensus agreement using standard principles of construct validity in neuropsychological assessment (Lezak et al., 2012). The different methodological approaches across studies may also explain the discrepancy in age-related changes in the cognitive organization. While the two graph theory studies reported differences in the cognitive organization across age groups, this was not the case by the studies using other methodologies. Screening and extraction in the original search from 2022 were done by one single reviewer and the selected studies were verified by a second reviewer. To minimize risks related to single-reviewer screening, the updated review in 2025 was done blindly and independently by two reviewers with verification by a third reviewer.

In conclusion, we identified a cognitive organization that is rather

stable across studies, cohorts, and methodologies. This cognitive organization includes four factors, i.e. memory, language, executive functions, and processing speed. Several studies have also identified a fifth factor including visuospatial abilities. This cognitive organization should be confirmed in future studies directly investigating the cognitive organization. Furthermore, it is yet to be clarified whether this cognitive organization remains invariant throughout age, while the current literature shows that aging does have an effect on these cognitive factors separately (age-related effects on direct measures of cognitive performance). Longitudinal studies using a multivariate methodology on a sufficient number of cognitive variables are a priority. Advancing in our understanding of cognitive aging can result in a more accurate and personalized clinical assessment and intervention in people at risk of cognitive impairment.

Author contributions

EG-C contributed to the design of the study, organized the database and reviewed the references for their eligibility, contributed to the interpretation of the data, and wrote the first draft of the manuscript. AH contributed to organize the database and review the references for their eligibility, contributed to the interpretation of the data, and reviewed the manuscript. YM contributed to organise results and discussion and reviewed the first draft of the manuscript. LP-L contributed to acquisition of data and reviewed the first draft of the manuscript. JB contributed to the conception and design of the study, obtained funding, co-supervised the study, and revised the final version of the manuscript. DF contributed to the conception and design of the study, verified the eligibility of the references included, wrote sections of the manuscript, contributed to the interpretation of the results, obtained funding, and supervised the study. All authors approved the submitted version.

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Declaration of Competing Interest

Daniel Ferreria consults for BioArctic and has received honoraria from Esteve. All other co-authors declared no conflicts of interest relevant to the current study.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at [doi:10.1016/j.arr.2025.102997](https://doi.org/10.1016/j.arr.2025.102997).

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