Year: 2020

Theory of mind development from adolescence to adulthood: Testing the two-component model

Meinhardt-Injac, Bozana ; Daum, Moritz M ; Meinhardt, Günter

DOI: https://doi.org/10.1111/bjdp.12320

Originally published at:
Meinhardt-Injac, Bozana; Daum, Moritz M; Meinhardt, Günter (2020). Theory of mind development from adolescence to adulthood: Testing the two-component model. British Journal of Developmental Psychology, 38(2):289-303.
DOI: https://doi.org/10.1111/bjdp.12320

the british psychological society
promoting excellence in psychology

British Journal of Developmental Psychology (2020), 38, 289–303

www.wileyonlinelibrary.com

Theory of mind development from adolescence to adulthood: Testing the two-component model

Bozana Meinhardt-Injac*[1,2], Moritz M. Daum[3,4] and Günter Meinhardt[2]

[1]Catholic University of Applied Science Berlin (KHSB), Berlin, Germany
[2]Department of Psychology, Johannes Gutenberg University, Mainz, Germany
[3]Department of Psychology, University of Zurich, Switzerland
[4]Neuroscience Center Zurich, University of Zurich and ETH Zurich, Switzerland

The ability to infer mental and affective states of others is crucial for social functioning. This ability, denoted as Theory of Mind (ToM), develops rapidly during childhood, yet results on its development across adolescence and into young adulthood are rare. In the present study, we tested the two-component model, measuring age-related changes in social-perceptual and social-cognitive ToM in a sample of 267 participants between 11 and 25 years of age. Additionally, we measured language, reasoning, and inhibitory control as major covariates. Participants inferred mental states from non-verbal cues in a social-perceptual task (Eye Test) and from stories with faux pas in a social-cognitive task (Faux Pas Test). Results showed substantial improvement across adolescence in both ToM measures and in the covariates. Analysis with linear mixed models (LMM) revealed specific age-related growth for the social-perceptual component, while the age-related increase of the social-cognitive component fully aligned with the increase of the covariates. These results support the distinction between ToM components and indicate that adolescence is a crucial period for developing social-perceptual ToM abilities.

Statement of contribution

What is already known on this subject?

- To date, much research has been dedicated to Theory of Mind (ToM) development in early and middle childhood. However, only a few studies have examined development of ToM in adolescence.
- Studies so far suggest age-related differences in ToM between adolescents and young adults.

What this study adds

- The study offers several methodological advantages including a large sample size with a continuous distribution of age (age 11–25) and the use of a comprehensive test battery to assess ToM and covariates (language, executive functions, reasoning).
- The results provide evidence for *asymmetries* in the development of two ToM components (social-perceptual and social-cognitive; the two-component account) across the studied age range:
- the social perceptual component showed specific development, while the age-related increase of the social-cognitive component fully aligned with increase of the covariates.
- Adolescence is a crucial period for developing social-perceptual ToM abilities.

Correspondence should be addressed to Bozana Meinhardt-Injac, Catholic University of Applied Science Berlin (KHSB), Köpenicker Allee 39 – 57, D - 10318 Berlin, Germany (email: Bozana.Meinhardt-Injac@KHSB-Berlin.de).

DOI:10.1111/bjdp.12320

Theory of Mind (ToM) denotes the ability to represent and understand mental states, intentions, and feelings of others, and to predict one's own and others' behaviour. ToM is fundamental for social interactions and adaptive social behaviour (for a meta-analysis see Slaughter, Imuta, Peterson, & Henry, 2015). Recent studies suggest that an improvement in ToM abilities occurs at any age, including adulthood, provided ToM stimulating-experiences, such as social and conversational inputs (Peterson & Wellman, 2018; Pyers & Senghas, 2009). While the vast majority of ToM research considers early childhood, adolescence is a likewise important period for socio-emotional development (for reviews, see Fuhrmann, Knoll & Blakemore, 2015; Steinberg, 2005). During adolescence, social interactions represent the key context for the construction and manifestation of self- and social understanding (Carpendale & Lewis, 2004; Zerwas, Balaraman, & Brownell, 2004). The social world of adolescents becomes richer and wider and relationships outside the family become more important (Collins & Laursen, 2004; Larson & Verma, 1999).

Despite the high relevance of ToM for dealing with the socio-emotional challenges of adolescence, very few studies have examined Theory of Mind (ToM) in this period (Brizio, Gabbatore, Tirassa, & Bosco, 2015; Hughes & Devine, 2015). These studies showed that ToM performance of adolescents is better compared to children or pre-adolescents (Bosco, Gabbatore, & Tirassa, 2014; Devine & Hughes, 2013; Im-Bolter, Agostino & Owens-Jaffray, 2016), but worse compared to young adults (Dumontheil, Apperly, & Blakemore, 2010; Humphrey & Dumontheil, 2016; Symeonidou, Dumontheil, Chow & Breheny, 2016; Tousignant, Sirois, Achim, & Massicotte, 2017; Valle, Massaro, Castelli & Marchetti, 2015; Vetter, Leipold, Kliegel, Phillips, & Altgassen, 2013). Age-related improvements from adolescence to adulthood, however, appear to vary depending on the ToM measures used (Tousignant *et al.*, 2017). Adolescents show a lower level of perspective-taking (i.e., Director Task – Humphrey & Dumontheil, 2016; Symeonidou, *et al.*, 2016) and exhibit weaker recognition of basic and complex emotions than young adults (Tousignant, *et al.*, 2017; Vetter, *et al.*, 2013). In contrast, adult-like levels in understanding cognitive states (e.g., white lies, faux pas), in social knowledge, and in empathy may be reached already in adolescence (Rice, Anderson, Velnoskey, Thompson, & Redcay, 2016; Tousignant, *et al.*, 2017; White, Hill, Happé, & Frith, 2009). These findings suggest that some but not all ToM components continue to develop until young adulthood.

In different research fields, including developmental psychology, social neuroscience, and research on disorders characterized by social deficits (e.g., autism) ToM is often described as a multi-factorial construct comprising multiple subcomponents (Kennedy & Adolphs, 2012; Schaafsma, Pfaff, Spunt, & Adolphs, 2015). The two-component model distinguishes between social-perceptual and social-cognitive ToM components (Tager-Flusberg & Sullivan, 2000; see also Apperly & Butterfill, 2009). In social-perceptual tasks, the mental states of others are inferred based on *non-verbal* cues (i.e., facial expressions, eyes, body motion). Social-cognitive tasks require explicit *verbal* reasoning about others' affective and mental states. Currently, there is a debate whether social-perceptual and social-cognitive ToM components are independent or inter-related in child development (Osterhaus, Koerber & Sodian, 2016; Schuwerk, Vuori, & Sodian, 2015). Further, it is unclear whether both are related to general cognitive processes (Meinhardt-Injac, Daum, Meinhardt, & Persike, 2018; Schneider, Slaughter, & Dux, 2015).

Alongside evidence for parallel age-related improvements in ToM and in cognitive functions, there are stable inter-relations between these constructs across development (Rakoczy, 2017). Different aspects of language including semantics, syntax, and pragmatics have been identified as significant covariates of ToM development, particularly in verbal ToM tasks (e.g., Astington & Jenkins, 1999; Harris, de Rosnay, &

Pons, 2005; for a meta-analysis see Milligan, Astington, & Dack, 2007). ToM tasks further require coordination and suppression of different perspectives (e.g., own versus other) which may explain the involvement of executive functions (e.g., inhibitory control) in ToM performance (Rakoczy, 2017). Moreover, individual differences in reasoning account for some, albeit small, variability in ToM (for a meta-analysis see Baker, Peterson, Pulos, & Kirkland, 2014). According to the two-component model, different cognitive functions are involved for the social-perceptual and the social-cognitive ToM component, and different developmental trajectories are postulated (Tager-Flusberg & Sullivan, 2000). However, empirical evidence is scarce and results are mixed, leaving an ambiguous state of evidence for the two ToM component model (Osterhaus *et al.*, 2016).

Development at different rates would be evidenced in favour of the two-component account, since this would indicate involvement of different functions for either component. Second, development of each component should be separable from development in relevant general cognitive functions, since this suggests that a ToM component comprises a complex of specific ability.

At the time, there are two tests (Eye Test by Baron-Cohen *et al.*, 2001, and Faux Pas Test by Lawson, Baron-Cohen & Wheelwright, 2004) which have frequently been used to measure a social-perceptual and a social-cognitive component of ToM, respectively (Osterhaus *et al.*, 2016; Schneider *et al.*, 2015; Tager-Flusberg & Sullivan, 2000). Both tests require inference of the affective states, but in the Eye Test only non-verbal information is provided, whereas in Faux Pas test participants judge the 'upset' of characters from stories presented in verbal form. Both tests are sensitive to developmental differences in ToM (Banerjee, *et al.*, 2011; Osterhaus, *et al.*, 2016; Radecki, Cox, & MacPherson, 2019; Rice, *et al.*, 2016; Vetter, *et al.*, 2013) and to ToM deficits in clinical populations (i.e., Asperger's syndrome; Baron-Cohen, *et al.*, 1999; Baron-Cohen, *et al.*, 2001; Lawson, *et al.*, 2004; Stone, Baron-Cohen, & Knight, 1998).

The present study is an inquiry into the two putative ToM components. We aimed at testing whether there are different developmental trajectories of social-perceptual and social-cognitive ToM across adolescence into young adulthood, while controlling for age-related change in language, executive functions, and reasoning as major covariates of general cognitive development with potential links to ToM (see above). Our approach is a first attempt to test the two-component model, since either component can claim an own domain of ability only if its development does not fully align with general cognitive development. It is also explorative in nature, since the age-dependency of social-perceptual and social-cognitive ToM measures has so far not been addressed across adolescence into young adulthood.

Methods

Participants

In total, 293 volunteers between 11 and 25 years of age participated in the study. The participants were recruited in middle-class schools and at the university via leaflets, informative letters, and emails. All participants were native speakers of the German language, and 21 of them were bilingual. All bilingual participants started to learn German language before 4 years of age. None of the participants reported severe head injuries or other impairments concerning perception, hearing, and cognitive and mental functions including psychiatric disorders, learning disabilities, or ADHD. The age-continuous sample consisted of 9–23 participants per year of age, having gender distribution balanced across ages. After outlier clearing, $N = 267$ valid cases, 175 female, entered statistical analysis. Detailed descriptions of the sample and outlier clearing methods are provided in the Supporting information.

Prior to the study, all potential participants and parents of adolescent participants were informed in written form about the study aims, methods, sources of funding, any possible conflicts of interest, and institutional affiliations of the researchers. Only participants who had returned their written agreement to be contacted about the study were included in the sample. Subjects received small monetary compensation or course credit for participation. According to the Declaration of Helsinki, written informed consent was obtained from all participants; for adolescents, consent was also obtained from their parents.

Materials

Eye Test (ET)

The German version of the Reading the Mind in the Eyes Test – revised (Baron-Cohen *et al.*, 2001; Bölte, 2005) was used to measure participants' attribution of complex emotional and mental states based on non-verbal cues from the eyes. Participants were given a handout with definitions of all emotional concepts and were instructed to study them before the task started and to ask questions whether clarification was necessary. During the task, the handout was available and participants were alerted to using it. A total of 36 greyscale photographs of the eye region of different actors were presented to participants consecutively. Each photograph revealed a complex emotional or mental state, such as 'thoughtful' or 'worried'. With each photograph, four adjective descriptions of complex emotions or states were presented, one of them matching the expression depicted. Participants were asked to select the adjective that matched the depicted expression best. The presentation was self-paced, and each photograph was presented until the participant responded. The proportion of correctly identified photographs was measured.

Faux Pas Test (FPT)

Faux pas recognition in conversation was tested using the Social Stories Questionnaire (SSQ, Baron-Cohen *et al.*, 1999; Lawson, *et al.*, 2004). Faux pas recognition requires (1) noticing that different story characters have different knowledge, (2) appreciating the emotional impact of a statement, and (3) knowledge about social norms in different social contexts (Baron-Cohen *et al.*, 1999; Osterhaus *et al.*, 2016). The SSQ consists of 10 short social episodes from different social contexts, each falling into three sections.

Across all stories, ten sections contain a blatant target utterance, ten contain a subtle target utterance, and ten contain no target utterance. For each section, participants indicate whether it contains faux pas and, if so, identify the utterance by marking it (out of 4–6 utterances). The number of correctly identified faux pas out of 20 is measured. A paper–pencil version of the test is available at https://www.autismresearchcentre.com/arc_tests.

Language (LA)

A standard treasury of word test was used to measure verbal IQ (MWT-B, Lehrl, 2005). In 37 trials, participants are asked to detect the only real word from a five-word sequence that contains 4 artificial words. Test duration was ~5 min. Detailed information on the MWT-B can be found in Lehrl (2005). The proportion of correctly identified words was measured.

Inhibitory control (IC)

Despite its suggested relevance to social functioning, executive functions are predominantly studied in non-social domains (Hill, 2004). To investigate inhibitory control as a core component of executive functions, the use of social stimuli may be more appropriate, particularly in adolescence (e.g., Aïte *et al.*, 2018). In the present study, we used social stimuli in a perceptual competition paradigm (Schmitz, Cheng, & De Rosa, 2010) as a test of the ability to ignore irrelevant objects while focusing on target faces. The participants categorized face gender in compound face-house images. Two graded levels of opacity were applied on the distractor stimulus (35 and 65%). When faces and houses are overlaid in transparency, successful face gender categorization is possible only if the irrelevant house object can be efficiently suppressed. The task comprised two levels of opacity (low and high), two orientations (upright and inverted), and 30 replications, resulting in 120 experimental trials. Stimulus presentation was self-paced. The proportion of correct gender categorizations was measured.

Reasoning (RE)

A short version of Raven's standard progressive matrices task (Raven, 2000) was used to measure abstract non-verbal reasoning. In this test, all trials have a visual-geometric design with a missing piece. Subjects choose one out of eight elements to complete the matrix. Stimulus presentation lasts until the participant makes a selection. Forty matrices are presented, ordered by difficulty. There is an overall time limit of 10 min for the entire test. Participants are informed about the time limit prior to testing. The proportion of correct responses (including all trials that were not carried out due to the time limit) was measured.

Since proportion correct was measured in all five tests, higher test scores indicate better performance.

Procedure

All tests were computer-administered, conducted at the university laboratory in two one-hour sessions held on two consecutive days. Participants responded by clicking the left or right computer mouse button or by mouse clicks on pre-defined arrays on-screen. Prior to testing, they were asked to carefully read the instructions and were free to ask questions. For each test, except for the Faux Pas Test, 5–10 practice trials were provided to familiarize participants with task requirements and response procedures. Up to three participants were tested at a time in the same experimental room, separated by movable partition walls. A research assistant was permanently present to supervise the procedure and to answer questions. Inquisit 4.0 (Millisecond Software, Seattle, WA, USA) was used for programming computer-based test administration.

Ethics statement

The experimental procedures for the project 2017-JGU-psychEK-009 (Johannes Gutenberg University) were approved by the local ethics committee of the (Johannes Gutenberg University) University.

Results

Descriptive statistics

Statistical analyses used z-scores. Note this implies same means for Eye Test and Faux Pas Test, but reveals potentially different distribution across age. Moving averages for a full-year integration window (see Figure 1, solid curves) illustrate an overall flatter course of Faux Pas Test scores compared to Eye Test scores. The latter reflected lower levels in early adolescence, followed by a steeper rise across teenage years.

Correlation analysis

Table 1 shows zero-order Pearson correlations. Most tests correlated strongly, while the Eye Test and the Faux Pas Test correlated modestly, but significantly ($r = .25^{***}$, $r_{\text{rank}} = .20^{**}$). All tasks showed strong correlations with age (rs $\geq .3$, ps $\leq .001$), pointing to age-related growth as a major common driver behind task correlations. The partial correlation of both ToM tests, controlled for age, fell short of statistical significance and indicated a negligible amount of shared variance, $r_{\text{xy.age}} = .112$, $t(265) = 1.92$, $p = .055$; $r^2_{\text{xy.age}} = .0125$.

Linear mixed model (LMM) and linear model (LM) analysis

Successive comparison of linear mixed models (LMM, McCulloch & Searle, 2001) offers a way to reveal the specific age-related increase of ToM performance. First, we predicted ToM performance (the undistinguished data for Eye Test and Faux Pas Test) from the covariates only (baseline model, M0). Adding an Age factor (first test model, M1) factors out a specific ToM development, which is not captured by the age-related changes of the covariates. Further adding a ToM × Age interaction term (second test model, M2) distinguishes the ToM tests. Thus, M2 can potentially indicate different age-related improvement in Eye Test compared to Faux Pas Test. If there is a significant ToM × Age

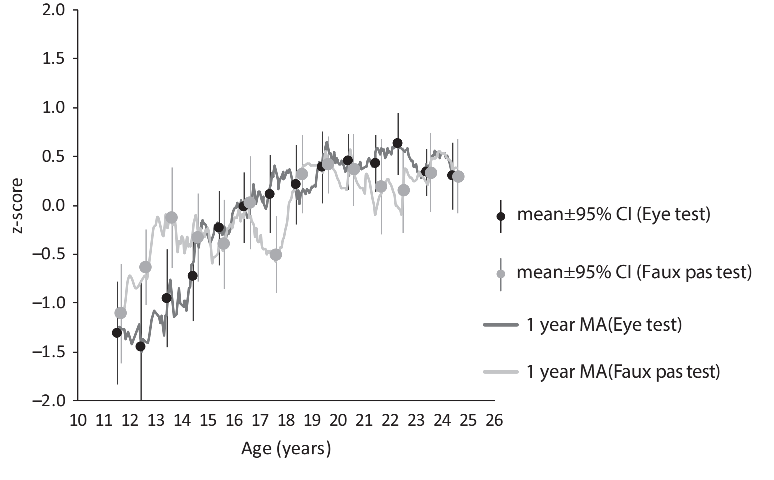

Figure 1. Mean z-scores for each year of age for Eye Test (black) and Faux Pas Tests (grey). Means with confidence intervals are shown for full-year age intervals, linked by moving averages for a full year integration window (smooth solid lines). Bars denote 95% confidence intervals of the means.

Table 1. Pearson product-moment correlations

	Age	LA	RE	IC	ET
Age					
LA	.69***				
RE	.40***	.40***			
IC	.29***	.29***	.26***		
ET	.52***	.52***	.31***	.36***	
FPT	.30***	.35***	.29***	.16**	.25***

Note.. Critical correlations were $r_{(\alpha\ =\ .001)} = .20$, $r_{(\alpha\ =\ .01)} = .16$, and $r_{(\alpha\ =\ .05)} = .12$.
$^{***}p \leq .001$; $^{**}p \leq .01$; $^{*}p \leq .05$; $^{\text{n.s.}}p > .05$.

term, follow-up analyses with linear models (LM models) reveal the specific covariate and age effects for each individual ToM test.

Following suggestions by Pinheiro and Bates (2000), model performance was compared with a likelihood ratio test. We had intercepts for participants as random effects in all LMM models (random subject factor) to account for the repeated measures structure of ToM. All other factors had fixed effects. All analyses, including likelihood ratio tests, were executed using R (R core Team, 2012) with lme4 package for LMM (Bates, Mächler, Bolker, & Walker, 2015). Estimates of global model fit (R^2) were calculated using the MuMIn package by Barton (2013).

Table 2 shows the results of the LMM analysis. Model M0 explained 22.2% of ToM variance and indicated the three covariates as highly significant ToM predictors. M1 (23.5% explained variance) revealed a significant Age parameter, indicating an age-related increase in ToM which is segregated from age-related improvements in language, inhibitory control, and reasoning. The likelihood ratio test showed that the 1.3% increase in model fit by adding the Age term was significant, $\chi^2(1) = 8.94, p < .005$. A significant Age × ToM term in M2 revealed different Age effects for Eye Test and Faux Pas Test. The 1.1% increase in model fit for M2 ($R^2 = .246$) relative to M1 ($R^2 = .235$) was significant, $\chi^2(2) = 8.07, p < .02$. The Age × ToM interaction of M2 is illustrated in Figure 2B. Either test survived the correction for repeated testing (Šidák-corrected error rate $\alpha_{\text{SID}} = .0253$ for a 5% overall alpha level).

Distribution analysis of residuals with Lilliefors KS test (Lilliefors, 1967) indicated no violations of normality for any model (M0: D = 0.034, $p = .148$; M1: D = 0.032, $p = .225$; M2: D = 0.030, $p = .275$; see Supporting information for a detailed description of LMM residuals). Significance of model parameters was robust against correction for multiple testing, except for the reasoning covariate (see Table 2).[1]

To further explore the Age × ToM effect, we ran LM analyses for each, the Eye Test and the Faux Pas Test. LM results for M1 (see Table 3) showed a significant slope coefficient for Age in Eye Test, but not in Faux Pas Test. The evaluation of the model fit revealed a significant improvement for M1 compared to M0 (only covariates) for the Eye Test, M1: $R^2 = .325$, M2: $R^2 = .356$, $R^2 = .031$, $F(263, 262) = 12.91, p < .001$, but not for the Faux Pas Test, M1: $R^2 = .152$, M2: $R^2 = .154$, $R^2 = .002$, $F(263,262) = 0.83, p = .368$.

[1] *Since gender effects have so far not been postulated in the literature, testing gender terms was not included in the strategy of successive LMM model comparisons. An exploratory test for gender effects by adding gender and all interaction terms involving ToM and age to model M3 showed no main effect of gender (*t*(521) = 1.13,* p *= .258), and no significant interactions (age gender:* t*(521) = −0.95,* p *= .343; ToM gender:* t*(263) = −0.52,* p *= .606; ToM age gender:* t*(263) = 0.384,* p *= .701).*

Table 2. Fixed effects estimates and global model fit (R^2) of LMM models

	Factor	Estimate (SE)	*t (df)*	*p*	R^2
M0	Intercept	0.000 (.037)	0.00 (263)	1	0.222
	Language	0.352 (.044)	8.07 (263)	<.001	
	Reasoning	0.124 (.043)	2.87 (263)	<.005	
	Inh. Control	0.124 (.041)	2.99 (263)	<.005	
M1	Intercept	−0.791 (.268)	−2.96 (262)	<.01	0.235
	Language	0.253 (.055)	4.65 (262)	<.001	
	Reasoning	0.103 (.043)	2.39 (262)	<.02	
	Inh. Control	0.111 (.041)	2.70 (262)	<.01	
	Age	0.044 (.014)	2.99 (262)	<.005	
M2	Intercept	−1.31 (.325)	−4.02 (466)	<.001	0.246
	Language	0.253 (.054)	4.65 (262)	<.001	
	Reasoning	0.103 (.043)	2.38 (262)	<.02	
	Inh. Control	0.111 (.041)	2.70 (262)	<.01	
	Age	1.03 (.369)	4.08 (464)	<.001	
	Age × ToM	−0.060 (.020)	−2.85 (265)	<.005	

Note. The family-wise error rate was α_{SID} = .017 for a 5% overall alpha level (Šidák-correction).

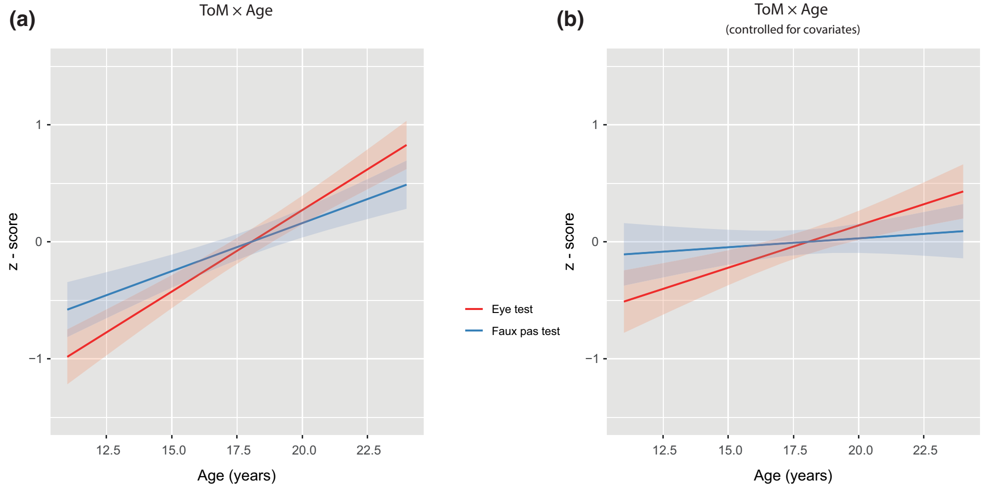

Figure 2. Illustration of the raw ToM × Age interaction, confounded with covariate effects (a), and the same interaction term, after controlling for Language, Reasoning, and Inhibitory Control (b). The shaded areas indicate the 95% confidence intervals of predicted values. [Colour figure can be viewed at wileyonlinelibrary.com]

The different age effects for Eye Test and Faux Pas Test are illustrated by the raw (unstandardized, β) slope estimates, which were β_{Age} = .07 (Eye Test) and β_{Age} = .02 (Faux Pas Test), respectively. The estimated slope of β = .07 corresponds to an about one standard (z) unit increase in the Eye Test performance across the studied age span, while the increase in the Faux Pas Test would be negligible (see also Figure 2). These results indicate a ToM-specific, age-related increase free of covariate effects only for the Eye Test, but not for the Faux Pas Test.

Table 3. LM Results for predicting eye test and Faux Pas Test from covariates and age

Test	Factor	*b*	*SE*(b)	*t*(259)	*p*	*R*	R^2
Eye Test	Language	.27	.07	3.90	<.001	.597	.356
	Reasoning	.05	.06	0.89	.377		
	Inh. Control	.19	.05	3.64	<.001		
	Age	.25	.07	3.59	<.001		
Faux Pas Test	Language	.23	.08	2.89	<.005	.393	.154
	Reasoning	.16	.06	2.46	<.02		
	Inh. Control	.03	.06	0.48	.634		
	Age	.07	.08	0.91	.365		

Note. The table shows standardized (*b*) coefficients with their standard errors, *t* – statistic with significance level, multiple correlation coefficient, and determination coefficient.

Discussion

The key findings of the present study are twofold. Our results reveal that the social-perceptual and social-cognitive ToM components dissociate in their development across adolescence and young adulthood and that they involve general cognitive functions to a different degree. We found an age-related increase in the social-perceptual ToM component (Eye Test) apart of improvements in language, inhibitory control, and reasoning. The age-related increase in the social-cognitive ToM component (Faux Pas Test), however, fully aligned with the development in these cognitive functions. A specific age-related improvement is thus evident only for the social-perceptual ToM component. This conclusion is, however, constrained by the possibility that not all relevant covariates have been identified for the latter ToM component. While our selection of covariates aimed at separating ToM components from most relevant dimensions of general cognitive development, it is possible that age-related growth in the social-perceptual component does not segregate from more specific covariates, for example, emotion recognition ability (Tousignant, *et al.*, 2017). A test in the context of specific social cognition covariates is, at the time, outstanding.

Recent longitudinal and cross-sectional studies show that ToM develops steadily across early and middle childhood (Peterson & Wellman, 2018; Wellman, Fang & Peterson, 2011). However, little is known about ToM changes across adolescence and during transition to adulthood. We observed a steady increase of average performance across adolescence for the social-perceptual component, while performance levels were volatile for the social-cognitive component, stabilizing not before young adulthood (see Figure 1). Discontinuous development even with retrograde local periods is known from other domains where availability of social norms is crucial (Luengo Kanacri, Pastorelli, Eisenberg, Zuffianò, & Caprara, 2013). However, the volatile performance in the social-cognitive component should be received with care, since this could likewise be an artefact of the specific samples of participants in mid and late adolescence (see also Limitations section below).

Advanced ToM tasks tap into distinct ToM components that may develop at different rates (Osterhaus *et al.*, 2016; Tager-Flusberg & Sullivan, 2000). Tager-Flusberg and Sullivan (2000) suggested a distinction between social-perceptual and social-cognitive components in their two-component theory (see also Apperly & Butterfill, 2009; Meinhardt-Injac *et al.*, 2018). The two components could be separated based on differential impairment in atypical populations (Williams Syndrome: Tager-Flusberg & Sullivan, 2000; Autism:

Schuwerk, Vuori, & Sodian, 2015). Results of the present study provide support for this model, as the data revealed (1) lacking of correlation between ToM components after controlling for age and (2) protracted development in the social-perceptual (i.e., Eye Test), but not in the social-cognitive component (Faux Pas Test). Similar results were reported by Devine and Hughes (2013) for children and adolescents (8–13 years of age), who showed that non-verbal Silent Films task performance, but not the Strange Stories task performance, was significantly influenced by age. In non-verbal material, the detection of the social cues is as relevant as their evaluation and interpretation (see also Geiger *et al.*, 2019). However, the distinction between social-perceptual and social-cognitive components of ToM based only on task requirements is not always straightforward (see also Osterhaus *et al.*, 2016; Tager-Flusberg & Sullivan, 2000).

There are claims that the social-cognitive component of ToM has tighter connections to language and other aspects of cognition than the social-perceptual component (Tager-Flusberg & Sullivan, 2000). In line with this, we found that development of the social-cognitive component aligns with cognitive development, while only the social-perceptual component showed specific age-related increase beyond that in language, inhibitory control, and reasoning. This does not imply that these cognitive functions are not involved in the social-perceptual component (Meinhardt-Injac *et al.*, 2018; Tager-Flusberg & Sullivan, 2000). Yet, it demonstrates that cognitive factors alone do not fully explain age-related changes in this ToM component. Protracted development in social-perceptual ToM component may reflect increasing sensitivity to nuanced changes in emotional facial expressions across adolescence, that is, fine-tuning of perceptual discrimination (Rodger, Vizioli, Ouyang, & Caldara, 2015; Thomas, De Bellis, Graham, & LaBar, 2007). Such a fine-tuning is driven by new social developmental tasks and increasing experience with more complex emotional and mental states (Garcia & Scherf, 2015; Motta-Mena & Scherf, 2016). This hypothesis is further supported by evidence for protracted development in face perception and recognition (Fuhrmann *et al.*, 2016), and by evidence for connections between perceptual processes and visual ToM tasks, including the Eye Test (Meinhardt-Injac *et al.*, 2018).

Note that the distinction between social-perceptual and social-cognitive component crucially depends on the source of information (non-verbal vs. verbal). Another important differentiation proposed in ToM research concerns affective and cognitive ToM components (Sebastian *et al.*, 2011; Shamay-Tsoory & Aharon-Peretz, 2007). Cognitive ToM (i.e., also termed 'cold' ToM) refers to the ability to represent one's own and others' thoughts, intentions, and desires. Affective ToM (also termed as 'hot' ToM) is concerned with the understanding of the own and others' emotional states and preferences. In this view, it does not matter whether affective and metal states are judged from non-verbal or verbal cues, or a combination of the two (see Yoni Task, Shamay-Tsoory & Aharon-Peretz, 2007), only content matters (e.g., thinking about something vs. liking something). Imaging studies have found large overlapping, but also differences in the neural networks involved in cognitive as opposed to affective ToM (Shamay-Tsoory & Aharon-Peretz, 2007). The activation of the neuronal structures, however, was not only modulated by content, but depended on the stimulus material and the source of information used in the test material (Schlaffke *et al.*, 2015). This suggests that the two models might be complementary rather than competing. Possibly, information about affective states could stronger rely on non-verbal cues, compared to information about cognitive states and intentions. This remains to be clarified in future studies.

In the last years, there is increasing interest in bi-directional associations between ToM performance and real-world social behaviours. We know that social context shapes ToM development (Brizio *et al.*, 2015), but also that social behaviour is predicted by ToM ability (Banerjee, *et al.*, 2011). In school-aged children, advanced ToM ability has been associated with social competence (i.e., more cooperation and less conflict), prosocial behaviour, and peer popularity (see Slaughter *et al.*, 2015, for a meta-analysis). Although social and environmental changes during adolescence and young adulthood are tremendous, at the time there is still little evidence on bi-directional associations with ToM development (Tamnes *et al.*, 2018). Since ToM ability is crucial for coping with social and personal challenges that first arise in adolescence, studying its underpinnings and characteristics is an important endeavour, which deserves attention in future research.

Limitations

The current study has two limitations that should be acknowledged. We included a large sample of participants with a continuous age distribution in our study; nevertheless, it is important to keep in mind that cross-sectional age differences are only an approximation of true developmental changes (Molenaar, Huizenga, & Nesselroade, 2003). With the applied cross-sectional research design, the present study suffers from constraints in establishing valid (causal) temporal associations between learning experiences at a given age and the increase in ToM ability. Further, the test we used to measure inhibitory control consists of non-verbal social stimuli (faces) that may underestimate the role of inhibitory control for verbally presented ToM tests. Nonetheless, separating ToM from general cognitive development, the data provide a first approximation of how social-perceptual and social-cognitive ToM change across adolescence into young adulthood.

Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

References

Aïte, A., Cassotti, M., Linzarini, A., Osmont, A., Houdé, O., & Borst, G. (2018). Adolescents'inhibitory control: Keep it cool or lose control. *Developmental Science*, *21*(1), e12491. https://doi.org/10.1111/desc.12491

Astington, J. W., & Jenkins, J. M. (1999). A longitudinal study of the relation between language and theory-of-mind development. *Developmental Psychology*, *35*, 1311–1320. https://doi.org/10.1037/0012-1649.35.5.1311.

Baker, C. A., Peterson, E., Pulos, S., & Kirkland, R. A. (2014). Eyes and IQ: A meta-analysis of the relationship between intelligence and "Reading the Mind in the Eyes". *Intelligence*, *44*, 78–92. https://doi.org/10.1016/j.intell.2014.03.001.

Banerjee, R., Watling, D., & Caputi, M. (2011). Peer relations and the understanding of faux pas: Longitudinal evidence for bidirectional associations. *Child Development*, *82*, 1887–1905. https://doi.org/10.1111/j.1467-8624.2011.01669.x

Baron-Cohen, S., O'riordan, M., Stone, V., Jones, R., & Plaisted, K. (1999). Recognition of faux pas by normally developing children and children with Asperger syndrome or high-functioning autism. *Journal of Autism and Developmental Disorders*, *29*, 407–418. https://doi.org/10.1023/A:1023035012436

Baron-Cohen, S., Wheelwright, S., Hill, J., Raste, Y., & Plumb, I. (2001). The "Reading the Mind in the Eyes" test revised version: A study with normal adults, and adults with Asperger syndrome or high-functioning autism. *Journal of Child Psychology and Psychiatry*, *42*, 241–251. https://doi.org/10.1111/1469-7610.00715

Barton, K. (2013). *MuMIn: Multi-model inference. R package version 1.9.13*. Vienna, Austria: Comprehensive R Archive Network (CRAN).

Bates, D., Mächler, M., Bolker, B., & Walker, S. (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software*, *67*, 1–48. arXiv:1406.5823 [stat.CO].

Bölte, S. (2005). *Reading Mind in the Eyes Test für Erwachsene (dt. Fassung) von S. Baron-Cohen [Reading the mind in the eyes test for adults (German version) by S. Baron-Cohen]*. Frankfurt, Germany: J. W. Goethe Universität Frankfurt/M: Eigendruck.

Bosco, F. M., Gabbatore, I., & Tirassa, M. (2014). A broad assessment of theory of mind in adolescence: The complexity of mindreading. *Consciousness and Cognition*, *24*, 84–97. https://doi.org/10.1016/j.concog.2014.01.003

Brizio, A., Gabbatore, I., Tirassa, M., & Bosco, F. M. (2015). "No more a child, not yet an adult": Studying social cognition in adolescence. *Frontiers in Psychology*, *6*, 1011. https://doi.org/10.3389/fpsyg.2015.01011

Carpendale, J. I., & Lewis, C. (2004). Constructing an understanding of mind: The development of children's social understanding within social interaction. *Behavioral and Brain Sciences*, *27*, 79–96. https://doi.org/10.1017/S0140525X04000032

Collins, W. A., & Laursen, B. (2004). Changing relationships, changing youth: Interpersonal contexts of adolescent development. *The Journal of Early Adolescence*, *24*, 55–62. https://doi.org/10.1177/0272431603260882

Devine, R. T., & Hughes, C. (2013). Silent films and strange stories: Theory of mind, gender, and social experiences in middle childhood. *Child Development*, *84*, 989–1003. https://doi.org/10.1111/cdev.12017

Dumontheil, I., Apperly, I. A., & Blakemore, S. J. (2010). Online usage of theory of mind continues to develop in late adolescence. *Developmental Science*, *13*, 331–338. https://doi.org/10.1111/j.1467-7687.2009.00888.x

Fuhrmann, D., Knoll, L. J., & Blakemore, S. J. (2015). Adolescence as a sensitive period of brain development. *Trends in Cognitive Sciences*, *19*, 558–566. https://doi.org/10.1016/j.tics.2015.07.008

Fuhrmann, D., Knoll, L. J., Sakhardande, A. L., Speekenbrink, M., Kadosh, K. C., & Blakemore, S. J. (2016). Perception and recognition of faces in adolescence. *Scientific Reports*, *6*, 33497. https://doi.org/10.1038/srep33497

Garcia, N. V., & Scherf, K. S. (2015). Emerging sensitivity to socially complex expressions: A unique role for adolescence? *Child Development Perspectives*, *9*, 84–90. https://doi.org/10.1111/cdep.12114

Geiger, A., Bente, G., Lammers, S., Tepest, R., Roth, D., Bzdok, D., & Vogeley, K. (2019). Distinct functional roles of the mirror neuron system and the mentalizing system. *NeuroImage*, *202*, 116102. https://doi.org/10.1016/j.neuroimage.2019.116102

Harris, P. L., de Rosnay, M., & Pons, F. (2005). Language and children's understanding of mental states. *Current Directions in Psychological Science*, *14*, 69–73. https://doi.org/10.1111/j.0963-7214.2005.00337.x.

Hill, E. L. (2004). Evaluating the theory of executive dysfunction in autism. *Developmental Review*, *24*, 189–233. https://doi.org/10.1016/j.dr.2004.01.001

Hughes, C., & Devine, R. T. (2015). Individual differences in theory of mind from preschool to adolescence: Achievements and directions. *Child Development Perspectives*, *9*, 149–153. https://doi.org/10.1111/cdep.12124

Humphrey, G., & Dumontheil, I. (2016). Development of risk-taking, perspective-taking, and inhibitory control during adolescence. *Developmental Neuropsychology*, *41*, 59–76. https://doi.org/10.1080/87565641.2016.1161764

Im-Bolter, N., Agostino, A., & Owens-Jaffray, K. (2016). Theory of mind in middle childhood and early adolescence: Different from before? *Journal of Experimental Child Psychology*, *149*, 98–115. https://doi.org/10.1016/j.jecp.2015.12.006

Kennedy, D. P., & Adolphs, R. (2012). The social brain in psychiatric and neurological disorders. *Trends in Cognitive Sciences*, *16*, 559–572. https://doi.org/10.1016/j.tics.2012.09.006.

Larson, R. W., & Verma, S. (1999). How children and adolescents spend time across the world: Work, play, and developmental opportunities. *Psychological Bulletin*, *125*, 701–736. https://doi.org/10.1037/0033-2909.125.6.701

Lawson, J., Baron-Cohen, S., & Wheelwright, S. (2004). Empathising and systemising in adults with and without Asperger Syndrome. *Journal of Autism and Developmental Disorders*, *34*, 301–310. https://doi.org/10.1023/B:JADD.0000029552.42724.1b

Lehrl, S. (2005). *MWT-B Mehrfachwahl Wortschatz-Intelligenztest*. Balingen, Germany: Spitta-Verlag.

Lilliefors, H. W. (1967). On the Kolmogorov-Smirnov Test for normality with mean and variance unknown. *Journal of American Statistical Association*, *62*, 399–402. https://doi.org/10.1080/01621459.1967.10482916

Luengo Kanacri, B. P., Pastorelli, C., Eisenberg, N., Zuffianò, A., & Caprara, G. V. (2013). The development of prosociality from adolescence to early adulthood: the role of effortful control. *Journal of Personality*, *81*, 302–312. https://doi.org/10.1111/jopy.12001

McCulloch, C. E., Searle, S. R. (2001). *Generalized, linear, and mixed models*. Series in probability and statistics. New York, NY: Wiley.

Meinhardt-Injac, B., Daum, M. M., Meinhardt, G., & Persike, M. (2018). The two-systems account of Theory of Mind: Testing the links to social-perceptual and cognitive abilities. *Frontiers in Human Neuroscience*, *12*, 25. https://doi.org/10.3389/fnhum.2018.00025

Milligan, K., Astington, J. W., & Dack, L. A. (2007). Language and theory of mind: Meta-analysis of the relation between language ability and false-belief understanding. *Child Development*, *78*, 622–646. https://doi.org/10.1111/j.1467-8624.2007.01018.x.

Molenaar, P. C., Huizenga, H. M., & Nesselroade, J. R. (2003). The relationship between the structure of interindividual and intraindividual variability: A theoretical and empirical vindication of developmental systems theory. In U. M. Staudinger & U. Lindenberger (Eds.), *Understanding human development*. Boston, MA: Springer.

Motta-Mena, N. V., & Scherf, K. S. (2016). Pubertal development shapes perception of complex facial expressions. *Developmental Science*, *20*, e12451. https://doi.org/10.1111/desc.12451

Osterhaus, C., Koerber, S., & Sodian, B. (2016). Scaling of advanced theory-of-mind tasks. *Child Development*, *87*, 1971–1991. https://doi.org/10.1111/cdev.12566

Peterson, C. C., & Wellman, H. M. (2018). Longitudinal theory of mind (ToM) development from preschool to adolescence with and without ToM delay. *Child Development*, *90*, 1917–1934. https://doi.org/10.1111/cdev.13064

Pinheiro, J. C., & Bates, D. M. (2000). Linear mixed-effects models: basic concepts and examples. In *Mixed-effects models in S and S-PLUS. Statistics and computing*. New York, NY: Springer. https://doi.org/10.1007/0-387-22747-4_1

Pyers, J. E., & Senghas, A. (2009). Language promotes false-belief understanding: Evidence from learners of a new sign language. *Psychological Science*, *20*, 805–812. https://doi.org/10.1111/j.1467-9280.2009.02377.x

R Core Team. (2012). *R: A language and environment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing.

Radecki, M. A., Cox, S. R., & MacPherson, S. E. (2019). Theory of Mind and psychosocial characteristics in older men. *Psychology and Aging*, *34*, 145–151. https://doi.org/10.1037/pag0000324

Rakoczy, H. (2017). Theory of Mind. In B. Hopkins, E. Geangu, & S. Linkenauger (Eds.), *The Cambridge Encyclopedia of child development* (pp. 505–512). Cambridge, UK: Cambridge University Press. https://doi.org/10.1017/9781316216491.081

Raven, J. (2000). The Raven's progressive matrices: Change and stability over culture and time. *Cognitive Psychology*, *41*, 1–48. https://doi.org/10.1006/cogp.1999.0735

Rice, K., Anderson, L. C., Velnoskey, K., Thompson, J. C., & Redcay, E. (2016). Biological motion perception links diverse facets of theory of mind during middle childhood. *Journal of Experimental Child Psychology*, *146*, 238–246. https://doi.org/10.1016/j.jecp.2015.09.003

Rodger, H., Vizioli, L., Ouyang, X., & Caldara, R. (2015). Mapping the development of facial expression recognition. *Developmental Science*, *18*, 926–939. https://doi.org/10.1111/desc.12281

Schlaffke, L., Lissek, S., Lenz, M., Juckel, G., Schultz, T., Tegenthoff, M., . . . Brüne, M. (2015). Shared and nonshared neural networks of cognitive and affective theory-of-mind: A neuroimaging study using cartoon picture stories. *Human Brain Mapping*, *36*(1), 29–39. https://doi.org/10.1002/hbm.22610

Schmitz, T. W., Cheng, F. H., & De Rosa, E. (2010). Failing to ignore: PARADOXICAL neural effects of perceptual load on early attentional selection in normal aging. *Journal of Neuroscience*, *30*, 14750–14758. https://doi.org/10.1523/JNEUROSCI.2687-10.2010

Schneider, D., Slaughter, V. P., & Dux, P. E. (2015). What do we know about implicit false-belief tracking? *Psychonomic Bulletin and Review*, *22*, 1–12. https://doi.org/10.3758/s13423-014-0644-z

Schuwerk, T., Vuori, M., & Sodian, B. (2015). Implicit and explicit theory of mind reasoning in autism spectrum disorders: the impact of experience. *Autism*, *19*, 459–468. https://doi.org/10.1177/1362361314526004

Sebastian, C. L., Fontaine, N. M., Bird, G., Blakemore, S. J., De Brito, S. A., McCrory, E. J., & Viding, E. (2011). Neural processing associated with cognitive and affective Theory of Mind in adolescents and adults. *Social Cognitive and Affective Neuroscience*, *7*, 53–63. https://doi.org/10.1093/scan/nsr023

Shamay-Tsoory, S. G., & Aharon-Peretz, J. (2007). Dissociable prefrontal networks for cognitive and affective theory of mind: A lesion study. *Neuropsychologia*, *45*, 3054–3067. https://doi.org/10.1016/j.neuropsychologia.2007.05.021

Slaughter, V., Imuta, K., Peterson, C. C., & Henry, J. D. (2015). Meta-analysis of theory of mind and peer popularity in the preschool and early school years. *Child Development*, *86*, 1159–1174. https://doi.org/10.1111/cdev.12372

Steinberg, L. (2005). Cognitive and affective development in adolescence. *Trends in Cognitive Sciences*, *9*, 69–74. https://doi.org/10.1016/j.tics.2004.12.005

Stone, V. E., Baron-Cohen, S., & Knight, R. T. (1998). Frontal lobe contributions to theory of mind. *Journal of Cognitive Neuroscience*, *10*, 640–656. https://doi.org/10.1162/089892998562942

Symeonidou, I., Dumontheil, I., Chow, W. Y., & Breheny, R. (2016). Development of online use of theory of mind during adolescence: An eye-tracking study. *Journal of Experimental Child Psychology*, *149*, 81–97. https://doi.org/10.1016/j.jecp.2015.11.007

Tager-Flusberg, H., & Sullivan, K. (2000). A componential view of theory of mind: Evidence from Williams syndrome. *Cognition*, *76*, 59–90. https://doi.org/10.1016/S0010-0277(00)00069-X

Tamnes, C. K., Overbye, K., Ferschmann, L., Fjell, A. M., Walhovd, K. B., Blakemore, S. J., & Dumontheil, I. (2018). Social perspective taking is associated with self-reported prosocial behavior and regional cortical thickness across adolescence. *Developmental Psychology*, *54*, 1745–1757.

Thomas, L. A., De Bellis, M. D., Graham, R., & LaBar, K. S. (2007). Development of emotional facial recognition in late childhood and adolescence. *Developmental Science*, *10*, 547–558. https://doi.org/10.1111/j.1467-7687.2007.00614.x.

Tousignant, B., Sirois, K., Achim, A. M., Massicotte, E., & Jackson, P. L. (2017). A comprehensive assessment of social cognition from adolescence to adulthood. *Cognitive Development*, *43*, 214–223. https://doi.org/10.1016/j.cogdev.2017.05.001

Valle, A., Massaro, D., Castelli, I., & Marchetti, A. (2015). Theory of mind development in adolescence and early adulthood: The growing complexity of recursive thinking ability. *Europe's Journal of Psychology*, *11*, 112–124. https://doi.org/10.5964/ejop.v11i1.829

Vetter, N. C., Leipold, K., Kliegel, M., Phillips, L. H., & Altgassen, M. (2013). Ongoing development of social cognition in adolescence. *Child Neuropsychology*, *19*, 615–629. https://doi.org/10.1080/09297049.2012.718324

Wellman, H. M., Fang, F., & Peterson, C. C. (2011). Sequential progressions in a theory-of-mind scale: Longitudinal perspectives. *Child Development*, *82*, 780–792. https://doi.org/10.1111/j.1467-8624.2011.01583.x

White, S., Hill, E., Happé, F., & Frith, U. (2009). Revisiting the strange stories: Revealing mentalizing impairments in autism. *Child Development*, *80*, 1097–1117. https://doi.org/10.1111/j.1467-8624.2009.01319.x

Zerwas, S., Balaraman, G., & Brownell, C. (2004). Constructing an understanding of mind with peers. *Behavioral and Brain Sciences*, *27*, 130–130. https://doi.org/10.1017/S0140525X04590039

Received 3 September 2019; revised version received 12 December 2019

Supporting Information

The following supporting information may be found in the online edition of the article:

Figure S1. Regression-scatterplots for all five tests (z-scores).
Figure S2. Distribution of standardized residuals (left) and plot of standardized residuals against predicted values (right) for the LMM models M0, M1 and M2.
Table S1. Descriptive statistics of the sample.