



Experimental Aging Research

An International Journal Devoted to the Scientific Study of the Aging Process

ISSN: 0361-073X (Print) 1096-4657 (Online) Journal homepage: www.tandfonline.com/journals/uear20

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To cite this article: A. Merlini, I. Gabbatore, A. Marini & F. M Bosco (02 Dec 2025): Affective and Cognitive Theory of Mind in Aging: What's the Role of Executive Functions and Cognitive Reserve on the Decline?, *Experimental Aging Research*, DOI: [10.1080/0361073X.2025.2586970](https://doi.org/10.1080/0361073X.2025.2586970)

To link to this article: <https://doi.org/10.1080/0361073X.2025.2586970>



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Affective and Cognitive Theory of Mind in Aging: What's the Role of Executive Functions and Cognitive Reserve on the Decline?

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ABSTRACT

Background: Theory of Mind (ToM), the ability to infer others' mental states, is central to social interaction and may be sensitive to age-related differences. This study explored variations in cognitive and affective ToM across adulthood and examined the roles of executive functions (EFs), general cognition, and Cognitive Reserve (CR).

Methods: Ninety-six participants were assigned to three groups: Young Older Adults (20–40), Older Adults (65–75), and Senior Older Adults (76–86). Cognitive ToM was assessed with the Strange Stories and II Order Stories tasks, and affective ToM with the Reading the Mind in the Eyes Test. Measures of processing speed, working memory, long-term memory, EFs (updating, shifting, inhibition), and CR were included.

Results: Both cognitive and affective ToM varied by age group, with younger adults performing better than older groups. Updating and shifting predicted ToM performance, accounting for group differences in cognitive ToM and partially in affective ToM. CR, particularly occupational activity, moderated the association between age group and cognitive ToM: differences emerged at low CR but not at high CR levels.

Conclusions: Findings suggest that age-related differences in ToM are associated with executive functioning and that higher CR may mitigate these differences, supporting the role of cognitive engagement in social-cognitive maintenance.

ARTICLE HISTORY


Received 6 September 2025
Accepted 5 November 2025

Introduction

Theory of Mind (ToM) is a complex and fundamental human ability that enables individuals to infer others' mental states, including beliefs, emotions, desires, and intentions. First introduced by Premack and Woodruff (1978), ToM is widely recognized as a cornerstone of social functioning (Yeh, 2013), enabling everyday interactions, social intelligence and interpersonal competence across the lifespan (Grainger et al., 2023; Preckel et al., 2018; Tirassa et al., 2006).

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 Supplemental data for this article can be accessed online at <https://doi.org/10.1080/0361073X.2025.2586970>

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Empirical research has consistently supported the multicomponential nature of ToM (Bosco et al., 2009; Brizio et al., 2015; Gabbatore et al., 2024; Jarvis et al., 2024), distinguishing primarily between a *cognitive* (or *cold*) component and an *Affective* (or *hot*) component, in line with the proposal by Shamay-Tsoory and Aharon-Peretz (2007). Cognitive ToM refers to the capacity to infer others' thoughts, beliefs, and intentions, while affective ToM, by contrast, involves the ability to infer others' emotions and feelings (Shamay-Tsoory et al., 2006). The selective nature of the two components, i.e., cognitive and affective, is indicated by a variety of studies in the cognitive neuroscience framework, using neuroimaging or neurostimulation (Kalbe et al., 2010; Laillier et al., 2019; Shamay-Tsoory et al., 2009). Furthermore, the distinction between cognitive and affective ToM is supported by evidence in developmental studies (Gabriel et al., 2021; Vetter et al., 2013), as well as by clinical studies in adulthood investigating, among others, psychiatric and neurodegenerative diseases (Bosco et al., 2024; Hillmann et al., 2021; Le Bouc et al., 2012; Walzak & Loken Thornton, 2018).

Moreover, ToM ability includes the understanding of *first-order* cognitive processes, namely the ability to self-represent that another person has mental states, and *second-order* processes, namely the ability to understand that another person has mental states about another person's mental states (Wimmer & Perner, 1983). Second-order representations, are more complex, develop later (Wimmer & Perner, 1983) and decline earlier, e.g., in Alzheimer's disease (Gregory et al., 2002).

Findings on the pattern of age-related differences of ToM in healthy aging remain mixed. Early studies (see for example Happé et al., 1998), had suggested that ToM may be preserved or even enhanced in older adulthood, potentially reflecting increased "social wisdom." However, these early conclusions have been frequently questioned due to the lack of control for general cognitive variables, such as fluid and crystallized intelligence (Moran, 2013), which may also undergo a decline along aging. More recent studies tend to indicate lower ToM performance in older age groups (see Marini et al., 2025; Henry et al., 2013 for a review).

With regard to cognitive ToM, a general age-related decline is consistently reported (Charlton et al., 2009; Fischer et al., 2017; Maylor et al., 2002; Phillips et al., 2011): younger adults typically outperform older adults above 70 years of age (Duval et al., 2011) on tasks requiring belief comprehension, particularly in second-order false belief tasks that demand more complex recursive reasoning about another person mental states on a third person (false) belief (McKinnon & Moscovitch, 2007; Raimo et al., 2022; Slessor et al., 2007). Findings concerning affective ToM are more varied (Fischer et al., 2017): some studies – such as those employing the *Faux Pas Test* (Stone et al., 1998) or the *Reading the Mind in the Eyes Test* (RMET; Baron-Cohen et al., 2001) – have found no significant age-related effect on the performance scores (Bottiroli et al., 2016; Castelli et al., 2010; Li et al., 2013; MacPherson et al., 2002; Wang & Su, 2013). Others, however, reported a decline in affective ToM in older adults, especially in tasks involving the inference of complex emotions from gaze or dynamic visual stimuli (Slessor et al., 2007). This inconsistency may be partly attributable to ceiling effects, small samples or the heterogeneity of the assessment tools used (e.g., verbal vs. visual modalities) and differences in task demands (Duval et al., 2011). Studies comparing cognitive and affective ToM within the same task have yielded mixed results. For instance, while Bottiroli et al. (2016) observed a decline in cognitive but not in affective ToM, other authors (Baksh et al., 2018; Fischer et al., 2017; Ruitenberg et al., 2020)

reported a decline in performance in both the domains. Notably, regardless of task accuracy, older adults tend to exhibit longer response times than younger individuals in both first- and second-order ToM tasks, whether cognitive or affective, suggesting a general slowing in social-cognitive processing (Ruitenbergh et al., 2020).

The relationship between ToM and other cognitive functions is a critical area of investigation, as ToM performance relies on neurocognitive resources that are sensitive to aging. General cognitive functions such as processing speed, working memory and semantic and episodic memory (i.e., the knowledge of generic information about the world vs. the capacity to recollect individual and specific events, respectively; Baddeley, 2001) have been identified as potential mediators of age effects on ToM (Charlton et al., 2009; Fischer et al., 2017; Rakoczy et al., 2012), as age-related declines in these supporting functions may contribute – either directly or indirectly – to ToM impairments. Crystallized intelligence (e.g., vocabulary knowledge) may act as protective factor to contrast ToM decline (e.g., Bopp & Verhaeghen, 2007), while fluid intelligence (e.g., working memory), which undergoes an age-related deterioration, could precipitate ToM decline (see Moran, 2013 for a review). Nevertheless, it's of notable interest that some studies (Keightley et al., 2006; Sullivan & Ruffman, 2004) found that the ToM decline in senior older adults was independent of age-related changes in fluid abilities (i.e., intelligence, working memory), suggesting that general cognitive functioning and ToM could rely on distinct, and only partially overlapping, cognitive processes and their relative patterns of neural substrates (Schurz et al., 2014). These findings contribute to enlarge and deepen the debate on the independence of ToM from other cognitive abilities (Moran, 2013).

An area that attracted quite much interest concerns the relationship between Executive Functions (EFs; Miyake et al., 2000), i.e., top-down control processes responsible for planning, coordinating, and monitoring cognitive operations, and ToM (see e.g., Bull et al., 2008). It has been proposed that EFs contribute directly to the development of ToM abilities (see Peloquin et al., 2023; Devine & Hughes, 2014 for a metanalysis), and increased executive demands have been found to result in systematically poorer ToM performances by both younger and older adults (German & Hehman, 2006), thus suggesting that EFs support the representational system. Moreover, EFs are known to decline with age (see Maldonado et al., 2020 for a review) and many studies examining the impact of their deterioration on late-adulthood (Bottiroli et al., 2016; Charlton et al., 2009; Clemente et al., 2023; Duval et al., 2011; Fischer et al., 2017; Rakoczy et al., 2012; Ruitenbergh et al., 2020), identified a reduced ToM performance that has been claimed to be ascribable to this EFs' decline. Among the EFs, shifting, namely the ability to flexibly change perspectives, appears to have a role in solving higher-order ToM tasks that require perspective switching (Peloquin et al., 2023). Similarly, both correlational and mediation analyses have shown cognitive ToM to be significantly associated with EFs performance, and particularly with inhibition and working memory updating (Bailey & Henry, 2008; Bernstein et al., 2011; Charlton et al., 2009; German & Hehman, 2006; Maylor et al., 2002; McKinnon & Moscovitch, 2007). Moreover, working memory updating has emerged as a key mediator of the age effect on cognitive ToM (Bottiroli et al., 2016; Phillips et al., 2011) suggesting that age-related declines in the ability to infer mental states may be driven by changes in executive functioning. For tasks involving first-order false beliefs or intention attribution, age appears to have an indirect effect, mediated by EFs (Duval et al., 2011), while some studies (McKinnon & Moscovitch, 2007) indicate that age-related decline in second-order

ToM skills may be direct and not fully mediated by EFs, thus pointing to the impairment of a specialized ToM module, independent from fluid declines.

In contrast, EFs show weaker and often non-significant associations with affective ToM in most studies (Keightley et al., 2006; Mahy et al., 2014; Sullivan & Ruffman, 2004; Wang & Su, 2013), specifically with complex emotion recognition tasks (Duval et al., 2011). Nevertheless, some exceptions have been reported in which, instead, a negative correlation between EFs (namely, inhibition and shifting) and affective ToM was found (Li et al., 2013), and the mediating role of EFs on the affective ToM age-related decline emerged (Rakoczy et al., 2012).

At the neural level, ToM is supported by a distributed network of interconnected brain regions (see Carrington & Bailey, 2009 for a review), including the medial prefrontal cortex (Amodio & Frith, 2006; Frith & Frith, 2021), temporal lobes, anterior cingulate cortex, temporoparietal junction, and inferior parietal lobule (Gallagher & Frith, 2003; Kobayashi et al., 2007; Sommer et al., 2007; Völlm et al., 2006). Specifically, Cognitive ToM has been primarily associated with the dorsolateral prefrontal cortex (Kalbe et al., 2010) and dorsomedial prefrontal cortex (Sommer et al., 2007), regions that also play critical roles in EFs and working memory (Salthouse et al., 2003); moreover, the right temporoparietal junction was found to be part of both the ventral attention network (i.e., the system responsible for directing the attentional focus toward unexpected salient and behaviorally relevant objects in the environment; Corbetta et al., 2008) and the ToM network (Schuwerk et al., 2017). Affective ToM, on the other hand, involves the ventromedial prefrontal cortex, ventral anterior cingulate cortex, and ventral striatum – areas implicated in emotional processing, decision-making, and regulation of social behavior (Sebastian et al., 2012; Shamay-Tsoory & Aharon-Peretz, 2007). Similarly, some brain areas such as the orbital frontal cortex (Hynes et al., 2006) and inferior lateral frontal cortex (Andreasen et al., 2008; Hooker et al., 2010) had been found to account uniquely for affective ToM. Lesion studies (e.g., Xi et al., 2011) have provided evidence of a double dissociation: damage to the ventromedial prefrontal cortex impairs affective ToM, whereas damage to the dorsolateral prefrontal cortex compromises cognitive ToM.

The neural overlap between ToM and other cognitive functions becomes particularly salient in the context of aging. Age-related decline is more pronounced in the dorsal prefrontal cortex (Moran et al., 2012), which supports cognitive ToM and also executive functioning (Salthouse et al., 2003), while the ventral prefrontal cortex, associated with affective ToM, appears relatively preserved (Leclerc & Kensinger, 2010). This differential vulnerability may help explain the selective decline observed in certain ToM components among older adults (Wang & Su, 2013). Functional neuroimaging studies have shown reduced dorsomedial prefrontal cortex activation in older adults during specific ToM tasks (Moran et al., 2012). In addition, white matter integrity, as measured by Diffusion Tensor Imaging (DTI), is significantly correlated with ToM performance in aging populations (Charlton et al., 2009), and these correlations are mediated by EFs, processing speed, and general intelligence, suggesting that age-related white matter degradation may disrupt the functional connectivity necessary for ToM performance. Aging also impacts other brain regions critical for ToM performance, such as the superior temporal sulcus (Sowell et al., 2003), which is involved in decoding social cues, such as eyes, faces and biological motion (Frith & Frith, 2003). Older adults often exhibit difficulties in interpreting biological motion cues to actions (Billino et al., 2008; Norman et al., 2004) and emotions (Insch et al., 2012), a key social cue linked to intentionality (Frith & Frith, 2003); difficulties in social decoding may partially mediate age-related declines in reasoning about false beliefs (Phillips et al., 2011).

Considering the neuropsychological decay of aging on ToM ability, it is especially compelling to investigate potential moderating factors that may attenuate age-related decline. One such factor is Cognitive Reserve (CR), defined as the brain's capacity to compensate for challenges and maintain cognitive performance through its structural attributes or engagement of broader neural networks (Stern, 2012). In recent years, there is a growing interest in the reorganization of neural circuits (Castelli et al., 2010) and the role of CR in preserving cognitive functions (Delgado-Losada et al., 2019). ToM abilities, as well, have begun to receive empirical attention, both in clinical populations (Buonocore et al., 2018; Lavrencic et al., 2018) and in cognitively healthy older adults (Fastame & Carta, 2023; Lavrencic et al., 2016; Li et al., 2013), specifically exploring the role that education, occupational activity, leisure time activity in compensating the effect of age-related decline. However, despite some promising findings (Şandor et al., 2025), the evidence on the protective role of CR on the cognitive and ToM decay remains inconclusive and fragmented. This highlights the need for further systematic investigation to clarify the extent to which CR can mitigate the detrimental effects of aging on mindreading capacities.

Study Aim

The present study aimed to investigate age-related differences in ToM and examine the cognitive mechanisms and protective factors that may influence ToM performance across the adult and aging period. Specifically, the study pursued the following objectives:

- (1) To examine age-related differences by comparing the performance of distinct age groups – Young Adults (20–40 years old), Older Adults (65–75 years old), and Senior Older Adults (76–86 years old) – on the Cognitive and Affective components of ToM, as well as on EFs (i.e., updating, shifting, and inhibition).
- (2) To explore the associations between ToM abilities and relevant demographics (Age and Education), general cognitive functions (Processing Speed, Working Memory and Long-Term Memory), EFs (Updating, Shifting, and Inhibition) and CR (Educational, Occupational, Leisure-time).
- (3) To identify the cognitive predictors of ToM performance in older age, testing the incremental contribution of demographic factors, general cognitive abilities, EFs, and CR indicators to the variance on overall (Global) ToM performance as well as of Cognitive and Affective ToM performance.
- (4) To examine whether EFs mediate the relationship between age and ToM, in order to clarify the extent to which executive decline accounts for age-related changes in ToM abilities.
- (5) To test whether CR moderates the impact of aging on ToM performance, buffering against age-related decline in Cognitive, Affective and overall (Global) ToM.

Materials and Methods

Participants

This study is part of a multicenter research project on healthy aging, conducted in collaboration with another Italian university. The sample consisted of 96 individuals,

including 64 older participants (aged 65 to 86 years) divided into age-based subgroups of 32 participants each: Older Adults (OA; age range = 65–75 years; $M = 69.94$, $SD = 3.29$), Senior Older Adults (SOA; age range = 76–86 years; $M = 81.09$, $SD = 3.37$), and 32 Young Adults (YA, aged 20 to 40 years, age range = 20–40 years; $M = 27.91$, $SD = 5.47$). The three groups (OA, SOA and YA) were balanced in terms of sex (14 women and 14 men per group). Moreover, the three groups were matched for educational level, which ranged between primary school license and university degree ($\chi^2_{(4, N=96)} = 127$, $p = .998$).

For all participants inclusion criteria were being Italian native speakers, absence of significant cognitive decline, verified by a score ≥ 19.5 on the Montreal Cognitive Assessment (MoCA, Nasreddine et al., 2003), adequate language comprehension, as assessed by a short version of the Token Test (TT; De Renzi & Vignolo, 1962), cutoff ≥ 4.5 ($M = 4.937$, $SD = .181$), and adequate language production ability, based on the Naming subtest of the Aachen Aphasia Test (AAT; Huber et al., 1983), cutoff $\geq 108/120$ raw scores ($M = 117.160$, $SD = .279$). Cognitive status was assessed using the Italian version of the MoCA, with reference to Italian normative data (Conti et al., 2015). In line with these norms, a cutoff score of ≥ 19.5 ($M = 23.662$, $SD = 2.187$) was adopted to exclude participants with significant cognitive impairment. This value reflects cultural and educational corrections validated for the Italian population, which typically yields lower MoCA raw scores than the original English norms. Exclusion criteria were an history or current diagnosis of psychiatric or neurological disorders, severe sensory impairments (e.g., uncorrected vision or hearing loss), history of substance abuse and use of mood stabilizing medication.

Procedure

Participants were recruited from local social clubs, senior centers, and cultural associations, as well as via the major social media platforms (e.g., Facebook, Instagram, X). Participation was voluntary and people demonstrating interest in the research project were provided with a letter containing a detailed explanation about the purposes of the project and the experimental procedures. If they met the inclusion criteria, participants were enrolled in the study after signing a written informed consent and a privacy notice in accordance with the Declaration of Helsinki.

All assessment procedures were administered by master's degree students in psychology previously trained to use standardized instructions and scoring procedures provided in each task's manual. The testing material was divided into two sessions according to two different randomized orders, aiming to reduce cognitive load and fatigue that could have compromised the results and avoid any bias due to order effect. The assessment sessions were conducted individually in a quiet setting, either at the university facilities or at the participant's home; each session lasted about one hour, with the possibility for the participant to ask for breaks or interrupt the procedure in any moment.

Materials and Tasks

A comprehensive depiction of the experimental materials and tasks employed is presented in Figure 1.


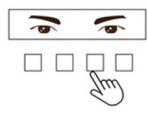

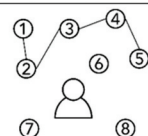
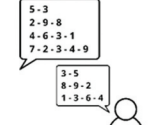

<i>a. Theory of Mind measures</i>	
	<p><i>Cognitive ToM</i></p> <p>A selection of 6 items from the <i>Strange Stories</i> task (Happé, 1994, adapted by Mazzola & Camaioni, 2002), targeting the comprehension of first- and second-order ToM (Wimmer & Perner, 1983; Perner & Wimmer, 1985). Two second-order false belief tasks, namely <i>John and Mary</i> (Wimmer & Perner, 1983) and <i>Peter's Birthday</i> (Sullivan et al., 1994) tasks, requiring participants to infer what one character believes about what another character thinks (i.e., "He thinks that she thinks..."). The total achievable score for Cognitive ToM tasks was 8, as each item was scored 0/1.</p>
	<p><i>Affective ToM</i></p> <p><i>Reading the Mind in the Eyes Test</i> (RMET; Baron-Cohen et al., 2001), which evaluates the ability to infer emotions based on subtle facial cues, in nonverbal modality. Participants are asked to look at 36 photographs showing the eye region of a variety of faces and select the most appropriate emotional state from four descriptors proposed. One point is awarded for each correct response (maximum score: 36).</p>
	<p><i>Global ToM</i></p> <p>A comprehensive index of Global ToM was computed for each participant by calculating a weighted sum of the two previously described components, i.e., Cognitive and Affective ToM. This measure was designed to capture the shared variance between the two components while controlling for their distinct scoring scales, representing general mentalizing capacity and providing a more stable and reliable summary measure of overall ToM performance across individuals.</p>
<i>b. General cognitive functions measures</i>	
	<p><i>Processing Speed</i></p> <p>Trail Making Test Part A (TMT-A; Reitan, 1958; Giovagnoli et al., 1996). In this task, participants are instructed to connect a sequence of numbered circles (1 to 25) in ascending numerical order, as faster as they can. The time taken to complete the task corresponds to the raw score; in order to align the directionality of the scores with those of the other measures the values are reversed to ensure that higher scores reflect greater ability.</p>
	<p><i>Working Memory</i></p> <p>Digit Span tasks from the Wechsler adult intelligence scale (WAIS-IV; Wechsler, 1997; De Beni et al., 2008). Specifically, we administered the backward condition, where participants are required to recall a list of numbers in reverse order with respect to the original presentation. The series range from 2 to 8 digits, and the raw score corresponds to the total number of correct series reproduced, for a maximum of 16.</p>
	<p><i>Long-Term Memory</i></p> <p>Immediate and Deferred Recall Test (Spinnler & Tognoni, 1987). Participants are presented with a brief narrative read aloud by the examiner and are instructed to recall its content both immediately and after a delay of approximately 10 minutes, during which they engage in unrelated nonverbal tasks. Performance is scored based on the number of key events and details recollected (ranging from 0 to 8 for both immediate and deferred recall).</p>

Figure 1. Overview of the materials and tasks employed in the study to assessing the examined variables, i.e., (1a) ToM components (Global, cognitive and affective), (1b) general cognitive functions (processing Speed, Working Memory, Long-term Memory), (1c) executive functions (Updating, Shifting and Inhibition) and (1d) cognitive reserve.

Statistical Analyses

All analyses were conducted using SPSS (Version 29.0.1.0), with a significance level of $\alpha = .05$. Bonferroni corrections were applied to adjust for multiple comparisons where appropriate.

First, to examine age-related differences in ToM performance, a preliminary one-way analysis of variance (ANOVA) was conducted with age group (three levels: YA, OA and



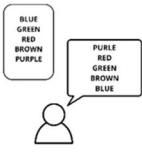

<i>c. Executive Functions measures</i>	
	<p><i>Updating</i></p> <p>Listening Span Test (Daneman & Carpenter, 1980; adapted by Pazzaglia et al., 2000). Participants are presented with sets of sentences, starting from two and gradually increasing to a maximum of six per set. They are required to make a true/false judgment on the content of each sentence, and subsequently recall the final word of each sentence within the set, performing two conflicting tasks. Performance scores correspond to the number of correct final words remembered.</p>
	<p><i>Shifting</i></p> <p>Modified Card Sorting Test (mCST; Nelson, 1976). Participants are asked to place 48 response cards sequentially according to shared attributes - colour (yellow, red, green, blue), shape (circle, cross, triangle, star), and number (ranging from 1 to 4) - by matching them with one of four reference cards. The correct sorting rule must be inferred based on feedback provided by the examiner, and it has to change every 6 correct placed cards. Performance scores correspond to the number of correctly sorted cards.</p>
	<p><i>Inhibition</i></p> <p>Stroop Colour and Word Test (SCWT; Brugnolo et al., 2016), consisting of the sequential presentation of three stimulus tables: the first containing colour names printed in black ink, the second coloured squares, and the third colour names printed in an ink colour incongruent with the word meaning (colours in this version: blue, green, red, brown, and purple). Participants are instructed to read aloud in the shortest time possible firstly the words, then the colours of the squares, and in the last table to name the ink colour of the incongruent items, resisting the interference of the written words. This condition specifically assesses inhibitory control, as it requires the suppression of automatic reading responses in favour of naming the ink colour. Performance scores correspond to the number of correct responses within the first 30 seconds.</p>
<i>d. Cognitive Reserve</i>	
	<p><i>Cognitive Reserve Index</i></p> <p>The Cognitive Reserve Index questionnaire (CRIq; Nucci et al., 2013) is a validated instrument developed to assess an individual's CR. The CRIq examines three core domains: educational attainment, occupational history, and engagement in leisure activities. Each domain is evaluated through structured questions investigating duration, intensity, and cognitive demands of relevant life experiences. Each dimension provides a separate score and the resulting composite score reflects the estimated level of cognitive reserve, where higher scores indicate a greater capacity of cognitive resilience.</p>

Figure 1. Continued.

SOA) as the between-subjects factor and Global ToM score as the dependent variable. Subsequently, age-related differences in specific ToM components and EFs were assessed using two separate multivariate analyses of variance (MANOVAs). The first MANOVA (3×2 design) included age group as the between-subjects factor and Cognitive ToM and Affective ToM scores as dependent variables. The second MANOVA (3×3 design) evaluated age group differences across three EFs domains: Updating, Shifting, and Inhibition. Bonferroni-adjusted post hoc comparisons were conducted to examine pairwise group differences. Assumptions of normality and homogeneity of variance were tested prior to all analyses and were satisfied.

Second, Pearson's correlation analyses were conducted to explore the relationships between Affective and Cognitive ToM and all the other demographic and cognitive variables assessed, including age and education, general cognitive functions, EFs and CR measures. Given the number of pairwise correlations conducted, p-values were corrected for multiple testing using the False Discovery Rate (FDR) approach according to the Benjamini-Hochberg procedure (Benjamini & Hochberg, 1995). This method was chosen to balance Type I error control with statistical power in the context of exploratory correlational analyses.

Third, three hierarchical regression analyses were performed on the subsamples of OA and SOA (64 participants) separately for Global, Cognitive and Affective ToM as dependent variables. Predictors were entered in four successive blocks using a stepwise selection approach: (1) Age and years of Education; (2) the three General Cognitive Functions, i.e., Processing Speed, Working Memory and Long-term Memory; (3) the three EFs, i.e., Updating, Shifting and Inhibition; and (4) the four CR indices, i.e., Educational, Occupational, Leisure-time and Total. To conduct these analyses, all variables had been mean-centered to reduce nonessential collinearity and enhance the interpretability of the results.

Fourth, two mediation models were estimated to assess whether executive functions mediate the relationship between Age and ToM performance (Global, Cognitive and Affective). Mediation analyses were conducted using the Model 4 of PROCESS macro for SPSS (version 4.2; Hayes, 2022), which employs a nonparametric bootstrap procedure with 5,000 samples to estimate the indirect effects. The PROCESS macro was selected for its methodological robustness and statistical validity, even when applied to small samples. In the mediation analyses, only Executive Function (EF) measures (Updating, Shifting, and Inhibition) were entered as mediators, as they are theoretically recognized as the core control processes underpinning age-related differences in ToM (e.g., German & Hehman, 2006; Moran, 2013). General cognitive measures (Processing Speed, Working Memory, and Long-term Memory) were not included to preserve model parsimony and statistical power, and to avoid potential multicollinearity among correlated predictors (Preacher & Hayes, 2008).

Lastly, to examine whether CR moderates the relationship between Age and ToM (Global, Cognitive and Affective), three moderation analyses was conducted using Model 1 of the PROCESS macro for SPSS (version 4.2; Hayes, 2022). Statistical significance for mediation and moderation models was evaluated using bootstrapping with 5,000 resamples and it was considered significant if the 95% bias-corrected confidence interval for the interaction effect did not include zero.

Power Analysis

Post hoc statistical power analyses were performed using G*Power 3.1 (Faul et al., 2009) to assess the adequacy of the sample size across each analysis, based on the observed effect sizes obtained from the data. For the one-way ANOVA conducted on Global ToM for the 3 levels of age groups (YA, OA and SOA), with the observed effect size (partial $\eta^2 = .205$) converted into Cohen's $f(V) = .507$, a sample size of 96 participants and an alpha level of .05, the analysis indicated a statistical power ($1 - \beta$) of approximately .99, suggesting a very high likelihood of detecting a true effect of age group on Global ToM performance. For the 3 (age group: YA, OA, SOA) \times 2 (ToM component: Cognitive and Affective) MANOVA, conducted on the total sample of 96 participants, the observed effect size (Pillai's Trace = .255) was converted into Cohen's $f^2(V) = .342$ to estimate statistical power, indicating a medium effect size, and the resulting power ($1 - \beta$) to detect the observed effects was .99. The separate 3 \times 3 MANOVA on EFs (Updating, Shifting and Inhibition) yielded similar power estimates, with Pillai's Trace, indicating a very large effect, and Power

$(1 - \beta) > .99$. The obtained power values were well above the conventional threshold of .80 (Cohen, 1988), indicating great sensitivity to identify age effects on ToM components.

Pearson correlation analyses assessing associations among cognitive and reserve-related variables demonstrated high sensitivity, with statistical power $\geq .88$ for detecting medium-sized effects ($r = .30$) in a sample of 96 participants across 15 variables, applying the Benjamini–Hochberg correction for multiple comparisons. However, the sample size was insufficient to reliably detect small effects ($r = .20$), a limitation that should be considered when interpreting the results of these analyses.

Post hoc statistical power analyses were conducted for the hierarchical multiple regression models; for the Global ToM model, which included 4 predictors and yielded an observed effect size of $f^2 = .63$ ($R^2 = .385$), the achieved power ($1 - \beta$) was calculated to be .99 with a sample size of 64 and $\alpha = .05$. For the Cognitive ToM model, which included 3 predictors and yielded an observed effect size of $f^2 = .36$ ($R^2 = .266$), the achieved power ($1 - \beta$) was calculated to be .98, while for the Affective ToM model, which comprised five predictors and produced a larger effect size ($f^2 = 0.78$, from $R^2 = .439$), the resulting statistical power was .99, indicating that the regression was highly powered to detect a large effect. The minimum detectable f^2 with this design at 95% power and $\alpha = .05$ was approximately $f^2 = .30$, indicating that both regression models had excellent statistical power to detect the observed effects, but they were less powered to find smaller effects.

Post hoc statistical power analysis was performed for the multiple regression model predicting Global ToM from Age and the three mediators. For a linear multiple regression with 3 predictors, $N = 96$ and an effect size of $f^2 = .855$ (derived from $R^2 = .461$), the achieved power ($1 - \beta$) was estimated to be $> .99$, indicating a very high sensitivity to detect the presence of effects in the model, as for the Cognitive ToM model with an effect size of $f^2 = .423$ (from $R^2 = .298$), the achieved power ($1 - \beta$) was calculated to be $> .99$. A similar result was obtained for the multiple regression model predicting Affective ToM, based on the observed $R^2 = .403$, corresponding to an effect size of $f^2 = .674$, the achieved statistical power ($1 - \beta$) was $> .99$. Given this sample size, with this design at 95% power and $\alpha = .05$, the minimum detectable f^2 was approximately $f^2 = .20$, indicating a good power to find also medium effects.

The post hoc power analysis for the moderation models revealed that the study had only about 56% power to detect an interaction effect of the observed size ($f^2 = .073$): with $N = 64$, the study was adequately powered to detect a moderate interaction effect, but underpowered for small effects, suggesting a moderate power and indicating a risk of non-detecting small interaction effects.

Results

Age-Related Difference in Global, Cognitive and Affective ToM

The one-way between-subjects ANOVA conducted to examine age-related differences among age groups on *Global ToM* scores revealed a significant main effect of *Age group* ($F(2, 93) = 11.96, p < .001$), with a large effect size ($\eta^2_p = .205$), indicating that ToM performance varied significantly across age groups. Bonferroni-adjusted post hoc comparisons showed that YA scored significantly higher on the Global ToM measure compared to

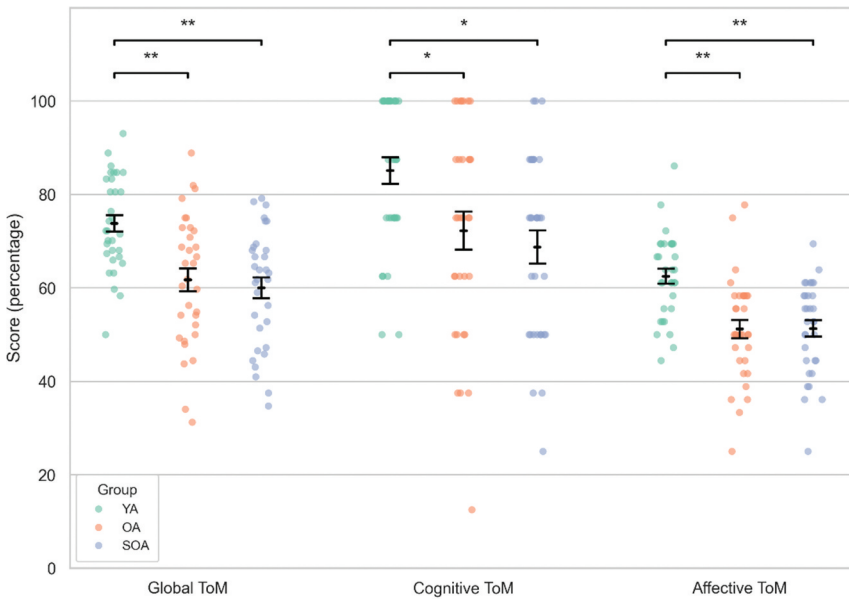


Figure 2. Means (expressed in percentages) and standard errors for each ToM component evaluated (Global, Cognitive and Affective), in each age group (YA = Young Adults, 20–40 years old; OA = Older Adults, 65–75 years old; SOA = Senior Older Adults, 76–86 years old). * $p < .05$, ** $p < .001$.

OA ($p < .001$), and SOA ($p < .001$). The difference between older adults and significantly older adults was not statistically significant ($p = 1.000$).

A multivariate analysis of variance (MANOVA) was conducted to examine the effect of *Age group* (YA, OA and SOA) on two components of ToM (*Cognitive* and *Affective*). The multivariate test revealed a significant effect of *Age group* (Pillai's Trace = .255, $F(4, 186) = 6.79$, $p < .001$, $\eta^2_p = .127$), and significant effects of *Age group* was found on both *Cognitive* ($F(2, 93) = 6.01$, $p = .004$, $\eta^2_p = .115$) and *Affective ToM* ($F(2, 93) = 13.21$, $p < .001$, $\eta^2_p = .221$). Bonferroni-adjusted post hoc comparisons revealed that YA scored significantly higher than both OA and SOA on both components. Specifically, for *Cognitive ToM*, YA outperformed OA ($p = .034$) and SOA ($p = .004$), with no significant difference between the two older groups ($p = 1.000$). Similarly, for *Affective ToM* scores, YA scored significantly higher than both OA and SOA ($p < .001$), while no significant difference emerged between the older groups ($p = 1.000$). See Figure 2

Age-Related Difference in Executive Functions

The MANOVA showed a significant and strong multivariate effect of *Age group* (YA, OA and SOA) on EFs (Updating, Shifting, and Inhibition) performance (Pillai's Trace = .618, $F(6, 184) = 13.72$, $p < .001$, $\eta^2_p = .309$). Specifically, significant *Age group* effects were found for all three EFs measures: *Updating* ($F(2, 93) = 28.63$, $p < .001$, $\eta^2_p = .381$), *Shifting* ($F(2, 93) = 5.43$, $p = .006$, $\eta^2_p = .105$) and *Inhibition* ($F(2, 93) = 47.03$, $p < .001$, $\eta^2_p = .503$). Bonferroni-adjusted post hoc comparisons revealed that YA performed significantly

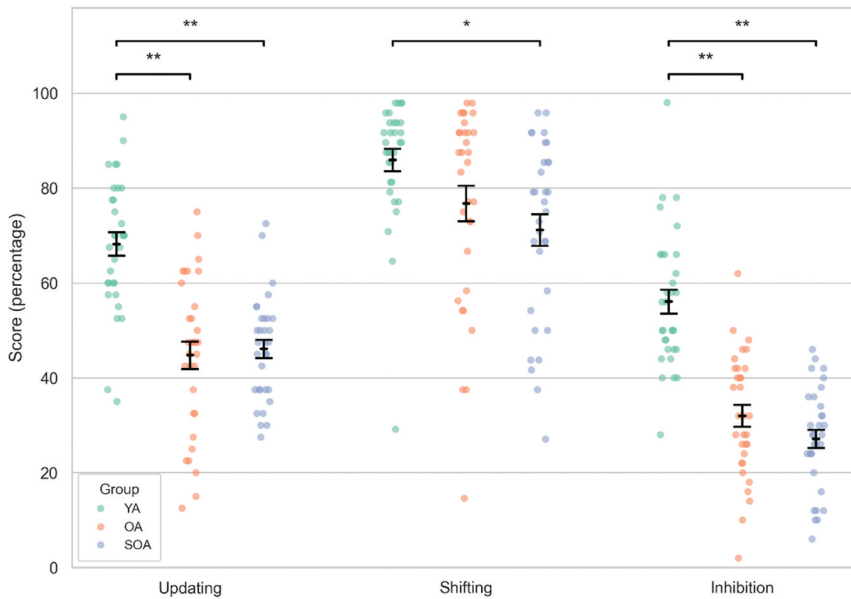


Figure 3. Means (expressed in percentages) and standard errors for each EFs component evaluated (Updating, Shifting, Inhibition), in each age group (YA = Young Adults, 20–40 years old; OA = Older Adults, 65–75 years old; SOA = Senior Older Adults, 76–86 years old). * $p < .05$, ** $p < .001$.

better than both older groups in *Updating* ($p < .001$) and *Inhibition* ($p < .001$). For *Shifting*, YA significantly outperformed the SOA ($p = .005$), but the differences between YA and OA ($p = .136$), and between OA and SOA ($p = 1.000$), were not statistically significant. The results are shown in [Figure 3](#)

Correlations Between tom Components and Demographic, General Cognitive Functions, EFs and CRIs

Pearson's correlation coefficients are reported in [Table 1](#), exploring the associations between Global, Cognitive and Affective ToM performances and demographic (i.e., Age and Education) Cognitive variables and CR variables, which descriptive values are shown in [Table 2](#). Descriptive statistics for the general cognitive functioning measures (Processing Speed, Working Memory, and Long-term Memory) across the three age groups are reported in [Supplementary Table S1](#).

Global ToM scores were positively correlated with years of Education ($r(94) = .454, p < .001$), cognitive – Processing Speed ($r(94) = .361, p = .001$), Working Memory ($r(94) = .447, p < .001$), Long-Term Memory ($r(94) = .317, p = .004$) – and EFs variables – Updating ($r(94) = .605, p < .001$), Shifting ($r(94) = .534, p < .001$), and Inhibition ($r(94) = .321, p = .003$), as well as with Total ($r(62) = .386, p = .004$) and Educational CRI ($r(62) = .307, p = .021$). Global ToM was, finally, negatively correlated with Age ($r(94) = -.459, p < .001$).

A similar pattern of results was found for Cognitive ToM, although slightly weaker, being positively associated with Education ($r(94) = .414, p < .001$), Attention ($r(94) = .215,$

Table 1. Pearson's correlation coefficients (*r*) between the investigated variables: ToM components (Global, Cognitive and Affective), demographics (Age and Education), general cognitive functions (i.e., Processing Speed, Working Memory and Long-term Memory), EFs (i.e., Updating, Shifting and Inhibition) and CR measures (i.e., Educational, Occupational, Leisure-time and Total CRI).

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.
1. Global ToM	–														
2. Cognitive ToM	.923**	–													
3. AffectiveToM	.703**	.375**	–												
4. Age	–.459**	–.347**	–.463**	–											
5. Education	.454**	.414**	.329*	–.179	–										
6. Processing Speed	–.361**	–.215*	–.474**	–.447**	–.250*	–									
7. Working Memory	.447**	.371**	.391**	–.260*	.302**	–.264**	–								
8. Long-term Memory	.317**	.242*	.317**	–.316**	.282**	–.213*	.327**	–							
9. Updating	.605**	.483**	.566**	–.620**	.502**	–.412**	.410**	.372**	–						
10. Shifting	.534**	.443**	.468**	–.323**	.353**	–.328**	.358**	.323**	.470**	–					
11. Inhibition	.321**	.258*	.296**	–.729**	.205*	–.275**	.270**	.249*	.545**	.244*	–				
12. Occupational CRI	.200	.249*	.010	.014	.652**	–.200	.299*	.124	.300*	.220	.094	–			
13. Educational CRI	.307*	.285*	.201	.238	.856**	–.158	.291*	.244*	.343**	.305*	–.184	.596**	–		
14. Leisure-time CRI	.118	.027	.235	.079	.016	–.156	.167	.233	.115	.168	.109	–.022	.001	–	
15. Total CRI	.386*	.311*	.331*	–.013	.720**	–.314*	.459**	.347**	.484**	.361**	.173	.748**	.682**	.570**	–

Two-tailed significance levels are indicated as follows: * $p \leq .05$, ** $p < .01$. Benjamini-Hochberg correction was applied.

Table 2. Descriptive analysis (Means and standard deviations) for the CR variables examined, as measured by the subcomponents of the CRIq (i.e., Educational, Occupational, Leisure-time and Total CR), in the OA and SOA groups.

Variables	Older Adults (OA) M (SD)	Senior Older Adults (SOA) M (SD)
Occupational CRI	113.84 (23.23)	110.13 (23.81)
Educational CRI	111.84 (17.04)	115.38 (13.99)
Leisure-time CRI	115.58 (22.81)	118.84 (27.31)
Total CRI	118.29 (19.05)	119.56 (18.57)

Table 3. Hierarchical multiple linear regression analysis of ToM performance (Global, Cognitive and Affective).

Steps and predictors	b	SE B	β	t	p
Global ToM					
Step 1: Education	.088	.060	.179	1.466	.148
Step 2: Working Memory	.111	.126	.109	.883	.381
Step 3: Shifting	.066	.028	.285	2.354	.022
Updating	.095	.046	.252	2.043	.046
Cognitive ToM					
Step 1: Education	.110	.048	.267	.267	.026
Age	-.030	.018	-.188	-1.676	.099
Step 2: Shifting	.053	.023	.272	.272	.025
Affective ToM					
Step 1: Education	.294	.136	.305	2.171	.034
Age	-.027	.040	-.071	-.661	.511
Step 2: Processing Speed	-.063	.023	.295	-2.802	.007
Step 3: Updating	.251	.080	.370	3.143	.003
Step 4: Occupational CRI	.063	.023	-.358	-2.746	.008

Note. Stepwise regression analysis identified and included only the relevant variables in the model, while eliminating those not deemed statistically significant. Steps included 1. Demographics (Age, Education), 2. General Cognitive Functions (Processing Speed, Working Memory, Long-term Memory), 3. Executive Functions (Updating, Shifting, Inhibition), 4. Cognitive Reserve (Occupational, Educational, Leisure-time and Global).

$p = .050$), Long-Term Memory ($r(94) = .242, p = .026$), Updating ($r(94) = .483, p < .001$), Shifting ($r(94) = .443, p < .001$), Inhibition ($r(94) = .258, p = .019$), Total CRI ($r(62) = .311, p = .021$) and Educational CRI ($r(62) = .285, p = .031$), while negatively correlated with Age ($r(94) = -.347, p = .001$).

Affective ToM was positively associated with Education ($r(94) = .329, p = .003$), Processing Speed ($r(94) = .474, p < .001$), Working Memory ($r(94) = .391, p < .001$) Long-Term Memory ($r(94) = .317, p = .004$), Updating ($r(94) = .566, p < .001$), Shifting ($r(94) = .468, p < .001$), Inhibition ($r(94) = .296, p = .007$) and Total CRI ($r(62) = .331, p = .015$), while showing a negative correlation with Age ($r(94) = -.463, p < .001$).

Predictive Relationships Among EFs and ToM Components

Three hierarchical regression analyses were conducted with ToM components (Global, Cognitive and Affective) as dependent variables. See Table 3.

In the Global ToM model, the overall model was significant ($F(4, 59) = 9.090, p < .001$), explaining 38.5% of the variance (adjusted $R^2 = .343$), with four significant predictors: Education was a positive predictor ($\beta = .179, p = .148$) as well as Working Memory

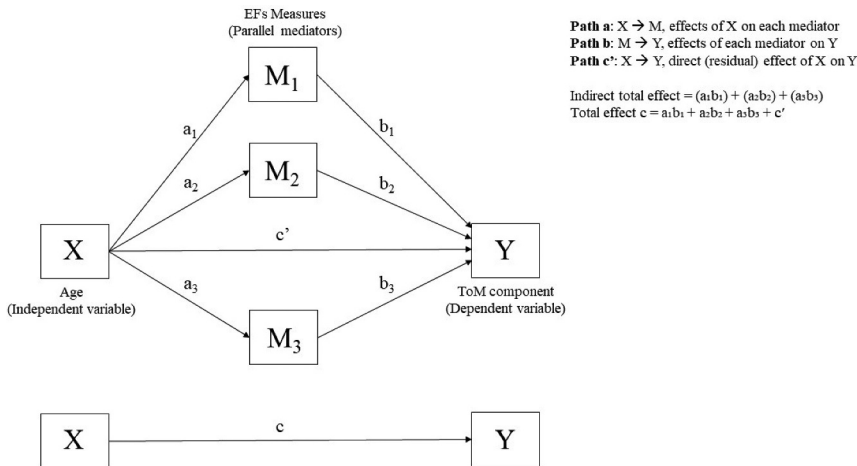


Figure 4. Diagram of a multiple mediation model in which the effect of Age (X) on ToM performance (Y) is hypothesized to occur both directly and indirectly through three EFs mediators: Updating (M_1), Shifting (M_2), and Inhibition (M_3). Each mediator receives an effect from X (paths a_1 , a_2 , a_3) and transmits it to Y (paths b_1 , b_2 , b_3), alongside a direct path from X to Y (c').

($\beta = .109$, $p = .381$), yet in the final model they didn't appear to be significant anymore, after the inclusion of Shifting ($\beta = .285$, $p = .022$) and Updating ($\beta = .252$, $p = .046$), which emerged as significant positive predictors.

The Cognitive ToM model was overall significant ($F(3, 61) = 7.37$, $p < .001$), explaining 26.6% of the variance (adjusted $R^2 = .230$). Three predictors were retained: Education ($\beta = .267$, $p = .026$) and Shifting ($\beta = .272$, $p = .025$) emerged as significant positive predictors, whereas Age did not reach statistical significance ($\beta = -.188$, $p = .099$).

For Affective ToM, the final model ($F(5, 59) = 9.22$, $p < .001$) accounted for 43.9% of the variance (adjusted $R^2 = .391$) and included five predictors: Education ($\beta = .305$, $p = .034$), Age ($\beta = -.071$, $p = .511$), Processing Speed ($\beta = .295$, $p = .007$), Updating ($\beta = .370$, $p = .003$), and Occupational CR ($\beta = -.358$, $p = .008$).

Executive Functions Mediation of ToM Analysis

As displayed in Figure 4, three mediation models were conducted to explore the significance of direct and indirect effects of Age (X) on ToM components (respectively: Global, Cognitive and Affective) through the three mediators (M), represented by the EFs measures (Updating, Shifting, Inhibition).

Global ToM: the overall model was significant, $R^2 = .461$, $F(4, 91) = 19.48$, $p < .001$. Age significantly predicted all three executive functioning variables: Updating ($\beta = -.186$, $p < .001$, 95% CI $[-.234, -.137]$), Shifting ($\beta = -.125$, $p = .001$, 95% CI $[-.201, -.050]$), and Inhibition ($\beta = -.280$, $p < .001$, 95% CI $[-.333, -.226]$). In turn, Updating was a significant positive predictor of Global ToM ($\beta = .125$, $p = .0003$, 95% CI $[.059, .192]$), and so was Shifting ($\beta = .075$, $p = .0006$, 95% CI $[.033, .117]$), while Inhibition was not a significant predictor ($\beta = -.028$, $p = .315$, 95% CI $[-.083, .027]$). While the direct effect of Age on Global ToM was not statistically significant ($\beta = -.018$, $p = .117$,

95% CI [-.041, .005]), total indirect effect of Age on Global ToM through the mediators was significant, (indirect effect = -.025, 95% CI [-.044, -.008]), as well as specific indirect effects via Updating (indirect effect = -.023, BootSE = .007, 95% CI [-.037, -.012]) and Shifting (indirect effect = -.009, BootSE = .004, 95% CI [-.018, -.003]), but not via Inhibition (indirect effect = .008, BootSE = .007, 95% CI [-.006, .022]).

Cognitive ToM: The overall model was statistically significant, $F(4, 91) = 9.63, p < .001$, accounting for approximately 29.8% of the variance ($R^2 = .298$). Age significantly predicted all three EFs variables: Updating ($\beta = -.186, p < .001, 95\% \text{ CI } [-.234, -.137]$), Shifting ($\beta = -.125, p = .001, 95\% \text{ CI } [-.201, -.050]$), and Inhibition ($\beta = -.280, p < .001, 95\% \text{ CI } [-.333, -.226]$), suggesting age-related declines in executive functioning across domains. In turn, Updating ($\beta = .078, p = .010, 95\% \text{ CI } [.019, .136]$) and Shifting ($\beta = .050, p = .008, 95\% \text{ CI } [.014, .087]$) were significant positive predictors of Cognitive ToM, whereas Inhibition did not significantly predict ToM ($\beta = -.011, p = .650, 95\% \text{ CI } [-.060, .037]$). The direct effect of Age on Cognitive ToM was not statistically significant ($\beta = -.007, p = .467$), suggesting full mediation. The total indirect effect of Age on Cognitive ToM through executive functioning was significant (indirect effect = -.018, 95% CI [-.033, -.002]); specifically, significant indirect effects were found through both Updating (indirect effect = -.014, 95% CI [-.026, -.004]) and Shifting (indirect effect = -.006, 95% CI [-.013, -.001]), while the indirect effect via Inhibition was not significant (indirect effect = .003, 95% CI [-.009, .015]).

Affective ToM: The overall model was significant, $F(4, 91) = 15.34, p < .001$, accounting for 40.3% of the variance ($R^2 = .403$). Age significantly predicted all three EFs components: Updating ($\beta = -.186, p < .001, 95\% \text{ CI } [-.234, -.137]$), Shifting ($\beta = -.125, p = .001, 95\% \text{ CI } [-.201, -.050]$), and Inhibition ($\beta = -.280, p < .001, 95\% \text{ CI } [-.333, -.226]$). In turn, both Updating ($\beta = .216, p = .001, 95\% \text{ CI } [.085, .346]$) and Shifting ($\beta = .110, p = .009, 95\% \text{ CI } [.028, .192]$) significantly predicted Affective ToM performance, while Inhibition did not ($\beta = -.076, p = .166, 95\% \text{ CI } [-.185, .032]$). The direct effect of Age on Affective ToM remained significant after accounting for the mediators ($\beta = -.048, p = .034, 95\% \text{ CI } [-.093, -.004]$), suggesting partial mediation. The total indirect effect of Age on Affective ToM through the three mediators combined was found to be significant (indirect effect = -.032, BootSE = .0186, 95% CI [-.071, .004]). At the level of individual mediators, significant indirect effects were observed through Updating (indirect effect = -.040, BootSE = .013, 95% CI [-.069, -.016]) and Shifting (indirect effect = -.014, BootSE = .006, 95% CI [-.027, -.003]), whereas the indirect effect via Inhibition was not significant (indirect effect = .021, BootSE = .016, 95% CI [-.012, .053]).

Cognitive Reserve Moderation on ToM Analysis

A moderation analysis was conducted to examine whether CR moderates the effect of Age on ToM components. The occupational component of CR was selected as the moderator variable in line with the current conceptualization of CR, which emphasizes the importance of domain-specific assessments over global composite measures (Stern et al., 2023). This variable was chosen because it had shown relevant associations in prior analyses and provided theoretically distinct information, avoiding redundancy with educational

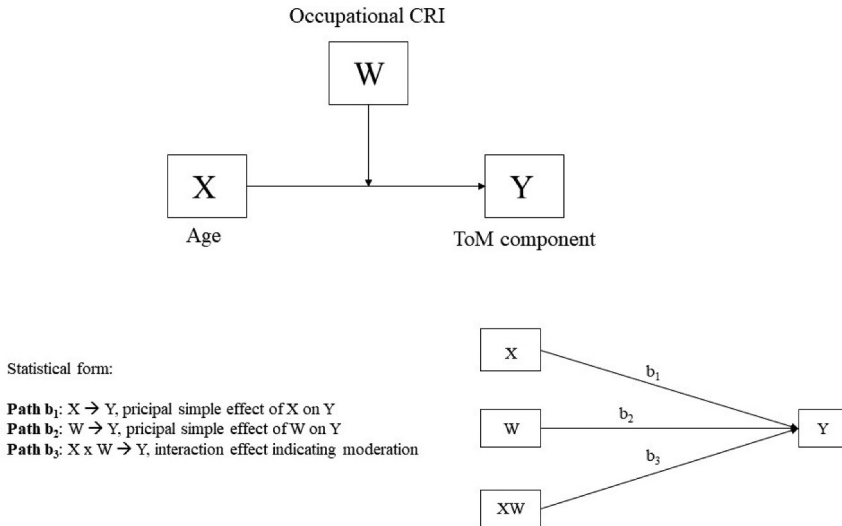


Figure 5. Diagram of the moderation models testing whether the relationship between Age (X) and ToM (Y) is moderated by Occupational CRI (W). The interaction term ($X \times W$) captures whether the effect of Age on ToM changes depending on levels of W. The model includes main effects of X and W, as well as their interaction.

attainment, which was already accounted for through the inclusion of the variable “Education.” A diagram representing the conceptual and the statistical form of the analysis can be found in Figure 5

For Global ToM, the overall model was statistically significant ($F(3, 61) = 5.36, p = .002$), accounting for 20.9% of the variance in Global ToM scores ($R^2 = .209$). There was a significant main effect of Age on Global ToM ($\beta = -.052, p = .050, 95\% \text{ CI } [-.104, -.001]$), indicating that higher age was associated with lower ToM performance. The main effect of Occupational CRI was not significant ($\beta = -.019, p = .435, 95\% \text{ CI } [-.0687, .0299]$), and neither was the interaction between Age and CRI ($\beta = .0024, p = .083, 95\% \text{ CI } [-.0003, .0052]$) nor the change in R^2 associated with the interaction term was $\Delta R^2 = .040, F(1, 61) = 3.10, p = .083$. To probe the interaction, the conditional effect of Age on Global ToM was examined at low (16th percentile), average (50th), and high (84th percentile) levels of Occupational CRI. Age significantly predicted lower ToM scores at low levels of CRI ($\beta = -.110, p = .001, 95\% \text{ CI } [-.172, -.047]$) and at average CRI levels ($\beta = -.053, p = .042, 95\% \text{ CI } [-.105, -.002]$). However, at high levels of Occupational CRI, the effect of Age was not significant ($\beta = .0003, p = .994, 95\% \text{ CI } [-.095, .096]$).

For Cognitive ToM, the overall model was statistically significant ($F(3, 61) = 5.15, p = .003$) and explained 20.2% of the variance ($R^2 = .202$). Neither the main effect of Age ($\beta = -.026, p = .209, 95\% \text{ CI } [-.067, .015]$) nor the main effect of Occupational CRI ($\beta = -.018, p = .360, 95\% \text{ CI } [-.057, .021]$) was statistically significant. However, the interaction term between age and Occupational CRI was ($\beta = .002, p = .039, 95\% \text{ CI } [.001, .005]$), indicating that the relationship between Age and Cognitive ToM depends on the level of Occupational CRI. The inclusion of the interaction term led to a statistically significant increase in explained variance ($\Delta R^2 = .058, F(1, 61) = 4.47, p = .039$). The conditional effect of Age on Cognitive

ToM was examined at low (16th percentile), average (50th), and high (84th percentile) levels of Occupational CRI. Age was a significant negative predictor of Cognitive ToM at low levels of CR ($\beta = -.081, p = .002, 95\% \text{ CI } [-.130, -.031]$). At average levels of CR, the effect was non-significant ($\beta = -.027, p = .182, 95\% \text{ CI } [-.068, .013]$), and at high levels of CR, the effect of Age reversed in direction but remained non-significant ($\beta = .024, p = .532, 95\% \text{ CI } [-.052, .099]$).

By contrast, for Affective ToM, the overall model was not statistically significant ($F(3, 61) = 2.40, p = .076$), explaining only 10.6% of the variance ($R^2 = .106$). There was a significant main effect of Age on Affective ToM ($\beta = -.117, p = .025, 95\% \text{ CI } [-.219, -.015]$), indicating that increased age was associated with lower Affective ToM performance. The main effect of Occupational CRI was not significant ($\beta = -.006, p = .898, 95\% \text{ CI } [-.103, .091]$). Additionally, the interaction between Age and Occupational CRI was not significant ($\beta = .001, p = .840, 95\% \text{ CI } [-.005, .006]$), and the change in explained variance due to the interaction term was negligible ($\Delta R^2 = .001, F(1, 61) = 0.04, p = .840$).

Discussion

The present study investigated age-related differences in Theory of Mind (ToM) abilities in healthy aging. Examining the differences in the Global ToM scores across the three age groups selected, confirmed overall age-related differences, with lower ToM scores among older adults, in line with prior findings (see Henry et al., 2013 for a review). Specifically, younger adults outperformed both older adult groups, confirming an earlier onset of decline reported by Duval et al. (2011), who observed such changes post-70 years. This earlier difference, evident already by age 65, suggests that ToM abilities may show lower performance from this age onward, potentially stabilizing thereafter, as highlighted by the non-significant difference emerged between the two older age groups, a datum that appears in line with recent literature (Bottiroli et al., 2016; Raimo et al., 2022; Wang & Su, 2013).

Both cognitive and affective components of ToM exhibited similar age-related decline patterns in line with prior research on this topic (Bailey & Henry, 2008; Baksh et al., 2018; Duval et al., 2011; Fischer et al., 2017; Keightley et al., 2006; Laillier et al., 2019; Maylor et al., 2002; Raimo et al., 2022; Rakoczy et al., 2012; Ruitenberget al., 2020; Sullivan & Ruffman, 2004; Walzak & Loken Thornton, 2018). The cognitive ToM component, assessed via the *Strange Stories* task (Happé, 1994) and the II order ToM task (Sullivan et al., 1994; Wimmer & Perner, 1983), aligns with a broad consensus in the literature documenting deterioration with age in this task (Charlton et al., 2009; Fischer et al., 2017; Maylor et al., 2002; Phillips et al., 2011; Rakoczy et al., 2012; Wang & Su, 2013) and contradicts earlier studies suggesting preservation of cognitive ToM (Happé et al., 1998; Slessor et al., 2007; Wang & Su, 2006). With respect to affective ToM, our findings support previously reported age-related decline (Duval et al., 2011; Fischer et al., 2017; Raimo et al., 2022; Rakoczy et al., 2012), with even larger effect sizes than those observed in the cognitive domain. This is particularly evident in tasks involving visual emotion recognition (Bailey & Henry, 2008; Pardini & Nichelli, 2009; Phillips et al., 2002; Rakoczy et al., 2012), such as the Reading the Mind in the Eyes Test (RMET; Baron-Cohen et al., 2001), where our results replicate the decline found in prior research (Duval et al., 2011; Fischer et al., 2017; Raimo et al., 2022) and contrast with findings from Yildırım et al. (2019) and Castelli et al. (2010). The literature suggests that age-related impairments in social cue extraction are more pronounced in tasks

requiring the decoding of nonverbal stimuli – such as point-light figures (Billino et al., 2008), emotional expression (e.g., Ruffman et al., 2008), and eye gaze (Slessor et al., 2007) – compared to tasks involving verbal reasoning about emotions, as findings show preserved affective ToM performance in verbal tasks (Bottiroli et al., 2016; Phillips et al., 2011; Raimo et al., 2022; Wang & Su, 2013), possibly due to compensatory engagement of language-related neural regions (Castelli et al., 2010). Neuroimaging studies further support this dissociation, with evidence of relative preservation of ventral prefrontal regions, linked to affective perspective-taking, compared to greater decline in dorsal prefrontal regions, linked to cognitive perspective-taking (Healey & Grossman, 2018).

Correlational analyses revealed significant associations between ToM performance and a range of variables including age, education, general cognitive abilities (Processing Speed, Working Memory, Long-term Memory), and EFs (Updating, Shifting, Inhibition), in line with prior findings (e.g., Cavallini et al., 2013; Duval et al., 2011; Laillier et al., 2019; Rakoczy et al., 2012; Slessor et al., 2007). Notably, in contrast to the mixed results in the literature regarding affective ToM, our data showed stronger correlations between RMET scores and EFs than for the Strange Stories task, further supporting the role of domain-general cognitive mechanisms (see Slessor et al., 2007). Conversely, Cognitive Reserve (CR) indices showed weak or non-significant correlations with ToM measures, consistent with prior findings (Fastame & Carta, 2023; Lavrencic et al., 2016). This lack of robust association suggests that CR may not directly enhance ToM abilities but, instead, act indirectly by supporting compensatory recruitment of executive and neural resources when task demands increase (Stern, 2012; Stern et al., 2023). In other words, CR might promote resilience at the neural or strategic level rather than manifest as superior baseline ToM performance, or through domain-specific mechanism more easily captured in moderation analyses than in simple correlations.

Hierarchical regression models indicated that for Global ToM, EFs – particularly Shifting and Updating – explained the largest share of variance, rendering Age, Education, and Working Memory non-significant. These results suggest that dynamic executive processes mediate the relationship between Age and ToM performance more substantially than static demographic factors. When examining the two ToM components separately, distinct predictive patterns emerged: cognitive ToM was primarily predicted by Shifting ability and Educational level, highlighting the importance of cognitive flexibility and formal knowledge acquisition. In contrast, affective ToM was significantly predicted by Processing Speed, Updating, and Education. Notably, occupational CR was negatively associated with affective ToM, suggesting a possible trade-off between analytical processing strategies and intuitive emotion decoding, or a reduced sensitivity to socio-emotional cues in individuals with high levels of structured cognitive engagement. Age was retained in all regression models but did not emerge as a significant predictor once EFs were accounted for, reinforcing the idea that executive decline, rather than chronological age per se, drives ToM impairments (Bailey & Henry, 2008; Cavallini et al., 2013; Charlton et al., 2009; Phillips et al., 2011; Rakoczy et al., 2012).

Mediation analyses confirmed that age-related differences in EFs – particularly Updating and Shifting – fully mediated the relationship between Age and both Global and Cognitive ToM, in line with prior studies (Bottiroli et al., 2016; Charlton et al., 2009; Li et al., 2013). Inhibition did not contribute significantly, in contrast with Otsuka et al. (2021) and Wang and Su (2013), suggesting that the flexible manipulation of information is more relevant for mental state reasoning than the suppression of dominant responses, in line with prior

findings (Bottiroli et al., 2016; Cavallini et al., 2013; Phillips et al., 2011). For Affective ToM, only partial mediation was observed, indicating a residual direct effect of Age beyond the contribution of EFs. This may reflect additional influences such as socio-emotional changes, motivational factors, or neural alterations in emotion-processing systems (Duval et al., 2011; Slessor et al., 2007). In contrast with Rakoczy et al. (2012), the different trend between Cognitive and Affective revealed that the influence of EFs on ToM component was component-specific. The pattern of partial mediation for Affective ToM suggests the involvement of different cognitive and neural pathways and the presence of additional mechanisms beyond domain-general control processes. Consistent with prior studies (Duval et al., 2011; Slessor et al., 2007; Wang & Su, 2013), Affective ToM appears to rely more heavily on ventromedial and orbitofrontal regions, which are relatively preserved in aging compared to the dorso-lateral prefrontal areas supporting executive control and Cognitive ToM (Healey & Grossman, 2018; Leclerc & Kensinger, 2010). Moreover, affective ToM involves more automatic and emotion-driven processes, such as facial emotion decoding (e.g., Bailey & Henry, 2008; Raimo et al., 2022), which are less dependent on deliberate regulation and therefore less sensitive to age-related executive decline (Henry et al., 2013).

Moderation analyses provided novel insights into the protective role of occupational cognitive reserve. Although the Age \times Occupational CRI interaction was not significant for Global ToM at a conventional level, exploratory probing indicated that age-related declines were most pronounced in individuals with low or average CRI, but were absent in those with high CRI, suggesting a buffering effect consistent with cognitive reserve theory. For Cognitive ToM, this moderation effect was statistically significant: age-related decline was evident only at low levels of CRI and reversed at high levels. These findings support the hypothesis that Occupational CR, often involving cognitively demanding occupations and sustained engagement in complex, socially interactive and problem-solving contexts, may specifically scaffold the preservation of belief-attribution and perspective-taking skills in later life, in line with the recent results of Şandor et al. (2025). In contrast, no moderation by CRI was found for Affective ToM, and CRI did not attenuate age-related decline. This suggests that Affective ToM relies less on domain-general cognitive resources and more on intuitive or socio-emotional capacities that may be more susceptible to age-related neural changes and less modifiable through experiential enrichment. However, the mixed findings about this relationship (i.e., the positive significant correlation between the two components and the negative significant coefficient found in the regression model) point to a complex relationship between these components. Therefore, the non-significant result for the moderation effect should be interpreted with caution, and the analysis would benefit from replication in a larger sample to ensure robustness and reduce the risk of false negatives. Future research adopting longitudinal and multimodal approaches will be essential to clarify these subtle but potentially crucial pathways linking CR and ToM in aging.

The findings of the present study are consistent with existing literature on age-related decline in ToM abilities. They support the notion of a dissociation between Cognitive and Affective components of ToM, and underscore the critical role of EFs – particularly Updating and Shifting – in explaining individual variability in ToM performance. Moreover, the results highlight the heterogeneous nature of decline across ToM subcomponents and point to occupational CR as a potential protective

factor against age-related impairments in social-cognitive functioning. These data provide a valuable baseline for assessing the effectiveness of cognitive training programs aimed at enhancing ToM in older adults, which are developing in the last decade (e.g., Rosi et al., 2015). They also help identify specific cognitive mechanisms – namely EFs – that should be targeted in such interventions and that could enhance ToM plasticity in aging (Lecce et al., 2017). This is especially relevant given that the complex relationship between ToM and EFs also extends to other domains, such as communicative abilities, where the nature of the connection remains unclear (Bosco, Gabbatore, et al., 2018; Bosco, Tirassa, et al., 2018; Parola et al., 2018), and is further puzzled in the context of aging (see Petriglia et al., 2025). In older adults, both pragmatic and cognitive functions supporting communication can be compromised to various degrees (Bambini et al., 2021; Hilviu et al., 2025; Hilviu et al., 2022). Gaining a clearer understanding of the interrelations among ToM, EFs, and other cognitive and communicative skills could therefore support the development of more effective training programs designed to enhance these abilities. Such interventions may ultimately improve older adults' quality of life and help mitigate social isolation (e.g., D'Ortenzio et al., 2025).

A relatively small number of participants represents a limitation of this study, and restricts the ability to detect small effects, especially in the context of moderation analyses. The observation of significant effects despite this limitation is promising and underscores the importance of replicating and extending these findings in larger samples. A further limitation concerns the use of the RMET as a measure of affective ToM. Although this is among the most widely employed and psychometrically validated tasks in social cognition research, recent work (see Higgins et al., 2024) has questioned whether it captures genuine mental state inference or rather relies on emotion recognition and linguistic or perceptual processes. Therefore, the present results on affective ToM should be interpreted with this consideration in mind. Moreover, future studies will need to address this issue by integrating complementary or alternative paradigms able to minimize emotion-recognition or verbal demands, leading to a more specific evaluation of affective ToM in aging. Finally, it should be noted that the present study employed a cross-sectional design, which limits the possibility to draw conclusions about intraindividual changes or causal effects of aging on ToM performance. Future longitudinal studies will allow confirmation of the developmental trajectories and mediating mechanisms proposed here.

Overall, this study contributes to the understanding of ToM preservation in aging and offers promising directions for promoting social-cognitive health and improving quality of life in the elderly population, consolidating emerging evidence and contributing to a more fine-grained analysis of the pattern of ToM decay in aging.

Acknowledgments

We would like to thank *Università delle Tre Età di Nichelino* (Torino) for their collaboration in the recruitment process, and we would like to express our gratitude to all the participants to the research. During the preparation of this work the authors used InstaText and ChatGPT-4 in order to improve the readability and language of the manuscript. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

Disclosure Statement

No potential conflict of interest was reported by the author(s).

Funding

This research was supported by PRIN 2022 PNRR, Prot. n. P2022M9JCM, project title: “Standardization of the Multilevel procedure for discourse analysis and Training program for narrative production in Healthy adults - SMOOTH”. Avviso pubblico n. 1409 del 14/09/2022 – PRIN 2022 PNRR M4C2 Inv. 1.1. Ministero dell’Università e della Ricerca (Financed by EU, NextGenerationEU) – CUP G53D23007250001. Please note that the funding institution did not have any role in the study design, data collection, analysis, interpretation of data and in writing the manuscript.

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Data Availability Statement

The data are not publicly available for privacy or ethical restrictions.

Ethics Approval and Consent to Participate

The Bio-Ethical Committee of the University of Turin approved the study (Protocol No. 202174). All participants signed the informed consent form and gave their written permission to take part into the research project.

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