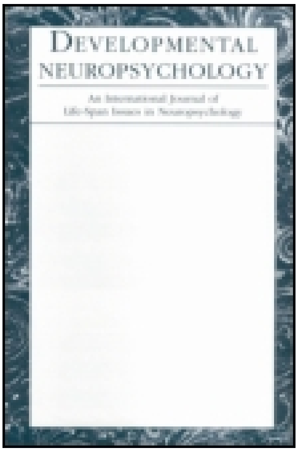

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Development of Affective Theory of Mind Across Adolescence: Disentangling the Role of Executive Functions

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Theory of mind, the ability to understand mental states, involves inferences about others' cognitive (cognitive theory of mind) and emotional (affective theory of mind) mental states. The current study explored the role of executive functions in developing affective theory of mind across adolescence. Affective theory of mind and three subcomponents of executive functions (inhibition, updating, and shifting) were measured. Affective theory of mind was positively related to age, and all three executive functions. Specifically, inhibition explained the largest amount of variance in age-related differences in affective theory of mind.

Adolescence is characterized by major challenges in the socioemotional domain (Steinberg & Morris, 2001). Peer relationships become more important and romantic relationships arise during this period requiring the development of more elaborate socioemotional skills (Lerner &

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Steinberg, 2004). These skills encompass interpreting others' mental states such as beliefs, desires, and emotions. To interpret others' mental states a well-functioning theory of mind (ToM) is necessary (Perner, 1991). ToM is a multidimensional construct that can be divided into two components: (1) affective ToM encompassing inferences about emotions (i.e., "hot" aspects) and (2) cognitive ToM encompassing inferences about knowledge and beliefs (i.e., "cold" aspects of ToM; Shamay-Tsoory, Harari, Aharon-Peretz, & Levkovitz, 2010).

Cognitive ToM is a prerequisite for affective ToM according to a model by Shamay-Tsoory et al. (2010). First, the development of a functioning cognitive ToM is required to understand others' perspective and to infer their mental states. Second, empathy is required to understand the emotions of another person. Only the integration of these two processes enables a functioning affective ToM (Shamay-Tsoory et al., 2010), which therefore represents a specific and cognitively challenging higher-order aspect of affective processing (Coricelli, 2005; Mier et al., 2010). In line with this notion, initial behavioral evidence shows that cognitive ToM seems to develop earlier than affective ToM (Ruffman & Keenan, 1996) as children first have to gain an understanding of others' beliefs in order to appreciate that beliefs guide others' emotions (Rieffe, Terwogt, & Cowan, 2005). This raises the possibility that affective ToM might show a more extended developmental trajectory than first- or second-order cognitive ToM. While the emergence and early ontogeny of cognitive ToM has been widely investigated (Wellman, Cross, & Watson, 2001) only a handful of studies exist on the development of affective ToM. The understanding of emotions such as surprise begins to develop between the age of 7–9 years (Ruffman & Keenan, 1996), while the more complex abilities involved in understanding social faux pas show development between 9–11 years (Baron-Cohen, O'Riordan, Stone, Jones, & Plaisted, 1999).

ToM development throughout *adolescence* until young adulthood is largely understudied, which particularly accounts for affective ToM (Blakemore, 2008). Only two studies have investigated possible ongoing development of *affective* ToM in adolescence. The time required to think about the appropriateness of emotions decreased throughout adolescence (Keulers, Evers, Stiers, & Jolles, 2010). Further, adolescents made more errors than adults in choosing the appropriate ending of vignettes depicting a character's response to her companion's emotions (Sebastian et al., 2012).

These behavioral findings are corroborated by emerging evidence of a protracted neural development of cognitive (for a review see Blakemore, 2008) and affective ToM across adolescence (Gunther Moor et al., 2012; Sebastian et al., 2012). Accordingly, the medial prefrontal cortex (MPFC) is a key brain area implicated in ongoing ToM development throughout adolescence. Specifically, the ventral MPFC is supposed to be related to affective ToM whereas the dorsal MPFC has been mainly associated with an ongoing development for cognitive ToM (Abu-Akel & Shamay-Tsoory, 2011; Blakemore, 2008). These findings are in accordance with lesion studies, which support this double-dissociation of affective and cognitive ToM in the MPFC (Shamay-Tsoory, Tibi-Elhanany, & Aharon-Peretz, 2006).

Taken together, these neuroimaging findings as well as initial evidence from two behavioral studies suggest ongoing development of affective ToM across adolescence. However, the first behavioral study (Keulers et al., 2010) focused on thinking time only and provided no measure of accuracy and the second (Sebastian et al., 2012) was a neuroimaging study with only 15 participants each in the adolescent and adult age group. Further, previous research has used static, non-naturalistic task material lacking important dynamic features of emotions. Thus, the first aim of the present study was to test for age-related variance in affective ToM across adolescence using the "facial scale" of the Cambridge Mindreading Face-Voice Battery (Golan, Baron-Cohen, & Hill, 2006) presenting complex emotional mental states. It consists of film clips depicting actors' face and upper body, which approximates real-life social interactions and thus enables the presentation of affective mental states requiring motion (e.g., insincerity). This instrument is suitable for the investigated age group since it was designed to detect subtle deficits in affective ToM in adults with high-functioning autism (Golan et al., 2006). The depicted emotions are complex and situation-based (Golan et al., 2006). In contrast to basic emotions, the depicted emotions might not be extractable at first sight and by use of emotion recognition only (Coricelli, 2005; Mier et al., 2010). Therefore, the task requires the individual to take over the other's perspective (cognitive ToM). Affective ToM is conceptualized as the integration of cognitive ToM and empathy (Shamay-Tsoory et al., 2010). Thus, tasks assessing affective ToM require both emotion recognition processes as well as higher-level understanding of cognitive ToM and lastly empathy. Moreover, according to the model by Shamay-Tsoory et al. (2010) cognitive ToM might be a prerequisite for the affective ToM task used.

In addition to the developmental trajectory of affective ToM, the cognitive processes driving these changes are of interest for cognitive and social developmental research. One major candidate for these cognitive processes that have been discussed are executive functions (EF; Zelazo, Müller Frye, & Marcovitch, 2003). EF involve higher-level cognitive processes that are important for goal-directed actions. In preschool children, EF have been shown to play an important role in cognitive ToM performance (Carlson & Moses, 2001). According to a meta-analysis, correlations among EF and ToM in young children yield a strong effect size of 1.08 (Perner & Lang, 1999).

However, no study has yet investigated the protracted development of affective ToM and how this might relate to the ongoing development of EF during adolescence. This is surprising, given that executive functioning in affective situations seems to still be under development during adolescence as evidenced by heightened risk-taking and sensation-seeking behavior (Steinberg, 2005). Therefore, adolescence has been labeled a critical or sensitive period in development of regulation of affect and behavior (Steinberg, 2005). Regulation of one's own automatic and prepotent emotions and thoughts is required for affective ToM (Ochsner & Gross, 2005). A better understanding of the normative development of the role of EF in affective ToM will help to elucidate the complex relationship of cognitive and socioemotional abilities during this turbulent age period. Moreover, it is important to delineate the range of normal adolescent changes in these abilities in typical samples (Paus, Keshavan, & Giedd, 2008), given that this age range is a critical period for the development of psychopathology.

Further, the prediction that the EF-ToM relation may extend to affective ToM development across adolescence comes from two lines of research. First, recent studies show a substantial development of EF across adolescence (e.g., Luna, Garver, Urban, Lazar, & Sweeney, 2004). Neural correlates of this EF development were also observed, mainly in the dorsolateral prefrontal cortex (see Luna, Padmanabhan, & O'Hearn, 2010 for a recent review). The age period of adolescence is of specific interest for this type of research since adolescents have already developed basic abilities of affective ToM, while the ongoing sophistication of more complex affective ToM abilities might be driven by ongoing EF development (Apperly, Samson, & Humphreys, 2009). Moreover, Apperly and colleagues have argued that studies beyond childhood can inform accounts on the role of EF in the emergence of ToM (Apperly et al., 2009). EF and ToM might be related in later phases of the lifespan (such as in adolescence like in the present study). This generates the prediction that the relation between EF and ToM in childhood holds since EF are an essential part of the mature ToM abilities that children are developing (Apperly et al., 2009). Developing more sophisticated EF skills may further enhance one's ability to deal with others' emotional states more smoothly and therefore lead to improved social functioning.

Moreover, a second line of research directly indicates association of these two constructs in young adult samples. For example, participants' performance decreased in a stories task with affective ToM components when working simultaneously on an updating task (McKinnon & Moscovitch, 2007). Performance on a visual task of affective ToM (Eyes test; Baron-Cohen, Wheelwright, Hill, Raste, & Plumb, 2001) was selectively impaired by simultaneous performance of an inhibitory demanding task but not an updating task (Bull, Phillips, & Conway, 2008). In another study different aspects of EF related to performance on different affective ToM measures (Ahmed & Miller, 2011). However, most studies have not investigated systematically dissociable EF facets and instead have focused on either global composite measures of EF (Ahmed & Miller, 2011) or a single component of EF (McKinnon & Moscovitch, 2007). Following Miyake et al. (2000) EF can be conceptualized as three distinguishable subcomponents: (1) *inhibition* of prepotent responses, (2) *updating* information in working memory, and (3) *shifting* between tasks. Therefore, it is advantageous to measure all three distinguishable components of EF. Thus, from a conceptual perspective, the present study aimed at systematically delineating the role of these three specific EFs in affective ToM in an adolescent sample. Since affective ToM seems to be an integrative process relying on both cognitive ToM and empathy (Shamay-Tsoory et al., 2010), possibly additional complex cognitive processes (i.e., executive functions) are required to integrate and coordinate cognitive resources. Various EFs could play a role in affective ToM in the following ways: working memory might allow one to maintain and manipulate information in mind about a person's current as well as past emotional states, inhibition might allow an individual to inhibit her own mental state to put herself in the emotional shoes of another person, and shifting might be important in order to flexibly shift between one's own current emotional perspective and that of another.

To date, there are no studies investigating the links between affective ToM and EF in adolescence. Hence, the present study had two aims: (1) To examine age-related variance in a realistic affective ToM measure across adolescence in a large sample. We predicted that affective ToM will continue to develop across adolescence and (2) To examine the influence of inhibition, updating, and shifting in explaining age-related variance and individual differences in affective ToM. We predicted that all three EFs might explain age-related variance in affective ToM. This is corroborated by studies finding increasing inhibition (Velanova, Wheeler, & Luna, 2008), updating (Gathercole, Pickering, Ambridge, & Wearing, 2004), and shifting (Luna et al., 2004) across adolescence.

METHOD

Participants

The sample consisted of 139 participants (23% male, 77% female) aged 12.08 to 22.92 years ($M = 17.02$, $SD = 3.40$). All participants spoke German as their first language. School-aged participants mostly attended high schools preparing for university and did not differ from university students with respect to age-corrected verbal and nonverbal abilities: Vocabulary subtest, t (137) = –.77, p = .441; $M_{\text{high school}}$ = 13.70, $SD_{\text{high school}}$ = 2.23; $M_{\text{university}}$ = 13.97, $SD_{\text{university}}$ = 1.9, and Matrices subtest, t (136) = .54, p = .588; $M_{\text{high school}}$ = 12.74, $SD_{\text{high school}}$ = 2; $M_{\text{university}}$ = 12.57, $SD_{\text{university}}$ = 1.75. Further, these age groups did not differ in terms of their parents' level of education: mother's education: χ^2 (1, N = 132) = .214, p = .726; father's education: χ^2 (1, N = 130) = .407, p = .59. Exclusion criteria were established by self-report (or parental report for participants under 18) and comprised any psychiatric disorders such as autism spectrum disorder, attention deficit hyperactivity disorder, depression, mania, or schizophrenia. Participants were recruited via flyers or personal advertisement in high schools, sport-clubs, and at the university. Written informed consent was obtained before participation from each participant and from either a parent or guardian for participants under 18. Participants received monetary compensation or course credit (undergraduate psychology students). All procedures were approved by the University Ethics Committee.

Materials

Affective Theory of Mind

Faces test. The Faces test represents the "facial scale" of the Cambridge Mindreading Face-Voice Battery (Golan et al., 2006). It was translated into German by a professional translator and run on a computer using the experimental software E-Prime (Version 2, Psychology Software Tools, Inc.). Silent clips of male and female adult actors of different age groups (young, middle-aged, and old adults) that expressed complex emotions in the face and torso (from the shoulders upward) were presented on a LCD screen 23.6 inches away from participants. Film clips varied from 3–5 seconds and faded after presentation. Participants subsequently selected which of four numbered adjectives (different adjectives for each film clip) best described the emotion of the person via button press. Examples of correct adjectives are resentful, subdued, empathic, and vibrant. After participant's button press the next film clip was presented. No feedback was given during the task. Response time was unrestricted and adjectives stayed on screen until participant's response. Participants were told to answer as accurately as possible. Due to technical problems, one item of the original test was not shown. Therefore, the task comprised 49 items that were presented in a random order (preceded by two practice items). A handout containing definitions of all adjectives was provided at the beginning of the task to minimize mistakes due to misunderstanding vocabulary.

Internal consistency was calculated for the Faces test, which yielded acceptable consistency (Cronbach's alpha = .60; Evers, 2001). Golan et al. (2006) showed that the Faces test highly correlated with the Eyes test (r = .74, p < .01), which is a standard measure of affective ToM. Furthermore, the Faces test correlated with the Reading the mind in the voice test (r = .49, p < .01) and with the parallel constructed vocal scale of the Cambridge Mindreading Face-Voice Battery (r = .57, p < .01). The Faces test additionally correlated negatively with the Autism Spectrum Quotient (r = –.47, p < .01). Therefore, it can be concluded that there is good construct validity.

Basic Cognitive Abilities

Nonverbal and verbal ability. In order to get an estimate of basic cognitive ability for both verbal and nonverbal domains, the following subtests of the Wechsler Adult Intelligence Scale (WAIS, German adaptation, von Aster, Neubauer, & Horn, 2007) and the Wechsler Intelligence Scale for children (WISC–IV, German adaptation, Petermann & Petermann, 2007) were conducted according to participant's age: Vocabulary and Matrices subtests (see Wechsler, 1999). These two subtests were collected as quick estimators, similar to other studies (Ahmed & Miller, 2011; Sebastian et al., 2012). The Vocabulary subtest reflects expressive vocabulary. It was chosen since knowledge of words may play an especially important role in the Faces test and since the test shows the highest correlation with the subindex verbal comprehension (WIE: $r = .90$; WISC–IV: $r = .92$; von Aster et al., 2007; Petermann & Petermann, 2007). The Matrices subtest is a marker for nonverbal fluid intelligence and was chosen since this subtest has the highest correlation with the subindex perceptual organization (WIE: $r = .84$; WISC–IV: $r = .83$; von Aster et al., 2007; Petermann & Petermann, 2007). Response time for both tasks was unrestricted. Reliability of these subtasks was acceptable or good (Vocabulary test r = .76, Matrices test r = .92 taken from WAIS; von Aster et al., 2006). Construct validity of both the WAIS (von Aster et al., 2006) and WISC–IV (Petermann & Petermann, 2007) has been well established.

Executive Functions

The specific tests of EF were selected since they have been suggested to tap into the three main components of EF (Miyake et al., 2000). Further, these tasks have shown acceptable to good reliability in similar age groups, that is, inhibition $r = .90$, updating $r = .76$, shifting $r = .97$ (Friedman et al., 2006). The tasks have been validated in terms of their prediction of other cognitive skills (Miyake et al., 2000). Moreover, studies have shown that performance in these tasks seems to increase across adolescence for antisaccade (Luna et al., 2004; Velanova et al., 2008), letter memory (Tamnes et al., 2010), and similar tasks to color shape (Luna et al., 2004; Velanova et al., 2008). All tasks were presented on a LCD screen with a sitting distance of approximately 23.6 inches. Participants were asked to be as accurate as possible on each task but were not given instructions about speed.

Inhibition. To assess inhibitory control the antisaccade task was used (adapted from Miyake et al., 2000). During each trial (total 92 trials) of this task, participants were required to focus on a fixation point on the center of the screen that was presented for a variable and unpredictable amount of time (1–3-sec intervals). A visual cue (black square) then appeared on one side (e.g., left) of the screen. Shortly after presentation of the cue (225 msec), a target stimulus (arrow inside an open square) was briefly presented (100 msec) on the opposite side (e.g., right) of the screen and then masked. Participants were instructed to identify the direction of the arrow (left, right, or up) by pressing one of three response buttons. For this purpose participants were asked to shift their gaze to the side opposite the visual cue. The cues and targets were both presented 3.7 in. away from the fixation point and the participants were seated 23.6 in. from the computer monitor (thus, the visual angle from fixation point to target was approximately 9°). The proportion of correct responses (i.e., trials in which participants correctly identified the direction of the arrow) was the dependent variable.

Updating. The letter-memory task was used to measure the updating component of EF (adapted from Miyake et al., 2000). In this task, a list of letters was presented serially for 1,500 msec per letter. Participants were asked to recall the last three letters of each list and to enter them on the keyboard. List length varied between 5 and 9 letters and was unknown to participants in advance, therefore this task required constant updating of working memory contents throughout the trial. Participants performed 12 trials and had to remember the last three letters of each trial, resulting in a total of 36 letters recalled. Mean proportion of correctly recalled letters across 12 trials was used as the dependent variable.

Shifting. The color-shape task (Friedman et al. 2006), using geometric objects, was employed to measure shifting (adapted from Miyake et al., 2000). Participants had to classify objects by color (green or red) or by shape (circle or triangle) via button press. An external cueing paradigm was used, that is the task to be executed was written above the stimuli and was present until a response was made. First, there were two single-task blocks of 26 trials each for the color task and the shape task, respectively. Afterward participants performed the mixed block of 82 trials where tasks were pseudorandomly mixed. Following Miyake et al. (2000), as the dependent variable unspecific switch costs were used, computed as the difference in mean reaction time (RT) between the mixed-task block and the two single-task blocks. RT measures were computed on correct trials only.

RESULTS

Before analyses, univariate outliers with values more than three standard deviations above or below the mean were excluded. There was only one participant with an outlier total score in the inhibition task. This participant was excluded from further analyses. Descriptive data for the basic cognitive abilities, EF tests, and the affective ToM measure are presented in Table 1. Participants' nonverbal and verbal age-corrected abilities were in a normal to above-average range.

First, correlations with age were computed for all cognitive variables assessed (see Table 2). As expected there was no correlation with age in the age-corrected normative scores in Vocabulary subscale or Matrices subscale. Thus, basic cognitive ability was age appropriate

TABLE 1
Descriptive Statistics of Vocabulary and Matrices Test, Executive Functions, and Affective ToM

	Min	*Max*	*Mean*	*SD*	*Skewness*	*Kurtosis*
Vocabulary test	8	18	13.83	2.07	−.13	−.24
Matrices test	8	17	12.65	1.87	−.06	−.28
Inhibition	0.54	0.99	0.81	0.10	−.35	−.40
Updating	0	1	0.67	0.20	−.40	−.40
Shifting	215	1693	959	271	.26	.12
Affective ToM	0.43	0.88	0.66	0.10	−.14	−.26

Note. For both Vocabulary and Matrices, test scores are age-corrected ($M = 10$, $SD = 3$). For inhibition, updating, and affective theory of mind (ToM), scores are given as the proportion of correct responses. For shifting, the difference in mean reaction time (RT; in milliseconds) between the mixed block and the two task-pure blocks is shown.

TABLE 2
Correlation Matrix of Verbal and Nonverbal Ability, Executive Functions, Affective ToM, and Age

Measure	*1*	*2*	*3*	*4*	*5*	*6*	*7*
1. Vocabulary test		.20*	−.07	.07	−.16	.20*	.01
2. Matrices test			.01	.11	.11	.03	−.07
3. Inhibition				.32***	−.25**	.44***	.43***
4. Updating					−.22*	.33***	.49***
5. Shifting						−.23**	−.31***
6. Affective ToM							.59***
7. Age							

Note. Significant negative correlations with shifting indicate that better shifting ability (i.e., lower unspecific shifting costs) correlates with the other measures. ToM = theory of mind.
*$p < .05$. **$p < .01$. ***$p < .001$.

across the sample included in the present study. Age correlated significantly with all three EF measures: inhibition, updating, and shifting. Age also correlated with performance in affective ToM in the predicted direction ($r = .59$). Age accounted for 35% of the variance in affective ToM.

Second, correlational analyses were conducted assessing the single contributions of the EF tests and Vocabulary and Matrices test to inter-individual variability in affective ToM (see Table 2). Analyses revealed reliable correlations of affective ToM with all three EF tests in the expected direction, from shifting (lower shifting costs related to better affective ToM performance) to updating to the highest correlation for inhibition. In addition, verbal, but not fluid ability was related to performance in affective ToM. The correlations were not affected by controlling for gender.

Decomposing the Age Effect in Affective Theory of Mind

In our final analysis, we aimed at delineating the relative contribution of the various cognitive resources to the age effect observed in affective ToM on a multivariate level. We conducted a hierarchical linear regression analysis for accuracy in the Faces test controlling first for individual differences in Vocabulary test ($\beta = .23$, $t = 3.32$, $p < .01$) and Matrices test ($\beta = .01$, $t = 0.18$, $p = .86$). As expected from the correlational analyses, the Vocabulary test provided a significant (but small) contribution of 4.5% to the observed variance in affective ToM, whereas the Matrices test did not explain any variance (total model step 1: $R^2 = .045$, F (2,133) = 3.10, $p < .05$, estimated power = 0.6). In a second step, EF tests were entered into the equation. From the three EF tests the only significant predictive measure was inhibition (inhibition, $\beta = .26$, $t = 3.56$, $p < .01$; updating, $\beta = .01$, $t = 0.17$, $p = .86$; and shifting, $\beta = .02$, $t = .29$, $p = .77$). Including the three measures of EF significantly enhanced the prediction and added 26% of explained variance to the model (total model step 2: R^2 change = .26, F *(5,130)* = 11.27, F change = 16.03, $p < .001$, estimated power = 1.0, resulting in a total $R^2 = .30$, $p < .001$). Third, age was entered in the final step into the equation predicting affective ToM ($\beta = .48$, $t = 5.88$, $p < .001$). Age further significantly improved prediction, accounting for about 15% of the observed variance in affective ToM (total model step 3: R^2 change = .148, F (6,129) = 17.60, F change = 34.63,

$p < .001$, estimated power = 1.0, resulting in a total $R^2 = .450$, $p < .001$). Gender did not account significantly for variance in the Faces test in the regression analysis. Taken together, considering the beta weights of the final regression model with all predictors included (i.e., beta values reported above), inhibition emerged as an important and the only significant EF predictor of the affective ToM task.

DISCUSSION

The first aim of the present study was to investigate the development of affective ToM across adolescence with a new ecologically valid paradigm consisting of film clips depicting affective mental states. Ongoing development of affective ToM was found: Affective ToM and age were strongly correlated. Even after controlling for EF and basic cognitive abilities, age still explained a significant amount of variance in the Faces test. The second aim was to systematically investigate the role of inhibition, updating, and shifting in explaining age-related variance in affective ToM across adolescence. To our knowledge, the current study is the first to investigate the relationship of EF and affective ToM throughout adolescence until young adulthood. Related to our second aim, all three EFs correlated with affective ToM performance and explained a large portion of the variance. Specifically, the highest correlation was found between inhibition and affective ToM. Also in the final regression model with all predictors included, inhibition emerged as an important single EF predictor beyond age, updating, shifting, and Vocabulary test performance.

Given that 35% of variance in the Faces test was explained by age, the current study provides further evidence for ongoing affective ToM development across adolescence. This result extends findings from two recent studies (Keulers et al., 2010; Sebastian et al., 2012), to a larger sample using a more realistic affective ToM task. Further, the result underlines the importance of measuring affective ToM with more naturalistic and complex paradigms to avoid ceiling effects since most of previous studies employed rather simple tasks of affective ToM, (e.g., the child version of the Eyes test; Gunther Moor et al., 2012).

Present findings reveal a close relation between EF and the development of affective ToM. Since affective ToM seems to be an integrative process relying on both cognitive ToM and empathy (Shamay-Tsoory et al., 2010), possibly additional complex cognitive processes (i.e., executive functions) are required to integrate and coordinate cognitive resources. Inhibition correlated most strongly with affective ToM. This finding is consistent with previous evidence showing that an affective ToM task (the Eyes test) and inhibition were related in young adults (Ahmed & Miller, 2011), or showed dual task interference (Bull et al., 2008). For developing a more complex affective ToM adolescents and young adults need cognitive processes such as inhibition. This underlines the claim made by Apperly et al. (2009) that it is essential to study ToM not only in younger children but also during its extended developmental course (i.e., adolescence or young adulthood). Furthermore, it points to the importance of systematically differentiating among the role of the sub-processes of EF: inhibition, updating, and shifting.

Particularly inhibition might be involved in affective ToM tasks such as the Eyes or Faces test since social attributes, for example attractiveness might be automatically activated and have to be inhibited (Bull et al., 2008). Moreover, it has been argued that inhibition facilitates memory retrieval by suppressing immediate responses long enough to search memory and provide well-thought out answers (Lorsbach, Katz, & Cupak, 1998). This seems plausible since the videos last several seconds requiring to inhibit the first spontaneous guess and to consider the whole sequence.

The specific role for inhibition might also be in line with evidence of the brain regions involved in affective ToM and inhibition. The core region for affective ToM, the vMPFC, seems to code the emotional value of stimuli and select actions on this basis (Ochsner & Gross, 2005). Moreover, inhibition seems to be necessary to modulate the signal encoded in vMPFC (Hare, Camerer, & Rangel, 2009). Inhibitory processes are associated with dorso-lateral PFC activity. Therefore, the behavioral association of inhibition and affective ToM might possibly be related to the neural orchestration of the two underlying regions during emotionally laden decision making. Interestingly, Sebastian et al. (2012) found ongoing development of affective ToM on the neural level; the vMPFC showed a stronger activity in adolescents in contrast to adults. Further research is needed to investigate affective ToM development throughout adolescence both at the behavioral and neural level.

Furthermore, the Vocabulary test predicted a small amount of variance of affective ToM performance. This might possibly be since the task required the understanding of complex verbal descriptions of emotions. This is in accordance with evidence of the vital role of language in the development of ToM in children (Astington & Jenkins, 1999) and young adults (Ahmed & Miller, 2011). Most previous studies have employed affective ToM tasks that depend on the understanding of linguistic emotional terms (Ahmed & Miller, 2011; Bull et al., 2008; McKinnon & Moscovitch, 2007). Since verbal abilities continue to develop in adolescence, future studies should develop and employ more age-adequate tasks that have a lower verbal load. Similarly, basic cognitive functions might also play a role in affective ToM development. However, a recent study has found no relationship of processing speed and affective ToM development (Vetter, Leipold, Kliegel, Phillips, & Altgassen, 2012).

Similar to most of the previous developmental literature a limitation of the current study is the correlational approach investigating the relationship of ToM and EF. However, in the current study we first aimed to test the three sub-components of executive functions systematically. In a future study it would be interesting to test the role of inhibition in a dual-task paradigm in the same age group. A further limitation of the current study is the unequal gender distribution. However, in additional analyses gender was controlled for and had no significant impact on the outcome of the results. Therefore, it is unlikely that our results have been affected by this unequal distribution. Nevertheless, future research should replicate our findings with gender matched samples. Given that ongoing development of inhibition and affective ToM in adolescence may relate to problematic behaviors such as risk taking (Steinberg, 2005) it is important to examine this issue more directly in future studies. Finally, the present study is limited by not including a cognitive ToM task modeled in parallel to the affective ToM task, which would allow for direct comparison between the two components of ToM and to examine the role of EF in both aspects of ToM. Importantly, a parallel task would allow for investigation of whether there is a difference between affective and cognitive ToM requiring EF, specifically inhibition. Currently, in the available literature there is no existing instrument which has a comparable design and task difficulty that allows for such direct comparisons between both affective and cognitive ToM and would be appropriate for the investigated age group with avoidance of ceiling effects. Hence, future research should be aimed at constructing tasks that will enable those comparisons and follow up on the present findings.

Conclusions

Recently, Apperly and colleagues postulated that it is crucial to examine the role of EF in ToM in older children and adults (Apperly et al., 2009) in order to investigate whether there is an ongoing development of ToM after childhood and what role EF plays in this development. The current study adopted this approach in a sample of adolescents and young adults. Our findings suggest an extended development of affective ToM across adolescence and demonstrate processing overlaps between EF and affective ToM in this age span. Inhibition was found to play the most important role in affective ToM out of the three facets of EF measured. Future studies are needed to investigate the ongoing development of cognitive and affective ToM and disentangle the order of development, perhaps using longitudinal designs. To further explore the relation between ToM and EF, more research in different age groups is warranted. Moreover, future investigations of affective ToM at the neural level will help to shed light on this specific subcomponent of ToM.

REFERENCES

Abu-Akel, A., & Shamay-Tsoory, S. (2011). Neuroanatomical and neurochemical bases of theory of mind. *Neuropsychologia*, *49*, 2971–2984.

Ahmed, F. S., & Miller, L. S. (2011). Executive function mechanisms of theory of mind. *Journal of Autism and Developmental Disorders*, *41*, 667–678.

Apperly, I. A., Samson, D., & Humphreys, G. W. (2009). Studies of adults can inform accounts of theory of mind development. *Developmental Psychology*, *45*, 190–201.

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.

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.

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.

Blakemore, S. J. (2008). The social brain in adolescence. *Nature Reviews Neuroscience*, *9*, 267–277.

Bull, R., Phillips, L. H., & Conway, C. A. (2008). The role of control functions in mentalizing: Dual-task studies of theory of mind and executive function. *Cognition*, *107*, 663–672.

Carlson, S. M., & Moses, L. J. (2001). Individual differences in inhibitory control and children's theory of mind. *Child Development*, *72*, 1032–1053.

Coricelli, G. (2005). Two-levels of mental states attribution: From automaticity to voluntariness. *Neuropsychologia*, *43*, 294–300.

Friedman, N. P., Miyake, A., Corley, R. P., Young, S. E., Defries, J. C., & Hewitt, J. K. (2006). Not all executive functions are related to intelligence. *Psychological Science*, *17*, 172–179.

Gathercole, S. E., Pickering, S. J., Ambridge, B., & Wearing, H. (2004). The structure of working memory from 4 to 15 years of age. *Developmental Psychology*, *40*, 177–190.

Golan, O., Baron-Cohen, S., & Hill, J. (2006). The Cambridge mindreading (CAM) face-voice battery: Testing complex emotion recognition in adults with and without Asperger syndrome. *Journal of Autism and Developmental Disorders*, *36*, 169–183.

Gunther Moor, B., Op de Macks, Z. A., Gueroglu, B., Rombouts, S. A. R. B., Van der Molen, M. W., & Crone, E. A. (2012). Neurodevelopmental changes of reading the mind in the eyes. *Social Cognitive and Affective Neuroscience*, *7*, 44–52.

Hare, T. A., Camerer, C. F., & Rangel, A. (2009). Self-control in decision-making involves modulation of the vmPFC valuation system. *Science*, *324*, 646–648.

Keulers, E. H. H., Evers, E. A. T., Stiers, P., & Jolles, J. (2010). Age, sex, and pubertal phase influence mentalizing about emotions and actions in adolescents. *Developmental Neuropsychology*, *35*, 555–569.

Lerner, R., & Steinberg, L. (2004). *Handbook of adolescent psychology* (2nd ed.). New York, NY: Wiley.

Lorsbach, T. C., Katz, G. A., & Cupak, A. J. (1998). Developmental differences in the ability to inhibit the initial misinterpretation of garden path passages. *Journal of Experimental Child Psychology*, *71*, 275–296.

Luna, B., Garver, K. E., Urban, T. A., Lazar, N. A., & Sweeney, J. A. (2004). Maturation of cognitive processes from late childhood to adulthood. *Child Development*, *75*, 1357–1372.

Luna, B., Padmanabhan, A., & O'Hearn, K. (2010). What has fMRI told us about the development of cognitive control through adolescence? *Brain and Cognition*, *72*, 101–113.

McKinnon, M. C., & Moscovitch, M. (2007). Domain-general contributions to social reasoning: Theory of mind and deontic reasoning re-explored. *Cognition*, *102*, 179–218.

Mier, D., Lis, S., Neuthe, K., Sauer, C., Esslinger, C., Gallhofer, B., & Kirsch, P. (2010). The involvement of emotion recognition in affective theory of mind. *Psychophysiology*, *47*, 1028–1039.

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex "Frontal Lobe" tasks: A latent variable analysis. *Cognitive Psychology*, *41*, 49–100.

Ochsner, K. N., & Gross, J. J. (2005). The cognitive control of emotion. *Trends in Cognitive Sciences*, *9*, 242–249.

Paus, T., Keshavan, M., & Giedd, J. N. (2008). Why do many psychiatric disorders emerge during adolescence? *Nature Reviews Neuroscience*, *9*, 947–957.

Perner, J. (1991). *Understanding the representational mind*. Cambridge, MA: MIT Press/ Bradford Books.

Perner, J., & Lang, B. (1999). Development of theory of mind and executive control. *Trends in Cognitive Sciences*, *3*, 337–344.

Petermann, F., & Petermann, U. (2007). *Hamburg Wechsler Intelligenztest für Kinder-IV (HAWIK-IV)*. Bern, Switzerland: Huber.

Rieffe, C., Terwogt, M. M., & Cowan, R. (2005). Children's understanding of mental states as causes of emotions. *Infant and Child Development*, *14*, 259–272.

Ruffman, T., & Keenan, T. R. (1996). The belief-based emotion of surprise: The case for a lag in understanding relative to false belief. *Developmental Psychology*, *32*, 40–49.

Sebastian, C. L., Fontaine, N. M. G., Bird, G., Blakemore, S. J., De Brito, S. A., McCrory, E. J. P., & Viding, E. (2012). Neural processing associated with cognitive and affective theory of mind in adolescents and adults. *Social Cognitive and Affective Neuroscience*, *7*, 53–63.

Shamay-Tsoory, S. G., Harari, H., Aharon-Peretz, J., & Levkovitz, Y. (2010). The role of the orbitofrontal cortex in affective theory of mind deficits in criminal offenders with psychopathic tendencies. *Cortex*, *46*, 668–677.

Shamay-Tsoory, S. G., Tibi-Elhanany, Y., & Aharon-Peretz, J. (2006). The ventromedial prefrontal cortex is involved in understanding affective but not cognitive theory of mind stories. *Social Neuroscience*, *1*, 149–166.

Steinberg, L. (2005). Cognitive and affective development in adolescence. *Trends in Cognitive Sciences*, *9*, 69–74.

Steinberg, L., & Morris, A. S. (2001). Adolescent development. *Annual Review of Psychology*, *52*, 83–110.

Tamnes, C. K., Ostby, Y., Walhovd, K. B., Westlye, L. T., Due-Tonnessen, P., & Fjell, A. M. (2010). Neuroanatomical correlates of executive functions in children and adolescents: A magnetic resonance imaging (MRI) study of cortical thickness. *Neuropsychologia*, *48*, 2496–2508.

Velanova, K., Wheeler, M. E., & Luna, B. (2008). Maturational changes in anterior cingulate and frontoparietal recruitment support the development of error processing and inhibitory control. *Cerebral Cortex*, *18*, 2505–2522.

Vetter, N. C., Leipold, K., Kliegel, M., Phillips, L. H., & Altgassen, M. (2012). Ongoing development of social cognition in adolescence. *Child Neuropsychology*. Advance online publication. doi:10.1080/09297049.2012.718324

von Aster, M., Neubauer, A., & Horn, R. (2007). *WIE: Wechsler Intelligenztest für Erwachsene*. Frankfurt am Main, Germany: Harcourt Test Services.

Wechsler, D. (1999). *Wechsler Abbreviated Scale of Intelligence*. San Antonio, TX: The Psychological Corporation.

Wellman, H. M., Cross, D., & Watson, J. (2001). Meta-analysis of theory-of-mind development: The truth about false belief. *Child Development*, *72*, 655–684.

Zelazo, P. D., Müller, U., Frye, D., & Marcovitch, S. (2003). The development of executive function in early childhood. *Monographs of the Society for Research in Child Development*, *68*, Serial No. 274. Retrieved from http://libres.uncg.edu/ir/uncg/f/J_Boseovski_Development_2003.pdf