



# Theory of mind across lifespan from ages 16 to 81 years

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## ABSTRACT

**Purpose:** Impaired theory of mind (ToM) is a neurobehavioral phenotype of epilepsy. Given that the age transitions affect cognitive development and decline, it is important to refine ToM across the lifespan. This study evaluated ToM in healthy subjects, taking into account education, gender, and other functions, aiming to clarify its specificity and relationships to major demographic and cognitive domains.

**Methods:** A hundred and seventy subjects from ages 16 to 81 years (68 men) who received five to 17 years of schooling were evaluated using a Faux Pas Task (FPT) that is solved at the end of childhood and is highly sensitive to brain damage and tests for language, memory, praxis, visual perception, initiative, attention, shifting, and planning. Factor analysis, analysis of variance, and correlation and regression analyses were used to assess the data. **Results:** The analysis yielded six factors: Beliefs, Delusions, and Facts, which express the understanding of mental states and contextual details; Matching-Learning, Executive, and Working Memory. On this basis, six composite scores (CSs) were computed. Age and schooling showed significant effects on the Matching-Learning, Executive, and Working Memory CSs. The FPT raw scores and CSs were unrelated to age or schooling, while females showed better performance than males. The Beliefs CS and FPT scores were predicted by the Executive, Working Memory, Delusions, and Facts CSs and gender.

**Conclusions:** Theory of mind is a specific cognitive domain independent of age and formal education, but related to gender. Working memory, executive functions, and reality examination support some ToM processes. These findings may provide reference points against which impairment can be assessed.

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## 1. Introduction

### 1.1. Theoretical and neural aspects

The understanding of others' and one's own epistemic and affective mental states, called mentalization, mindreading, or theory of mind (ToM), is key to social cognition and interpersonal relations [1]. While ToM was extensively treated in humanities, it entered the scientific literature with Premack and Woodruff's study of nonhuman primates [2], soliciting an early philosophical debate. According to the Simulation-Theory, ToM derives from innate mental states concepts and basic mechanisms of assumption of others' mental states and projection of one's own mental states theory on the others [3]. The Theory-Theory retains that the understanding of one's own and others' mental states derives from personal experiences, knowledge, and education acquired in a particular sociocultural context [4,5].

The ToM is supported by a widespread neural network including the anterior cingulate gyrus, orbital and medial prefrontal cortex, medial temporal lobe, temporoparietal junction, cerebellum, and basal ganglia [6].

Therefore, it may be affected by different brain lesions, as well as by seizures starting in the frontal (frontal lobe epilepsy [FLE]) or temporal lobe (temporal lobe epilepsy [TLE]) or generalized seizures [7–12]. Distressing events, social anxiety, depression, and cumulative traumatic events may also impair ToM in patients with psychiatric disorders [13, 14] or epilepsy [15].

### 1.2. Theory of mind and age

The cognitive functions may vary with age, in particular during the transitional age from adolescence to young adulthood, which may favor development, or from middle age to elderly, which is at risk for cognitive decline [16]. On the other side, brain organization can change substantially as a result of practice and experience and, in healthy people, there is evidence of functional and structural brain changes after repeated motor and mental performance involved in work or leisure activities such as reading, music listening, computer-assisted tasks, or movement coordination [17]. Brain plasticity, triggered by repeated experiences, may cooperate to construct compensatory abilities, overcoming cognitive impairment [18].

Literature concerning ToM in healthy subjects provided conflicting results. Happè et al. [19] observed better ToM performances in the

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elderly in comparison with that in young adults. Maylor et al. [20] and Sullivan and Ruffman [21] described impaired ToM in subjects older than 70 years old in comparison with younger adults. Other studies using different measurements reported no age-related effects [22,23] or various levels of performance in old and very old subjects [24–30]. Few studies concerning epilepsy suggested that, in young and middle-aged healthy controls, age has no influence on ToM [8,15,31]. The epistemic and affective components of ToM [32], as well objective and self-rated ToM abilities [33], may be differently impaired as a function of aging. The ToM decline was attributed to age-related loss of other functions such as fluid intelligence, social cue decoding, information processing speed, updating information, or multiple executive functions [21,24,26–28,30,32–34]. However, some studies distinguished ToM from executive functions, fluid intelligence, memory, language, and information processing [19–21] or suggested that ToM may decline in old and very old subjects independently of other functions [20,25,29,34]. Finally, in healthy middle-aged and old subjects, ToM was predicted by measures of white matter integrity and verbal intelligence, suggesting a more important role for brain connectivity than single cortical regions and that this role is mediated by general cognition [28].

### 1.3. The influence of culture and gender

In healthy subjects, ToM was related to education, as expressed by acquired vocabulary [20] and intelligence level [19], but the level of education or years of schooling were rarely considered. In patients with epilepsy, ToM was predicted by the years of schooling [8,15]. Comparisons between children living in rural and urban zones, people living in US cities and native American Indians, or North American and Asian adults also suggested an influence of social and cultural variables on ToM [35]. Healthy women performed better than men on neuroimaging ToM tasks, showing a greater activation of the medial prefrontal cortex [36], whereas women and men with epilepsy showed no differences on advanced neuropsychological ToM tasks [8].

### 1.4. Domain specificity

Theory of mind development is characterized by acquisition of more and more complex performance. During childhood and adolescence, ToM evolves from precursors such as the ability to distinguish one's own and others' actions; learning by imitation; the recognition of intentional movements of the eyes, mouth, hands, or body; and the ability to pursue the direction of others' gaze and to catch and pursue others' attention. The capacity to solve the first- and second-order false beliefs is reached by ages 7–8 years. Higher-order functions, such as the recognition of Faux Pas (FP), metaphors, and fictions and reading the mind in the eyes, are acquired by ages 11–13 years [37,38]. Such a trend is similar in different sociocultural contexts, suggesting a domain specificity. Previous studies also indicated that ToM development is independent of general intelligence [37,39,40], and it even represents a basis for the development of executive functions [41]. Other findings in favor of ToM's specificity in childhood concern its dissociation from executive functions in autism [42,43], from intelligence in autism and Asperger's syndrome [44–48], and from intelligence and executive functions in Down's and William's syndromes [49]. In adult patients with frontal lobe or right hemisphere injuries [50–52], nontraumatic frontal lobe lesions [53,54], TLE or FLE [8,15,31], or congenital or early onset amygdala lesions [55–57], impaired ToM was also distinguished from other cognitive defects. On the contrary, some studies in preschool healthy children [58,59] or children with autism [44,60–64] suggested that ToM development depends of executive functions, while in healthy adults of different age, ToM was related to intelligence [19], executive functions [23], acquired vocabulary [20], inhibition control [24,32], or the updating of information [30]. The study of brain lesions also attributed ToM to the executive domain or demonstrated that the understanding of intentions and epistemic mental states correlate with executive functions [8,23] or

indicated that ToM relates to interference control [65] or language [66] or that it pertains to general metacognition [67].

### 1.5. Summary and study objectives

Theory of mind has been extensively investigated in children, adolescents, and patients with brain lesions or psychopathological disorders, but little is known about its changes, specificity, and determinants in the healthy adults. Previous studies compared gross epochs of adulthood, such as youth, middle-age, and old-age, or focused on very old subjects. The differences between young and old subjects in terms of ToM have been compared with the changes of memory or executive functions that typically decline with aging. However, there is a large variability of ToM performance in adults of similar age, while gender and education have been rarely taken into account. Many studies have investigated the basic components of ToM, such as the recognition of first-order and second-order false beliefs, although advanced ToM abilities, such as the understanding of metaphors, FP, lies, persuasion, or the coexistence of multiple mental states, which are habitual in adult life, have been inconsistently evaluated. The understanding of epistemic and affective mental states, which may reflect different neural mechanisms, has received poor attention. Theory of mind specificity has never been analyzed, although some studies assessed the interactions between ToM and executive functions, fluid intelligence, information processing, and memory (Table 1).

Given that impaired ToM often marks the neurobehavioral profile of epilepsy, while the transitional ages may affect cognitive improvement and decline, it is important to refine ToM across the lifespan. Furthermore, in different life epochs, gender, education, and other cognitive functions may affect ToM, cooperating to the determination of individual trends. A longitudinal study design may be a valid tool to determine ToM across adulthood. However, such an approach may incur in possible diseases and changes of the sociocultural and environmental context, with secondary impacts on ToM. A long-term assessment of healthy populations up to the elderly is a difficult task because of changes in health, residence, lifestyle, and changes of the investigators. A cross-sectional study design may cover a wide age range in subjects with definite health status and sociocultural background. Neuropsychological tasks focusing on advanced performance could detect subtle changes and the complexity of adults' ToM.

This study extended the pioneering studies of ToM in healthy subjects from ages 16 to 81 years. The specific objectives were as follows: a) to determine advanced ToM performance involving epistemic and affective mental states and interpersonal interactions, in male and female healthy subjects of various age who had received different levels of education, b) to clarify ToM's specificity, and c) to assess the impacts of gender, age, years of schooling, and other cognitive domains on ToM.

## 2. Methods

### 2.1. Participants

From 2007 to 2011, a series of healthy subjects recruited among the hospital staff and visitors, patients' family members, and external people were asked to participate to the study via a phone call and a brief meeting at hospital. The subjects interested in the study were screened for inclusion and exclusion criteria via an interview dealing with demographic features and medical history; medical and neurological examinations were not performed. Italian-speaking consenting participants were included if they were older than 15 years and received at least primary compulsory schooling. Individuals with past or present neurological or psychiatric illnesses, such as stroke, epilepsy, brain tumor, head injury, psychosis, major depression, obsessive–compulsive disorders, alcohol or drug abuse, severe medical illnesses, such as cancer, intractable metabolic disorders, or heart failures that could interfere with brain functions or prevent their cooperation were excluded. Social desirability

**Table 1**

Highlights from previous studies of theory of mind in healthy adults.

References	N (women)	Life epoch (mean age)	years of schooling (age group)*	Functions and tests	ToM performance	The correlates of ToM	Conclusions
Happè et al., 1998 [19]	86 (44)	UK Young (21) US Young (22 years 6 months) Old (73)	14.7 (US Young) Unknown in UK young and old subjects	ToM: HSS (physical; ToM-related). Memory: Jumbled passages.	Similar performance on the physical stories in young and old subjects. Better ToM and worse memory in the old subjects.	–	ToM has specific mechanisms and may be intact in the elderly. Well-educated subjects have better ToM.
Saltzman et al., 2000 [23]		Young (20.87) Old (71.61)	13.11 (Young) 12.75 (Old)	ToM: composite Knower-Guesser test. Intelligence: WAIS vocabulary.	Adequate ToM in old subjects (only impaired in a Knower-Guesser sub test).	Executive functions.	Old subjects may maintain adequate ToM
Maylor et al., 2002 [20]	75 (45)	Young (19) Young-old (67) Old-old (81)	Unknown	ToM: adapted HSS (memory load; no memory load). Intelligence: Mill Hill vocabulary test, digit symbol substitution test. Executive functions: WCST, letter fluency.	Physical stories: similar ToM performance between groups ToM stories with memory load: worse performance in the old-old and young-old subjects than in young subjects. ToM stories without memory load: worse performance in the old-old subjects than in young and young-old subjects.	Fluid and crystallized intelligence, mental speed, memory, age.	ToM declines after age 75. In the young-old subjects, the defects depend of impaired speed and memory. In the old-old subjects, ToM's decline is independent of speed, memory and executive defects.
MacPherson et al., 2002 [22]	90 (45)	Young (28.8) Middle-aged (50.3) Older (69.9)	12.4 (young) 14 (middle-aged) 15 (old)	ToM: FPT. Executive functions: WCST, Self-Ordered Pointing Task, Delayed-Response Task, Gambling task. Emotion recognition: EIT.	Very similar ToM performance in the young, middle-aged and old subjects.	–	Age affects the abilities dependent on the dorsolateral prefrontal cortex, but not ToM and emotion processing.
Sullivan & Ruffman, 2004 [21]	48 (27)	Young (30) Older (73) including Old (68) and Old-old (77) subjects	Unknown	ToM: Adapted HSS, video clips. Emotion recognition: ELT. Intelligence: AH4 fluid intelligence test, NART.	Physical stories: similar ToM performance between groups Strange stories: worse ToM performance in the old subjects but no differences when fluid intelligence is accounted for. Video clips: worse ToM performance independent of fluid intelligence. No differences between old and old-old subjects.	Fluid intelligence, age.	The old subjects have worse ToM than young adults; their impairment in part reflects a decline of fluid intelligence.
German & Hehman, 2006 [24]	47 (37)	Young (19.51) Old (78.22)	12.78 (young) 13.20 (old)	ToM: Story task. Intelligence: Mill Hill vocabulary test, Weschler test of adult reading, Forward and backward digit span, Digit symbol substitution test. Attention and executive functions: CWST, Day-night task, Hayling sentence completion task.	The young and old groups show no significant differences between ToM and control performance. An increase of executive performance demands affects ToM in both groups, with a significantly greater effect in the old group.	Age, memory span, working memory, processing speed, inhibition.	In old subjects, impaired ToM may result from decline of executive functions rather than be specific ToM's decline.
Keightley et al., 2006 [25]	60 (30)	Young (25.7) Older (72.5)	Unknown	ToM: Story task, Cartoon task. Intelligence: Mill Hill Vocabulary Scale, WAIS Letter Number Sequencing subtest. Attention and executive functions: Controlled Oral Word Association, SCWT, HVLT, TMT, TAS-20, JACFEE, JACNeuF.	Similar ToM performance in young and old subjects. In old subjects, ToM is independent of working memory but it relates to personality traits and emotional awareness.	–	The old subjects may preserve ToM that is affected by emotional factors.
McKinnon & Moscovitch, 2006 [26]	24 (gender not reported)	Young (20.12) Older (78.18)	15.90 (old) 14.74 (young)	ToM: tasks and versions of the deontic selection task involving social	Older adults are impaired relative to younger adults on social reasoning. Performance vary as a function of the demands these	–	Old subjects are impaired compared to the young on social reasoning, depending on general cognitive

*(continued on next page)*

Table 1 (continued)

References	N (women)	Life epoch (mean age)	years of schooling (age group) <sup>a</sup>	Functions and tests	ToM performance	The correlates of ToM	Conclusions
Bailey & Henry, 2008 [27]	69 (47)	Young (19.5) Older (72.2)	14.8 (young) 13.09 (old)	contracts and hazardous conditions. ToM: Video clips, Revised Eyes test. Attention and executive functions: CWST, Hayling test, Sentence Completion Test, WAIS-R forward and backward Digit Span, Alternating fluency, Oral Symbol Digit Modality Test.	tasks place on domain-general resources. Impaired ToM in the old subjects.	Inhibition	resources. Inhibitory control is an important mediator of ToM in the elderly.
Charlton et al., 2009 [28]	106 (51)	Middle-aged (55.81) Older (65.61; 75.03; 83.86)	Unknown	ToM: HSS. Intelligence: WAIS verbal and performance tests. Executive functions: WAIS Digit span backward and letter-number sequencing, TMT, WCST, category fluency, CWST. Processing speed: Adult information processing test.	Better ToM in subjects aged 50–59 years. Worse ToM at age 80 to 89 years.	Age, intelligence, information processing speed, white matter integrity.	ToM's decline with age is mediated by performance intelligence, executive functions and information processing speed.
Bernstein et al., 2011 [29]	94 (77%)	Young (19.2) Middle-aged (56.3) Older (67.6)	Unknown	ToM: Continuous false belief task. Memory: CVLT. Executive functions: TMT, CWST, Verbal Fluency. Processing speed: WAIS Digit Symbol subtest. Working memory: WAIS Letter-Number Sequencing. Vocabulary: Extended Range Vocabulary.	Middle-aged and older adults exhibit more false belief bias than young adults, independent of language, executive functions, processing speed, and memory.	Age	ToM's decline with age is independent of age-related cognitive changes.
Phillips et al., 2011 [30]	129 (gender unreported)	Young (25.81) Middle-aged (51.80) Older (73.67)	Unknown	ToM: Beliefs reasoning Video task, Beliefs stories. Executive functions: N-back task, Running memory task, Stroop task, Go-No-go task.	Older subjects are only impaired on the false beliefs tasks. Middle-aged subjects perform as well as the young subjects and obtain the best scores on the true beliefs tasks.	Age, working memory.	ToM's decline in old age is mediated by working memory defects.
Duval et al., 2011 [33]	70 (gender unreported)	Young (23.80) Middle-aged (52.55) Old (70.14)	15.44 (young) 13.95 (middle-aged) 10.36 (old)	ToM: Subjective ToM scale Cognitive ToM tests: Attribution of intention, False beliefs. Affective ToM: Eyes test. Composite ToM test: Tom's taste. Executive functions: TMT, Running span task, CWST, Memory: WMS logical memory.	Subjective ToM is very similar in age groups. Older subjects show worse cognitive and affective ToM than young subjects. Cognitive ToM declines from 70 years onwards.	Cognitive ToM relates to age and executive functions. Affective ToM does not relate to other functions.	The components of ToM are differently affected by age and executive functions.
Wang & Su, 2013 [32]	106 (53)	Young (26.53) Young-old (69.21) Old-old (78.75)	14.47 (young) 14.05 (young-old) 13.50 (old-old)	ToM: cognitive ToM story task. Executive functions: Hayling test.	The older groups perform worse than the young group on cognitive ToM tasks. No differences on the affective ToM task.	Cognitive ToM correlates with inhibition control.	The old subjects are only impaired on cognitive ToM and have intact affective ToM
Cavallini et al., 2013 [34]		Young (23.63) Young-old (64.93) Old-old	17.73 (young) 12.37 (young-old) 12.24 (old-old)	ToM: HSS Memory: working memory span, categorization, lexical decision tests.	The young adult outperform the older ones independent of working memory and inhibitory control.	Age, schooling, memory, and language.	Specific ToM impairment begins after 60 years, independent of other functions.

**Table 1** (continued)

References	N (women)	Life epoch (mean age)	years of schooling (age group) <sup>a</sup>	Functions and tests	ToM performance	The correlates of ToM	Conclusions
		(74.99)		Language: Primary Mental Abilities vocabulary and word fluency.			

CVLT, California Verbal learning Test. EIT, Emotion identification task. ELT, emotion-labelling task. FPT, Faux Pas Task. HSS, Happé Strange Stories. NART, National Adult Reading Test. HVL, Hopkins Verbal Learning Test. TAS-20, Twenty Item Toronto Alexithymia Scale. JACFEE, Japanese and Caucasian Facial Expressions of Emotion. Japanese and Caucasian Neutral Faces JACNeuF. CVLT, California Verbal Learning Test. CWST, Color Word Stroop Test. TMT, Trail Making Test. WMS, Wechsler Memory Scale. WAIS, Wechsler Adult Intelligence Scale. WCST, Wisconsin Card Sorting Test.

<sup>a</sup> Years of schooling.

was not assessed, nor was participation paid. The Institutional review board approved the study which was part of a study in neurological patients and all of the subjects gave their informed consent.

## 2.2. Neuropsychological assessment

The Raven Colored Progressive Matrices (RCPM), Token, Word Fluency (WFT) on Phonemic or Semantic Cues, Digit Span, Corsi Blocks Span, Short Story, Rey Complex Figure (RCF) Copying and Delayed Recall, Tower of London, Weigl Sorting, Attentive Matrices, Trail Making (TMT), and Street Completion (SCT) tests assessed reasoning, language, visuospatial, praxis, executive/attention, working memory, and long-term memory functions [31] (Table 2). Higher test scores indicate better performances, except for the TMT whose score is the number of seconds needed to complete the trail.

The Faux Pas Task (FPT) [68,69] evaluated the recognition and comprehension of social FP by requiring to identify epistemic and affective mental states and to distinguish intentional and nonintentional actions. A subject was asked to read 20 short stories and, after reading each story, to answer a detection question: "Did anyone say something they shouldn't have said?". If they answer "yes", four comprehension questions were asked ("Who said something they shouldn't have said?", "Why shouldn't they have said what they did?", "Why did they say that?", "How did they feel?"), assessing their abilities to identify the character making a FP, to determine the adequacy of interpersonal

behavior, to understand intentions, and to recognize affective states. During each story check, subjects were allowed to look at the passage, preventing memory failures. At the end of each story check, a control question verified if the subject has processed correctly the contextual information. Eight scores were computed: two detection scores indicating the recognition or the exclusion of an FP, four comprehension scores, and two control scores (ranges 0–10). An FPT index (FPT-I), representing the recognition and comprehension of FP relative to the comprehension of the contextual details, was calculated [70], (Table 2).

## 2.3. Statistical analysis

Separate multivariate analyses of variance (MANOVA) compared the test scores obtained by the subject groups divided by age (16–25 years; 26–35 years; 36–45 years; 46–55 years; 56–65 years; 66–81 years), years of schooling (5–11 years; 12–13 years;  $\geq 14$  years), or gender. Significance level was set at  $p \leq 0.002$  for 22 pair-wised comparisons. Two-way analysis of variance (ANOVA), covariance analysis, and  $\chi^2$  were used as indicated. Factor analysis, using multiple components extraction, varimax rotation, and eigen values greater than 1, assessed the distribution of the neuropsychological test scores; factor loadings greater than 0.4 were used for including an item into a specific factor. Separate composite scores (CSs) were computed as the arithmetic means of the Z scores computed from the raw test scores attributed to each factor. Correlation analysis, setting significance level as  $p \leq 0.006$ , and multiple stepwise regression analysis, entering gender, age, and years of schooling as continuous variables, and non-ToM CSs, assessed the determinants of the FPT raw scores and CSs.

**Table 2**

Cognitive functions and neuropsychological tests.

Function	Specific ability	Test <sup>a</sup>
Theory of mind	Existent FP recognition	FP recognition Comprehension question 1 Comprehension question 3
	Comprehension of epistemic mental states	Comprehension question 4
	Comprehension of affective mental states	Nonexistent FP exclusion
	Nonexistent FP	Control questions
Fluid intelligence	Analysis of factual details	Raven colored progressive matrices
	Abstract reasoning	Token test
Language	Sentence comprehension	Word fluency on phonemic and semantic cues
	Lexical-semantic retrieval	Street completion test
Visual processing	Perception of degraded figures	Tower of London
Executive functions and attention	Planning	Weigl sorting test
	Set shifting	Trail making test
	Divided attention	Attentive matrices
	Selective attention	Rey complex figure copying
Constructive praxis	Complex figure copying	Digit span
	Working memory	Corsi blocks span
Long-term memory	Delayed retrieval	Short story recall
		Rey Complex Figure delayed reproduction

<sup>a</sup> References 31, 68, 69. FP, Faux Pas.

## 3. Results

### 3.1. Participants

A hundred and seventy subjects (68 males, 102 females) were selected. Gender distribution was very similar in six groups divided by age and three groups divided by years of schooling (Table 3). The subjects who received 14 or more years of schooling were more numerous in the 26- to 35-year-old group than in other groups, while those who received 5–11 years of schooling (compulsory school) were more numerous in the older group ( $\chi^2 = 37.44$ ,  $p < 0.001$ ) (Table 3).

### 3.2. Neuropsychological test scores

#### 3.2.1. The faux pas task

Analysis of the FPT control scores revealed that seven subjects only made 1–3 mistakes at an FP or no-FP story. The 46- to 65- and 66- to 81-year-old groups obtained the highest and the lowest recognition and comprehension scores, respectively, although these differences were not significant (Pillai's value = 0.29,  $F = 1.11$ ,  $p = 0.29$ ) (Table 4). The groups with different years of schooling also obtained similar scores (Pillai's value = 0.11,  $F = 1.54$ ,  $p = 0.10$ ) (Table 5). Gender showed a global influence on the FPT scores (Pillai's value = 0.12,  $F$

**Table 3**  
Demographic features of the participants divided by gender and years of schooling.

		Gender		
		Men n = 68	Women n = 102	All subjects n = 170
Age groups	16–25	8	12	20
	26–35	21	15	36
	36–45	7	16	23
	46–55	8	21	29
	56–65	13	15	28
	66–81	11	23	34
Schooling groups	5–11	14	35	49
	12–13	35	41	76
	≥ 14	19	26	45
		Years of schooling		
		5–11 n = 49	12–13 (n = 76)	≥ 14 n = 45
Age groups	16–25	4	15	1
	26–35	2	15	19
	36–45	9	9	5
	46–55	7	12	10
	56–65	9	14	5
	66–81 <sup>a</sup>	18	11	5

<sup>a</sup> The older subjects received less years of schooling ( $p < 0.001$ ).

= 2.32,  $p = 0.017$ ), and posthoc tests of the between-subject effects revealed that the females had significantly higher scores at the second comprehension question (“Why shouldn’t they have said what they did?”) [ $F(1) = 11.76$ ,  $p = 0.001$ ] and not significantly higher scores at the third question (“Why did they say that?”) [ $F(1) = 3.77$ ,  $p = 0.05$ ] and total comprehension [ $F(1) = 6.28$ ,  $p = 0.013$ ] (Table 5). In order to verify as to whether age and schooling affect the impact of gender on ToM, a new MANOVA entered these variables as the covariates; results revealed a significant influence for gender (Pillai’s value = 0.11,  $F = 2.94$ ,  $p = 0.006$ ); females outperformed males at the second [ $F(1) = 12.26$ ,  $p = 0.001$ ] and third comprehension question [ $F(1) = 5.12$ ,  $p = 0.025$ ] and total comprehension [ $F(1) = 7.23$ ,  $p = 0.008$ ], while age and schooling, as continuous variables, had no effects. The FPT-I was very similar in the age groups and schooling groups, but it was higher in the females [ $t(168) = -2.35$ ,  $p = 0.02$ ]. Separate two-way ANOVAs entering the age and schooling groups confirmed these results, showing no interactions between the demographic variables. On the contrary, a two-way ANOVA revealed a significant interaction between gender and schooling group (Pillai’s value = 0.22,  $F = 2.15$ ,  $p = 0.005$ ) and, albeit not significant so, an effect of schooling (Pillai’s value = 0.17,  $F = 1.64$ ,  $p = 0.049$ ); the females who received 12 or more years of schooling obtained higher scores at the second and third comprehension question and higher total comprehension scores.

### 3.2.2. Other neuropsychological tests

The MANOVA showed a significant global influence for age (Pillai’s value = 0.97,  $F = 2.66$ ,  $p < 0.001$ ) (supplemental data). Tests of the between-subject effects revealed that, in comparison with all other

groups, the 66- to 81-year-old group had lower Trail Making Test A (TMTA) and Attentive Matrices scores ( $p < 0.001$ ). In addition, the older group had lower RCPM, Token, SCT, RCF Copying, Weigl Sorting, Trail Making Test B (TMTB), and Tower of London scores ( $p \leq 0.002$ ) in comparison with the 16- to 25- and 26- to 35-year-old groups and lower WFT on Phonemic or Semantic Cues, Digit Span, Corsi Block Span, and Short Story scores ( $p < 0.001$ ) in comparison with the 26- to 35-year-old groups. The 36- to 45-, 46- to 55-, and 56- to 65-year-old groups had lower Corsi Block Span, RCF Delayed Recall, and WFT on Phonemic Cues scores ( $p \leq 0.002$ ) than the 26- to 35-year-old group. The 46- to 55- and 56- to 65-year-old groups also had lower Corsi Block Span ( $p \leq 0.001$ ) than the 26- to 35-year-old group.

Schooling also had a significant global influence (Pillai’s value = 0.48,  $F = 3.46$ ,  $p < 0.001$ ) and tests of the between-subject effects revealed significant differences for the TMTA, TMTB, Attentive Matrices, Digit Span, RCF Copying, Weigl Sorting, WFT on Phonemic Cues, and Short Story scores. The subjects who received 5–11 years of schooling obtained significantly lower scores at the RCF Copying, Weigl Sorting, WFT on Phonemic or Semantic Cues, Digit Span, Short Story, Attentive Matrices, TMTA, and TMTB in comparison with those who received more than 12 years of schooling ( $p \leq 0.001$ ) (supplemental data). Females and males obtained similar scores (Pillai’s value = 0.13,  $F = 1.64$ ,  $p = 0.07$ ) (supplemental data).

### 3.3. Factor analysis

Factor analysis of the neuropsychological test scores yielded six factors. The Beliefs, Delusions, and Facts factors comprehended the

**Table 4**  
The Faux Pas Task scores in different age groups.

	16–25	26–35	36–45	46–55	56–65	66–81
Faux Pas recognition	9.90 ± 0.31	9.81 ± 0.53	9.57 ± 0.66	9.69 ± 0.60	9.86 ± 0.36	9.68 ± 0.81
No-Faux Pas exclusion	9.80 ± 0.70	9.75 ± 0.73	9.87 ± 0.34	9.79 ± 0.56	9.82 ± 0.55	9.74 ± 0.79
Comprehension question 1	9.75 ± 0.44	9.72 ± 0.57	9.65 ± 0.57	9.76 ± 0.51	9.82 ± 0.39	9.76 ± 0.49
Comprehension question 2	9.35 ± 0.93	9.31 ± 0.95	9.30 ± 0.97	9.52 ± 0.91	9.75 ± 0.52	9.41 ± 1.18
Comprehension question 3	8.75 ± 1.89	8.58 ± 1.32	8.78 ± 1.35	8.83 ± 1.47	8.79 ± 1.66	7.71 ± 1.85
Comprehension question 4	9.70 ± 0.47	9.44 ± 0.84	9.52 ± 0.73	9.48 ± 0.69	9.71 ± 0.54	9.47 ± 0.71
Total comprehension	37.55 ± 2.91	37.03 ± 2.86	37.22 ± 2.89	37.55 ± 2.91	38.07 ± 2.71	36.35 ± 2.29
Faux Pas control question	9.95 ± 0.22	9.83 ± 0.61	9.87 ± 0.46	10 ± 0	9.96 ± 0.19	10 ± 0
No-Faux Pas control question	10 ± 0	9.86 ± 0.42	9.91 ± 0.29	10 ± 0	10 ± 0	9.97 ± 0.17
Faux Pas Task - Index	1.91 ± 0.11	1.89 ± 0.12	1.89 ± 0.11	1.90 ± 0.11	1.92 ± 0.11	1.86 ± 0.14

**Table 5**  
The Faux Pas Task scores in males and females who received different years of schooling.

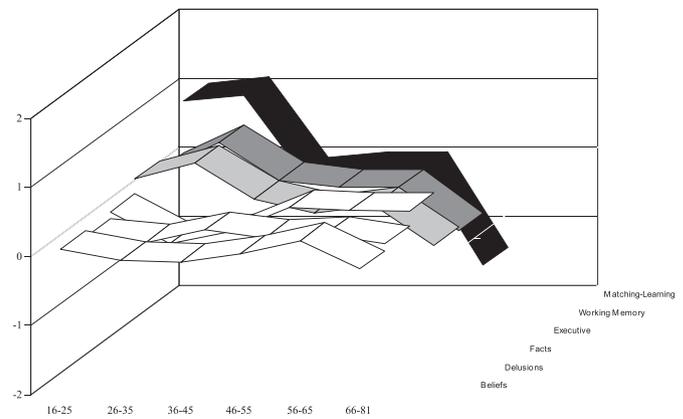
		5-11	12-13	≥14
Faux Pas recognition	All	9.67 ± 0.75	9.80 ± 0.46	9.73 ± 0.58
	Males	9.50 ± 0.76	9.86 ± 0.43	9.74 ± 0.56
	Females	9.74 ± 0.74	9.76 ± 0.49	9.73 ± 0.60
No-Faux Pas exclusion	All	9.80 ± 0.68	9.79 ± 0.68	9.78 ± 0.52
	Males	9.93 ± 0.27	9.57 ± 0.95	9.79 ± 0.42
	Females	9.74 ± 0.78	9.98 ± 0.16	9.77 ± 0.59
Comprehension question 1	All	9.69 ± 0.55	9.78 ± 0.45	9.76 ± 0.53
	Males	9.43 ± 0.76	9.77 ± 0.49	9.68 ± 0.58
	Females	9.80 ± 0.41	9.78 ± 0.42	9.81 ± 0.49
Comprehension question 2	All	9.43 ± 0.91	9.36 ± 1.04	9.60 ± 0.78
	Males	9.29 ± 0.91	8.91 ± 1.31	9.47 ± 1.02
	Females	9.49 ± 0.92	9.73 ± 0.50	9.70 ± 0.55
Comprehension question 3	All	8.41 ± 1.66	8.45 ± 1.69	8.80 ± 1.47
	Males	8.57 ± 1.50	7.91 ± 1.93	8.58 ± 1.64
	Females	8.34 ± 1.73	8.90 ± 1.32	8.96 ± 1.34
Comprehension question 4	All	9.95 ± 0.68	9.67 ± 0.53	9.36 ± 0.88
	Males	9.43 ± 0.76	9.63 ± 0.55	9.32 ± 0.88
	Females	9.54 ± 0.66	9.71 ± 0.51	9.38 ± 0.89
Total comprehension	All	37.04 ± 2.95	37.22 ± 2.91	37.49 ± 3.05
	Males	36.71 ± 3.43	36.23 ± 3.37	37.05 ± 3.56
	Females	37.17 ± 2.78	38.07 ± 2.14	37.81 ± 2.64
Faux Pas control question	All	10 ± 0	9.96 ± 0.26	9.82 ± 0.58
	Males	10 ± 0	9.97 ± 0.17	9.95 ± 0.23
	Females	10 ± 0	9.95 ± 0.31	9.73 ± 0.72
No-Faux Pas control question	All	9.96 ± 0.20	9.99 ± 0.12	9.89 ± 0.38
	Males	9.86 ± 0.36	9.97 ± 0.17	10 ± 0
	Females	10 ± 0	10 ± 0	9.81 ± 0.49
Faux Pas Task - Index	All	1.88 ± 0.13	1.89 ± 0.11	1.90 ± 0.12
	Males	1.87 ± 0.13	1.85 ± 0.13	1.89 ± 0.13
	Females	1.89 ± 0.12	1.93 ± 0.08	1.91 ± 0.10

Males vs females: question 2,  $p = 0.001$ ; question 2,  $p = 0.025$ ; question 4,  $p = 0.008$ ; FPT-I,  $p = 0.002$ .  
Gender × schooling interaction,  $p = 0.005$ . Schooling:  $p = 0.049$ .

recognition and comprehension of real FP, the exclusion of no-FP, and the control of contextual details. The Matching-Learning, Executive, and Working Memory factors included the processing, encoding,

**Table 6**  
Factor analysis of the Faux Pas Task and other neuropsychological test scores.

	Matching-Learning	Beliefs	Executive	Facts	Working memory	Delusions
Raven Colored Progressive Matrices	0.65					
Rey Complex Figure Copying	0.63					
Weigl Sorting	0.58					
Short Story	0.79					
Rey Complex Figure Recall	0.71					
Attentive Matrices	0.69					
Trail Making Test A	-0.69					
Trail Making Test B	-0.68					
Street Completion	0.64					
FPT-composite score		0.95				
Faux Pas recognition		0.75				
Comprehension question 1		0.77				
Comprehension question 2		0.79				
Comprehension question 3		0.71				
Comprehension question 4		0.75				
Total comprehension		0.95				
Word Fluency - phonemic			0.70			
Word Fluency - semantic			0.55			
Token test			0.67			
Tower of London			0.57			
FP Control question				0.89		
No-FP Control question				0.87		
Digit span					0.50	
Corsi Blocks span					0.47	
No-FP Exclusion						0.87
Total explained variance 67.47%	19.72%	19.52%	10.68%	7.82%	4.96%	4.76%



**Fig. 1.** Theory of mind and other cognitive domains as expressed by the composite test scores in subjects of different age.

learning of verbal and visuospatial information, initiative, updating, and planning, and working memory, respectively (Table 6).

### 3.4. Composite cognitive scores

Six CSs corresponding to the cognitive factors were computed (Beliefs, Delusion, Facts, Matching-Learning, Executive, Working Memory). The MANOVA showed a significant global influence for age (Pillai's value = 0.51,  $F = 3.10$ ,  $p < 0.001$ ). Tests of the between-subject effects revealed no differences for the FPT CSs and significant differences for the Matching-Learning [ $F(5) = 10.93$ ,  $p < 0.001$ ], Executive [ $F(5) = 14.06$ ,  $p < 0.001$ ], and Working Memory CSs [ $F(5) = 10.67$ ,  $p < 0.001$ ] (Fig. 1). Posthoc Bonferroni tests showed that the Executive CS was significantly lower in the 66- to 81-year-old group in comparison with the 16- to 25- ( $p < 0.001$ ), 26- to 35- ( $p < 0.001$ ), and 36- to 45-year-old ( $p = 0.005$ ) groups and in the 56- to 65-year-old group in comparison with the 25- to 35-year-old group ( $p = 0.005$ ). The Matching-Learning CS was significantly lower in the 66- to 81-year-old group in comparison with the 16- to 25- ( $p < 0.001$ ), 26- to 35- ( $p < 0.001$ ), 36- to 45- ( $p =$

**Table 7**  
The predictors of theory of mind and other cognitive functions.

Functions	Correlations	Predictors	Adjusted R <sup>2</sup>	F	p	Explained variance
Beliefs	Facts: $r = 0.24, p = 0.001$	Facts	0.053	10.55	0.001	16%
	Delusions: $r = 0.24, p = 0.002$	Delusions	0.098	10.13	<0.001	
	Working Memory: $r = 0.23, p = 0.003$	Working Memory	0.14	9.88	<0.001	
	Executive: $r = 0.20, p = 0.009$	Gender	0.16	9.29	<0.001	
	Matching-Learning: $r = 0.20, p = 0.01$					
FPT index	Facts: $r = 0.21, p = 0.006$	Delusions	0.15	30.09	<0.001	24%
	Delusions: $r = 0.39, p < 0.001$	Working Memory	0.19	21.00	<0.001	
	Working Memory: $r = 0.23, p = 0.002$	Facts	0.22	16.58	<0.001	
	Matching-Learning: $r = 0.20, p = 0.009$	Gender	0.24	14.64	0.001	
	Executive: $r = 0.18, p = 0.02$					
FP recognition	Facts: $r = 0.32, p < 0.001$	Facts	0.09	19.44	<0.001	15%
	Executive: $r = 0.25, p = 0.001$	Executive	0.15	16.39	<0.001	
	Matching-Learning: $r = 0.19, p = 0.013$					
FP total comprehension	Delusions: $r = 0.24, p = 0.001$	Delusions	0.05	10.57	<0.001	14%
	Working Memory: $r = 0.24, p = 0.002$	Working Memory	0.10	10.84	<0.001	
	Matching and Learning: $r = 0.18, p = 0.02$	Gender	0.14	10.09	<0.001	
Comprehension question 1	Executive: $r = 0.19, p = 0.013$	–	–	–	–	–
Comprehension question 2	Facts: $r = 0.18, p = 0.02$	–	–	–	–	–
Comprehension question 3	Working Memory: $r = 0.24, p = 0.002$	Working Memory	0.05	10.31	<0.001	12%
	Delusions: $r = 0.24, p = 0.002$	Delusions	0.10	10.33	<0.001	
		Gender	0.12	8.62	<0.001	
Comprehension question 4	Facts: $r = 0.39, p = 0.001$	Facts	0.15	30.24	<0.001	18%
	Delusions: $r = 0.21, p = 0.006$	Delusions	0.18	18.96	<0.001	
	Age: $r = -0.48, p < 0.001$	Executive	0.26	59.17	<0.001	
Matching-Learning	Schooling: $r = 0.36, p < 0.001$	Age	0.31	39.26	<0.001	32%
	Executive: $r = 0.51, p < 0.001$	Working Memory	0.32	28.03	<0.001	
	Working Memory: $r = 0.42, p < 0.001$					
	Age: $r = -0.54, p < 0.001$	Age	0.28	67.77	<0.001	
Executive	Schooling: $r = 0.47, p < 0.001$	Schooling	0.38	53.08	<0.001	43%
	Working Memory: $r = 0.52, p < 0.001$		0.43	44.03	<0.001	
	Age: $r = -0.44, p < 0.001$	Age	0.18	39.15	<0.001	
Working Memory	Schooling: $r = 0.38, p < 0.001$	Schooling	0.25	38.74	<0.001	25%

FP, Faux Pas. FPT, Faux Pas Task.

0.03), 46- to 55- ( $p = 0.007$ ), and 56- to 65-year-old groups ( $p = 0.007$ ).

Schooling showed a significant global influence (Pillai's value = 0.25,  $F = 3.92, p < 0.001$ ); tests of the between-subject effects revealed significant differences for the Matching-Learning [ $F(2) = 10.37, p < 0.001$ ], Executive [ $F(2) = 14.05, p < 0.001$ ], and Working Memory CSs [ $F(2) = 9.90, p < 0.001$ ], but no differences for the FPT CSs. In comparison with other groups, that with 5–11 years of schooling showed significantly lower Matching-Learning ( $p < 0.001$ ), Executive ( $p = 0.016$  compared to the 12- to 13-year-group;  $p < 0.001$  compared to the most educated group), and Working Memory CSs ( $p = 0.006$  compared to the 12- to 13-year-group;  $p < 0.001$  compared to the most educated group). The group with 12–13 years of schooling also had lower Executive CSs in comparison with the group that received more than 13 years ( $p = 0.008$ ).

Gender showed a global influence on the CSs (Pillai's value = 0.09,  $F = 2.55, p = 0.02$ ) with a significant effect on the Beliefs CS [ $F(1) = 4.49, p = 0.036$ ].

### 3.5. The determinants of theory of mind

#### 3.5.1. Theory of mind

The Facts and Delusions CSs had no correlations with age, schooling or the no-FPT CSs. The Beliefs CS showed significant correlation with the Facts, Delusions, and Working Memory CSs, a less significant correlation with the Executive and Matching-Learning CSs, and no correlation with age or schooling.

Given that the Beliefs CS includes different ToM abilities, additional correlations were analyzed. The FPT-I showed significant correlation with the Facts, Delusions, and Working Memory CSs and less significant correlation with the Matching-Learning and Executive CSs. The FP

recognition score significantly correlated with the Facts and Executive CSs and not significantly with the Matching-Learning CS. The total comprehension score significantly correlated with the Delusions and Working Memory CSs and not significantly with the Matching-Learning CS. The first question score had not significant correlation with the Executive and Facts CSs. The third question score had significant correlation with the Working Memory and Delusions CSs, while the fourth question score significantly correlated with the Facts and Delusions CSs.

The regression analyses entered the variables that resulted significant at group comparisons or correlation analyses. The Beliefs CS was predicted by the Facts, Delusions, and Working Memory CSs and gender. Separate analyses were repeated with individual recognition and comprehension scores. The FPT-I was predicted by the Delusions, Working Memory, and Facts CSs and gender. The FP recognition score was predicted by the Facts and Executive CSs. The total comprehension score was predicted by the Delusions and Working Memory CSs and gender. The third question score was predicted by the Working Memory and Delusions CSs and gender. The fourth question score was predicted by the Facts and Delusions CSs. Table 7 summarizes the results of the correlation and regression analyses.

#### 3.5.2. Other cognitive functions

The Matching-Learning CS significantly correlated with age, schooling, and the Executive and Working Memory CSs. The Executive CS correlated with age, schooling, and the Working Memory CS. The Working Memory CS also correlated with age and schooling.

Regression analysis revealed that the Matching-Learning CS was predicted by the Executive CS, age, and the Working Memory CS. The Executive CS was predicted by age, schooling, and the Working Memory CS. The Working Memory CS was predicted by age and schooling (Table 7).

## 4. Discussion

### 4.1. Theory of mind specificity

Impaired ToM often marks the neurobehavioral profile of epilepsy relatively to neurodevelopmental factors, clinical variables, and task demands. In order to clarify such impairments, it is important to know the level and determinants of advanced ToM in healthy subjects. The results of this study showed that ToM, as expressed by the FPT, is a specific cognitive domain independent of age and schooling. Females, in particular those with higher education, may surpass males, while reality examination, working memory, and executive functions cooperate to the understanding of existent mental states.

The FPT is a complex task that is acquired in late childhood and is sensitive to subtle brain damage, therefore resulting adequate to assess clinical and subclinical impairments [68]. In the present study, the FPT provided three factors: the recognition and comprehension of real mental states (Beliefs), the exclusion of inexistent mental states (Delusion), and the control of the contextual details (Facts). These factors were distinct from the Matching-Learning, Working Memory, and Executive factors, which supports ToM's specificity. These findings expand previous observations in elderly healthy subjects [19–21] and patients with epilepsy [8] who showed ToM abilities independent of language, memory, executive functions, fluid intelligence, and speed of information processing. This is also in keeping with the studies of autism (impaired ToM and intact executive functions) [42,43], autism or Asperger's syndromes (impaired ToM and normal intelligence) [45–48,60], Down's or William's syndromes (normal ToM and impaired intelligence and executive functions) [49], and frontal lobe [50–54] or amygdala lesions (selective ToM impairment) [55–57].

### 4.2. Theory of mind and age

The healthy subjects aged 16 to 81 years showed no significant differences at the FPT. Worth noting, the best performance, as expressed by the Beliefs CS, were observed in subjects of 56 to 65 years, who surpassed not only the older but also the younger subjects, although they showed lower memory, language, intelligence, and executive tests scores than younger subjects. This is in line with previous findings [28,30]. Furthermore, both the epistemic and affective ToM components were better with increasing age, and their decline in the 66- to 81-year-old group was not significant, although such a group had had the shortest schooling attendance. By contrast, the best Matching-Learning, Working Memory, and Executive CSs were observed in subjects of 26 to 35 years, after the transition from adolescence to young adulthood, suggesting an improvement of general cognition after neurodevelopment. Thus, during adulthood, ToM may have distinct trends with respect to other cognitive functions. These results extend previous studies that reported no significant aging-related ToM loss [19,22,23]. Moreover, present findings are opposite to the view that ToM would decline as a function of impaired executive functions, fluid intelligence, or information processing [21,26,28,30].

### 4.3. Theory of mind and education

Unlike previous investigations concerning patients with epilepsy [8,15] or healthy subjects [19], which found better performance in individuals with high education, this study revealed that schooling has very mild effects on ToM. It is possible the patients with epilepsy may receive few years of schooling as a consequence of the clinical and therapeutic burden. Moreover, poor school fulfillment may reflect a maladjustment to epilepsy and complex interactions between the disease, personal attitudes, and social environment. Long

schooling attendance, therefore, may be an index of successful psychosocial adjustment favoring ToM improvement. On the contrary, the healthy subjects with low education do not necessarily face psychosocial adversities, but they can acquire various experiences that stimulate ToM independently of formal education. Also note that, while neuropsychological tests refer to the solution of tasks of increasing difficulty solved across development [8,69,70], in daily life, ToM combines many stimuli and interactions that are more articulated than laboratory performance.

### 4.4. Theory of mind and gender

While gender had no influence on executive, language, memory, visuospatial, and praxis functions, it significantly affected ToM. Females showed a better capacity to comprehend the contextual situations, to guess others' intentions, and to exclude inexistent mental states, which was favored by higher education. This is in accord with previous studies demonstrating that healthy women perform better than men on ToM tasks [36]. It may be argued that unexplored variables, such as personality traits and maternal experiences linked to infant attachment, cooperate to improve ToM [13].

### 4.5. The determinants of theory of mind

Working memory, executive functions, reality examination and the sense of reality showed an impact on the capacity to elaborate complex mental states, in line with previous studies that reported an association between ToM and the updating of information [30], the maintaining of crucial information in working memory [45] or different executive functions [23]. The link between impaired ToM and these functions may be a consequence of prefrontal cortical damage [60,71,72]. Other possible mechanisms would involve the relationships between ToM and the manipulation of mental states based on abstract reasoning [19,20] or the inhibition of the interference caused by external stimuli on mental constructs [65].

### 4.6. Conclusions

As a whole, these results suggest that ToM can continue to improve after adolescence, acquiring competence during adulthood. The acquisition of fundamental ToM abilities has been linked to changes of the amygdala, prefrontal cortex, superior temporal sulcus, and temporoparietal junction [37,37,40,46], in keeping with a development trend that appears similar in different sociocultural contexts [35]. In this regard, the Simulation Theory [3] suggests that basic ToM mechanisms are the projection of ones' own mental states on the others, based on brain changes. After development, ToM may be implemented by experience and knowledge, with secondary changes of brain connectivity, in line with the Theory-Theory [4,5]. The lack of interaction between ToM and schooling in healthy subjects is in favor of the Theory-Theory, suggesting that proper psychological and environmental stimuli and cognitive-behavioral reserve may perfect ToM more than formal education. It may be argued that ToM has a biphasic trajectory: a fix development phase and an adult phase that varies relatively to personal and external variables. Motivation, healthy lifestyle, and inspiring environment could enrich ToM, counteracting the effects of aging and cultural deprivation.

A limitation of this study is the cross-sectional design, which may infer intraindividual changes from interindividual differences. However, this design has the advantage of covering a wide age range, in the absence of changes of the participants and operators. Another limitation is the lack of data on attachment style and socioeconomic vulnerability, which could influence ToM.

To conclude, ToM is a specific cognitive domain with a distinct trend across the lifespan. Studies including assessment of

psychosocial variables are needed to construct a canonical model for ToM. Present findings may provide initial reference points against which impairment can be assessed, laying the basis of large-scale normative cross-cultural studies.

### Declaration of Competing Interest

The author declares no conflicts of interests.

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### Appendix A. Supplementary data

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