**Age-Related Changes in Self-Referential Biases in Memory and Perspective Taking
in Male Adolescents and Young Adults**

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Abstract

Adolescence is a sensitive period for self-concept development, which affects how self-related information is memorized and the ability to take others' perspectives, which might differ from one's own. Little is known about whether these two self-referential processes are related in adolescence. The current study recruited 97 male participants aged 11-35 years. Using a self-referential memory task, we found a linear age-related decrease in memory biases for town-related adjectives compared to self-related adjectives. Using the Director task to assess perspective taking, we also found an age-related decrease in egocentric biases in perspective taking from adolescence to early adulthood (i.e., perspective taking abilities improved with age). However, there was no evidence that these two self-referential processes were related. Overall, our findings suggest that male adolescents display parallel but independent age-related changes in self-referential biases in memory and perspective taking.

Keywords: adolescence, social cognitive development, self-concept, self-referential processing, perspective taking, theory of mind

Highlights

- Age-related decrease in self-referential memory biases for town-related adjectives.
- Age-related decrease in egocentric biases in perspective taking.
- Self-referential biases in memory and perspective taking were not related.

Introduction

Adolescence starts with the onset of puberty and ends when the individual achieves a stable and independent role in society, roughly corresponding to 10-24 years (Dahl, 2004; Sawyer et al., 2018). This transformative period of life is characterized by significant changes in social cognitive behavior and in the self-concept (Crone & Fuligni, 2020; Erikson, 1968; Sebastian et al., 2008). Defined as how an individual perceives and describes oneself (e.g., “I am athletic”), the self-concept is known to become less concrete and more abstract with increasing age (Cole et al., 2001; Harter, 1990). For example, Montemayor and Eisen (1975) asked individuals aged 9 to 18 years to provide self-descriptions (by answering the question “Who am I?”) and found that children aged 9-11 years were more likely to describe themselves with concrete object labels, such as their home address or possessions, whereas adolescents aged 12-18 years were more likely to describe themselves with more abstract and differentiated trait labels, such as “curious” or “ambitious”.

To explore this shift towards a more abstract self-concept, research has focused on the effect of self-referential memory. It has been proposed that self-related information is processed more deeply and efficiently, and therefore leads to higher levels of recall, than other types of information (Craig et al., 1999; Kelley et al., 2002; Klein & Kihlstrom, 1986; Rogers et al., 1977). A typical self-referential memory paradigm presents participants with trait adjectives and asks them to judge the descriptiveness of the adjectives in reference to themselves (e.g., “Does this word describe me?”), in reference to a non-related but familiar other (e.g., “Does this word describe Harry Potter?”) and a control condition (e.g., “How many syllables does this word have?”). A subsequent surprise memory task is then used to assess whether adjectives that have been evaluated in relation to the self are better remembered (i.e., increased memory sensitivity

and faster memory recall). Indeed, several studies in children (aged 5-10 years; Cunningham et al., 2014; Halpin et al., 1984; Sui & Zhu, 2005), adolescents (aged 11-18 years; Dégeilh et al., 2015; Henderson et al., 2009; Moses-Payne et al., in press), and adults (aged 21-82 years; D'Argembeau et al., 2007; Gutchess et al., 2007; Mitchell et al., 2006) suggest that this is generally the case. Behavioral studies have shown that this self-referential memory effect emerges at around four years (Cunningham et al., 2014) and continues to increase from childhood to adolescence, in line with self-concept development (Harter, 1990; Ray et al., 2009).

Besides these age-related changes in self-referential processing, the developing self-concept might simultaneously affect the ability to take someone else's perspective, which often involves a trade-off between one's own perspective (the self-perspective) and the other's perspective. Perspective taking is a component of the ability to infer other people's mental states, which is known as "mentalizing" or "theory of mind" (Frith & Frith, 2003; Gallagher & Frith, 2003). While common theory of mind tasks are usually passed by the age of five (Frith & Frith, 2003), the ability to take another person's perspective in order to guide behavior continues to develop well beyond childhood (Dumontheil et al., 2010, 2012; Symeonidou et al., 2016). This has been shown using the Director task (Dumontheil et al., 2010). In this task, a "director" instructs participants to move objects around a set of shelves. There are two conditions: participants either take account of the director's perspective (Director condition) or they follow a simple rule without having to take into consideration the director's perspective (No Director condition). In both conditions, an initial improvement in accuracy was observed between childhood (aged 7-11 years) and mid-adolescence (aged 11-13 years; Dumontheil et al., 2010). Beyond mid-adolescence (aged 14-17 years), no further improvement in accuracy was observed in the No-Director condition, whereas in the Director condition, accuracy continued to improve

between adolescence and early adulthood (aged 19-27 years; Dumontheil et al., 2010). These results provide evidence for continued age-related improvements in perspective taking abilities in late adolescence (replicated in Symeonidou et al., 2016).

Self- and other-oriented thinking are suggested to be intertwined developmental processes (Crone & Fuligni, 2020). Simulation and self-projection theories of social cognition have posited that self-knowledge can be used to infer others' mental states and perspectives. Tamir and Mitchell (2010) argued that, in order to take someone else's perspective, perceivers first use their own introspection as a self-generated "anchor" value to then serially adjust (in a process called "anchoring-and-adjustment"). Moreover, research on the looking-glass self (Cooley, 1983) suggests that an individual's understanding of what they "are like" as a person (i.e., their self-concept) becomes progressively informed by their beliefs about how they are seen by others. This implies that perspective taking abilities can support the formation of a more differentiated self-concept.

One way to explore the importance of perspective taking in self-referential processing is to assess these skills in individuals with autism, which is a developmental condition that in some people is characterized by difficulties in mentalizing (Baron-Cohen et al., 1985). Toichi et al. (2002) were one of the first to test the hypothesis of atypical self-referential memory in high-functioning individuals with autism spectrum disorder (ASD). Compared to typically developing individuals, autistic adults did not show a self-referential memory effect (Toichi et al., 2002). However, subsequent research has found mixed results. For example, Lombardo et al. (2007) found an existing but diminished self-referential memory effect in high-functioning autistic adults (aged 19-45 years) compared to IQ-matched controls. Henderson et al. (2009) investigated age-related differences in self-referential memory in children and adolescents (aged 8-16 years)

and found comparable memory effects between autistic individuals and IQ-matched controls. Given that autistic adults show reduced mentalizing abilities and diminished self-referential memory it could be argued that these processes are connected. In the current study, we assessed age-related changes in, and the relationship between, self-referential memory (using the self-referential memory task) and perspective taking (using the Director task) in typically developing male adolescents and adults.

We examined three hypotheses. First, we investigated self-referential memory across adolescence and adulthood in males. Across age, we expected to find enhanced and faster memory performance (i.e., sensitivity) for self-related (vs. town-related) adjectives (hypothesis 1). Second, we aimed to replicate previous findings demonstrating age-related changes in perspective taking abilities. Participants completed the Director task (adapted from Dumontheil et al., 2010) and we expected adolescents to commit more egocentric errors (i.e., ignoring the director's perspective) than adults (hypothesis 2). Finally, we explored the relationship between self-referential memory and perspective taking abilities, however, given the mixed findings (e.g., Toichi et al., 2002; Lombardo et al., 2007; Henderson et al., 2009), this was a non-directional hypothesis (hypothesis 3).

Methods

Participants

One hundred and ten males (53 adolescents aged 11.2-17.5 years and 57 adults aged 22.2-35.6 years) took part in this experiment. Previous studies in adolescents and adults using variants of the tasks have found robust group differences with sample sizes of 20-30 participants per age group (Sui & Zhu, 2005; Symeonidou et al., 2016). As we did not know the size of our hypothesized effects, we aimed for a sample size of at least 45 adolescent participants and 45 adult participants, for a total of 90 participants. However, to avoid any arbitrary age-related grouping criteria, all analyses employed age as a continuous variable. Longitudinal research with adolescents, investigating gender differences in perspective taking development, has demonstrated higher levels of perspective taking abilities in 13-18-year-old girls compared with age-matched boys (Van der Graaff et al., 2014). Consequently, we recruited only male participants to test for within-group variation (Keulers et al., 2010; Maccoby, 1998). Data from 12 participants were excluded from all analyses due to parent-reported diagnoses of developmental disorders (two adolescents) and a technical error (one adolescent and nine adults). One additional adult participant was excluded for self-referential memory task performance below chance, leaving a total sample size of $N = 97$ (50 adolescents aged 11.2-17.5 years and 47 adults aged 22.2-35.6 years) for all subsequent analyses (see Table S1 in the supplementary information for detailed participant information).

Adolescents were recruited through social media and from three schools within the Greater London area. Adults were recruited using the university Psychology Department participant database. Testing was either conducted in a laboratory setting at the university or in schools. All included participants spoke English fluently and had no history of psychiatric,

developmental, or neurological disorders. Adult participants, and the primary caregiver of the adolescent participants, gave informed consent. The study was approved by the university ethics committee (Project ID Number: 3453/001). Following the completion of the study, participants were debriefed, given the opportunity to ask any questions, and compensated £10 for their time.

Design and Procedure

The experiment included four stages. First, participants completed the Autism Spectrum Quotient (AQ) questionnaire. Next, participants completed the first part of the self-referential memory task (learning phase), which was followed by the Director task (adapted from Dumontheil et al., 2010). Finally, participants completed the second part of the self-referential memory task (recall phase).

Autistic Traits

To control for age group differences in autistic traits we used the AQ questionnaire, which consists of 50 items assessing behaviors across five domains: social skills, attention switching, attention to detail, communication, and imagination. Items such as “I prefer to do things with others rather than on my own” are rated on a four-point scale (“definitely agree”, “slightly agree”, “slightly disagree”, “definitely disagree”; Baron-Cohen et al., 2001). Each item scores 1 point if the respondent records autistic-like behavior (e.g., to prefer doing things on their own rather than with others) either mildly or strongly. A higher score indicates a higher level of autistic traits. Although a useful screening method to quantify where an individual lies along the dimension of autistic traits, this self-report instrument was not diagnostic and has been used previously in typical adolescents and adults (Baron-Cohen et al., 2006). There were no

significant differences between adolescents and adults in the current study on the AQ ($t(95) = -1.19, p = .24$; see Table S3 in the supplementary information). We ran linear regressions examining how perspective taking accuracy and age related to AQ scores as well as how age and AQ scores related to measures of self-referential memory (memory sensitivity and response bias). All AQ related findings are reported and explained in the supplemental information (see Models J-L and Tables J-L).

Self-Referential Memory Task

The self-referential memory task was split into a learning phase and a recall phase (see Figure 1 A-B). At the beginning of each phase participants had the opportunity to ask questions after reading a short introduction. In both phases, there were two conditions: self and town. During the learning phase (see Figure 1a) participants had to judge how descriptive a set of self- and town-related adjectives (e.g., “calm”, “adventurous”) were of themselves (Self condition: “Does this word describe yourself?”) and of London (Town condition: “Does this word describe London?”). These questions were presented for 1500 ms before the target adjective was presented for 1000 ms. Participants then indicated how well the adjectives described themselves or London on an 11-point rating scale (0: “not very well at all”, 5: “not very well, but not too badly either”, 10: “very well”). This rating was self-paced. The task was programmed in Gorilla (<https://gorilla.sc/>; Anwyl-Irvine et al., 2020) and was presented on 13-inch laptops.

Forty adjectives (20 town-related and 20 self-related) were presented in a randomized order, and it took participants approximately 5 minutes to complete this part of the task. All adjectives used in this task were drawn from previous likableness ratings of trait adjectives (Anderson, 1968) and were of positive valence. In addition, self- and town-related words were

matched for word length and level of difficulty. The words were piloted with five 10- to 13-year-old males, who were presented with all adjectives and asked to define their meaning. This was to ensure that the youngest participants would understand each word. Based on their responses, 16 adjectives were replaced because they were considered inappropriate or too difficult to understand in the particular context. A list of all adjectives used in the self-referential memory task can be found in the supplementary information (see Table S2).

During the recall phase (see Figure 1B), which was completed after the Director task, participants were presented with 120 adjectives comprising all 40 target adjectives from the learning phase and an additional 80 distractor adjectives (40 self-related, 40 town-related), which they had not seen before. Participants were asked whether they remembered seeing the word during the learning phase by indicating how confident they were in their answer on a five-point rating scale (1: have definitely not seen, 2: might not have seen, 3: don't know, 4: might have seen, 5: definitely seen). This rating was self-paced. All 120 adjectives were presented in a randomized order. This recall phase took 12-15 minutes to complete.

Although both phases had no time restrictions to provide a rating, participants were encouraged to respond as fast as possible, while also thinking carefully about each adjective. Before participants could start one of the phases, they first had to complete two practice trials (one for each condition) to demonstrate that they had understood the instructions.

Figure 1*Tasks*

Note. The self-referential memory task (A-B). (A) Learning phase: participants had to decide whether randomly presented adjectives (20 self-related and 20 town-related) were good descriptions of either themselves (Self condition: “Does this word describe yourself?”) or London (Town condition: “Does this word describe London?”). Responses were given on an 11-

point rating scale. **(B)** Recall phase: participants had to judge whether they have already seen one of the randomly presented adjectives (40 target adjectives, 80 distractor adjectives) during the learning phase or not. Responses were given on a 5-point rating scale. The Director task **(C-D)**. In this example, participants were verbally instructed by the director to “move the large jar right”. **(C)** During experimental trials, an error would be committed when ignoring the director’s perspective and incorrectly moving the distractor object, which is not visible to the director. In contrast, a correct response would be to move the target object, which is visible to both director and participant. **(D)** During control trials, distractor objects were replaced with irrelevant objects (e.g., the duck).

Director Task

Task design and stimuli were taken from the computerized task used in Dumontheil et al. (2010; see Figure 1C-D. The stimuli (48 in total) consisted of sets of 4 x 4 shelves with objects located in half of the 16 slots. Five of the shelves had an opaque grey background, which occluded the view of the “director” who stood on the other side of the shelves (i.e., he viewed the shelves from behind). The director gave verbal instructions to move one of the eight objects to a different slot in the shelves. Before completing the task, participants were presented with standardized instructions and example stimuli on a PowerPoint presentation. The instructions required participants to use the director’s visual perspective to determine which objects he could and could not see, and thereby select and move the most appropriate object. To ensure that all instructions were understood correctly, each participant had to point out one object that only he but not the director could see (i.e., any object in occluded slots) and one object that was visible to both of them (i.e., objects in clear slots). All participants gave correct responses, indicating that they understood the instructions and were able to describe which objects the director could and could not see. Participants then completed one practice block with three trials. Again, all participants performed this correctly, demonstrating that they understood what was required of them. Similar to the procedure by Dumontheil et al. (2010), they were not given further feedback

regarding the requirement to take into account the director's perspective. The instructions were presented via headphones and participants used the computer mouse to move the object they thought the director was referring to into the appropriate slot on the shelves.

During experimental trials (eight in total), a relevant object could be seen by the participant but not the director (see Figure 1C). Participants were instructed to, for example, "move the large jar right". A correct response would consider the director's perspective, and thus the red jar (target object) would be selected and moved to the appropriate slot. An incorrect response would ignore the director's perspective and thereby move the bottom-most jar (distractor object), which is not visible to the director. In the control trials (eight in total), the object-shelf configurations were identical to that in the experimental trials, except that all relevant objects could be seen by both the participant and the director (see Figure 1D). It was therefore not necessary to consider the director's perspective to select the correct answer in these trials. During filler trials (32 in total), instructions only referred to objects in clear slots. For example, in Figure 1C the director could ask to "move the knife left". The order of the experimental, control, and filler trials was counterbalanced between participants.

Eight different object-shelf configurations were used, each presented once with an occluded distractor object (experimental trial) and once with an irrelevant object (control trial). In total, this resulted in 16 test blocks of different object-shelf configurations, which were all counterbalanced across participants. Stimuli were presented for 2 seconds before the first auditory instruction was given. Three auditory instructions were given per stimulus (i.e., one instruction per trial) and each lasted 2.2 seconds. For example, in Figure 1C the experimental trial would start with the director instructing participants to "move the small jar down". Within the same shelf-object configuration the director would ask the participant to then "move the

scissors up” before finally asking them to “move the large jar right”. After each auditory instruction the participant had 3.6 s to make their response. The task was programmed using E-prime version 2.0 (Psychology Software Tools, Inc.), presented on 13-inch laptops and took approximately 6 minutes to complete.

Statistical Analysis

Self-Referential Memory Task

A primary aim of this study was to determine whether there were age-related changes in self-referential memory and perspective taking. To assess age-related changes in the self-referential memory task, recall phase ratings on the five-point confidence scale (in response to the question “Do you remember seeing this word during Part 1?”) were binarized. Responses above 3 (coded as 1) indicated high confidence that the adjective had been seen during the learning phase, while responses made below 3 (coded as 0) indicated high confidence that the adjective had not been seen. Ratings equal to 3 indicated that participants did not know whether they had seen the presented adjective or not. These ratings were excluded from the analyses (this was the least common response option across participants (6%)).

Due to poor internet connection, self-referential memory data from one adolescent and two adult participants could not be collected, leaving a total sample size of $N = 94$ for the memory analyses. These analyses employed a signal detection theory framework (Anderson, 2015), which typically includes two measures: d-prime (d') and response biases. d' was computed by calculating the difference between the z-transformed probabilities of hits (i.e., the number of target adjectives correctly remembered) and false alarms (FAs; i.e., the number of distractor adjectives falsely thought to be remembered) ($d' = z(\text{hits}) - z(\text{FAs})$), separately for

each condition (self and town) and each participant. This allowed us to discriminate between the decision signal (hits) and noise (FAs; Stanislaw & Todorov, 1999). The larger the difference between the hit rate and FA rate, the better the participant's memory sensitivity. That is, the better their ability to correctly discriminate between (target) adjectives that have been previously presented and (distractor) adjectives that had not. In other words, memory sensitivity increases if the hit rate increases and/or FA rate decreases. Second, even in the absence of age differences in memory sensitivity, it could still be the case that younger participants are biased toward using one response more often than an alternative response. To test this possibility, we computed a commonly used measure of response bias, c , which is typically unaffected by changes in d' (Anderson, 2015). The response bias was estimated from the probabilities of hit and FA rates, $c = -[z(\text{hits}) + z(\text{FAs})]/2$. An increase in hit *and* FA rates would reflect a liberal criterion ($c < 0$), meaning participants are more likely to report an adjective as present during the learning phase, independently of whether this adjective had actually been seen or not. In contrast, a more conservative criterion ($c > 0$) would indicate that participants were less likely to report an adjective as present during the learning phase, resulting in less FAs, but more misses. The absolute value of c provides an indication of the strength of a participant's bias. That is, the responder's subjective strategy to indicate that an adjective had previously been seen or not. Further, median response times (RTs) were calculated from correctly recalled target adjectives (i.e., a confidence rating above three during the recall phase) for each participant. To better approximate a normal distribution, RTs were modelled on the log scale.

Director Task

To assess age-related changes in the Director task, filler trials (not designed to test participants perspective taking abilities) were excluded from the analyses (Dumontheil et al., 2010). Due to a task specific technical error, perspective taking accuracy data from two adolescent participants could not be analyzed, leaving a total sample size of $N = 95$ for the analyses of perspective taking accuracy. First, accuracy was modelled at the trial level using the binominal distribution (i.e., logistic regression). For each trial type (experimental and control), accuracy measures were obtained by coding correct responses as “1s” and incorrect responses as “0s”. Second, median RTs were calculated from correct trials (experimental and control).

Relationship between Self-Referential Memory and Perspective Taking

Only participants with complete data sets (i.e., self-referential memory task data and Director task data) were included in the analyses of the relation between self-referential memory and perspective taking, leaving a total sample size of $N = 93$. For those analyses we computed self-referential difference scores for each participant by subtracting self-referential performance measures (i.e., memory sensitivity and response bias) for self-related target adjectives from performance measures for town-related target adjectives. Larger self-referential difference scores indicate a stronger bias towards self-referentially encoded adjectives compared to town-referentially encoded adjectives.

Age-Related Analysis

For each dependent variable we assessed any association with age, which was thus used as the central independent (continuous) variable of interest. We started each analysis by

assessing whether, relative to the linear trend of age alone, the quadratic and cubic trends of age provided a better fit to the data (Luna et al., 2004). Polynomials were orthogonalized to avoid multicollinearity and afterwards the model with the lowest AIC (Akaike Information Criterion; Akaike, 1974) value was selected, which indicates better model fit. Moreover, a condition term (self vs. other) was used in the self-referential memory task for memory sensitivity and response bias, while a trial type term (experimental vs. control) was used in the Director task. Self-referential memory response times analyses also included a category term (target vs. distractor). Each of these terms was allowed to interact with one another. All data was modelled using mixed-effect models (“lme4” package version 1.1-21; Bates et al., 2018) in R version 3.6.3 (R Core Team, 2016). Subject-level random intercepts were included for all models (Baayen et al., 2008). To determine the random effects structures of our mixed-effects models, we began with the maximal model in order to minimize Type I error (Barr, 2013). We set the number of model iterations to 100,000 and used the “bobyqa” optimizer. When the maximal model gave convergence errors, we removed correlations between random slopes and random intercepts, and finally, removed random slopes for interaction effects. Main effects and interactions of the best fitting models were inspected using omnibus Type III *F* tests with Satterthwaite approximations for degrees of freedom for linear models and Wald X^2 tests for generalized models. Significant main effects and interactions were further inspected with Bonferroni-corrected post-hoc comparisons using the emmeans package version 1.4.4 (Lenth & Lenth, 2018). For full details about the fixed- and random-effects structure of all models see “Full Model Specification and Results” in the supplemental information.

Results

Self-Referential Memory

Memory Sensitivity

First, we examined the relation between age and memory sensitivity in the self-referential memory task (see Figure 3A below; hypothesis 1). To examine how participants' memory sensitivity (d') changed as a function of age and condition (self vs. town), we ran a linear mixed-effects model and did not find any main effects or interactions (p s > .32; see Model A and Table A in the supplemental information). This suggests that memory sensitivity for self- and town-related adjectives was not modulated by age.

Response Bias

A second linear mixed-effects model on response biases (c) revealed a main effect of Age, $\chi^2(1) = 8.43, p = .004$, a main effect of Condition, $\chi^2(1) = 14.77, p < .001$, and an Age x Condition interaction effect, $\chi^2(1) = 4.73, p = .03$ (see Figure 3B below as well as Model B and Table B in the supplemental information). Post-hoc analyses suggested that the response bias was overall greater (i.e., more conservative) for town-related than for self-related adjectives, contrast $\text{town} - \text{self} = 0.15, SE = .04, p_{\text{Bonf}} < .001$. The response bias also decreased with age, however, only for town-related adjectives (slope $\text{town} = -0.02, SE = .005, p_{\text{Bonf}} = .002$), and not for self-related adjectives ($p_{\text{Bonf}} > .89$). This finding indicates that participants of all ages used a similar decision criterion when recalling self-related adjectives. In contrast, compared to older participants, younger participants were more likely to use a conservative decision criterion when recalling town-related adjectives. That is, younger participants were more likely to respond that

town-related adjectives had not previously been presented during the learning phase, independently of whether they had actually been seen or not.

Figure 3

Effect of Age on Memory Sensitivity and Response Bias in the Self-Referential Memory Task

Note. (A) Effect of age on memory sensitivity. Mean d' (y-axis) is plotted as a function of age (x-axis) for each condition. There was no significant change with age in the efficiency of processing self (vs. town) related adjectives. (B) Effect of age on response bias. Mean c (y-axis) is plotted as a function of age (x-axis) for each condition. With increasing age, participants demonstrated a reduction in “conservative” response bias for town-related adjectives, which indicates that participants became more likely to report town-related adjectives as present during the learning phase. All colored lines and shaded .95 confidence intervals (CIs) show the linear trends as estimated by the linear mixed-effects models (A & B). ** $p_{\text{Bonf}} < .01$.

Reaction Times

To investigate how participants' RTs in the self-referential memory task changed as a function of age, condition (self vs. town) and category (target vs. distractor adjective), we ran a linear mixed-effects model (see Figure S1, Model C and Table C in the supplemental information; hypothesis 1). The model showed a significant main effect of Category, $\chi^2(1) = 12.32$, $p < .001$, and an Age x Condition x Category interaction, $\chi^2(1) = 14.10$, $p < .001$. Post-

hoc contrasts within the model suggested that the interaction between age, condition, and category was driven by RTs for town-related target adjectives becoming overall faster with increasing age compared to RTs for self-related target adjectives, contrast $\text{town}(\text{target}) - \text{self}(\text{target}) = -0.01$, $\text{SE} = .002$, $p_{\text{Bonf}} = .04$. In contrast, RTs for town-related distractor adjectives became overall slower with increasing age compared to RTs for self-related distractor adjectives, contrast $\text{town}(\text{distractor}) - \text{self}(\text{distractor}) = 0.01$, $\text{SE} = .002$, $p_{\text{Bonf}} = .003$.

Learning- and Recall Phase Ratings

To examine how participants' learning- and recall phase ratings changed as a function of age and condition, we ran two linear mixed-effects models (see Figure S2, Model D-E and Table D-E in the supplemental information). For learning phase ratings, we observed a main effect of Age, $\chi^2(1) = 8.75$, $p = .003$, a main effect of Condition, $\chi^2(1) = 175.75$, $p < .001$, but no significant Age x Condition interaction, $\chi^2(1) = 2.28$, $p = .13$ (see Figure S2A in the supplemental information). For recall phase ratings, we observed no main effect of Age, $\chi^2(1) = 3.27$, $p = .07$, a significant main effect of Condition, $\chi^2(1) = 7.31$, $p = .007$, and a significant Age x Condition interaction effect, $\chi^2(1) = 6.34$, $p = .01$ (see Figure S2B in the supplemental information). Post-hoc contrasts within the model suggested that the interaction between age and condition was driven by lower confidence ratings for town-related target adjectives than for self-related target adjectives, contrast $\text{town}(\text{target}) - \text{self}(\text{target}) = -0.11$, $\text{SE} = .04$, $p_{\text{Bonf}} = .007$. However, this tendency decreased linearly with age, slope $\text{town}(\text{target}) = 0.02$, $\text{SE} = .01$, $p_{\text{Bonf}} = .02$. In other words, older participants reported greater confidence in recognizing town-related target adjectives than did younger participants.

Perspective Taking

Accuracy

The generalized linear mixed-effects model on perspective taking accuracy in the Director task showed a significant main effect of the experimental treatment ($\chi^2(1) = 122.84, p < .001$; see Figure 4 below as well as Model F and Table F in the supplemental information; hypothesis 2). Planned contrasts showed that this was due to decreased accuracy in the experimental condition relative to the control condition (contrast_{control – experimental} = 3.35, SE = .30, $p_{\text{Bonf}} < .001$). In addition, this effect was modulated by an Age x Trial type interaction, $\chi^2(1) = 8.54, p = .003$. Post-hoc analysis suggested that perspective taking accuracy in experimental trials increased with age (slope_{experimental} = 0.07, SE = .02, $p_{\text{Bonf}} = .02$), while this was not the case in control trials ($p_{\text{Bonf}} = 1.11$). Thus, younger participants were less likely than older participants to account for the Director's perspective when making decisions.

Figure 4*Effect of Age on Perspective Taking Accuracy in the Director Task*

Note. Mean percentage correct (y-axis) is plotted as a function of age (x-axis) for each trial type. During experimental trials, participants had to consider the director's perspective to select the correct answer, while this was not necessary to correctly answer in control trials. With increasing age, participants demonstrated a greater ability to take account of another person's perspective. All colored lines and shaded .95 CIs show the linear trends as estimated by the trial-level generalized linear mixed-effects model. * $p_{\text{Bonf}} < .05$.

Reaction Times

To examine how RTs in the Director task changed as a function of age and trial type, we ran a linear mixed-effects model (see Model G and Table G in the supplemental information). We observed no main effect of Age, $\chi^2(1) = .57$, $p = .45$, a significant main effect of Trial type whereby RTs in the experimental condition were slower than in the control condition $\chi^2(1) = 21.83$, $p < .001$, and no significant Age x Trial type interaction, $\chi^2(1) = .04$, $p = .84$.

Interrelation between Self-Referential Memory and Perspective Taking

After demonstrating age-related changes in both self-referential memory and perspective taking, we turned to another central question of interest: do participants across our age range show a link between their ability to process self-related adjectives and their ability to infer other people's perspectives (hypothesis 3)? To answer this question, we ran linear regressions to investigate how age and perspective taking accuracy (i.e., mean percentage errors on experimental trials in the Director task) related to self-referential difference scores (memory sensitivity difference scores and response bias difference scores). Both linear regressions showed no significant main or interaction effects (see Models H-I and Tables H-I in the supplemental information) indicating that age-related differences in self-referential memory were unrelated to differences in perspective taking.

Discussion

In the current study, we found age-related changes in self-referential processing in both the memory and perspective taking domains during male adolescence. With regard to memory, we observed no association between age and memory sensitivity for self- and town-related adjectives. However, we found an age-related decrease in memory biases for town-related adjectives. Specifically, young adolescents used a more conservative decision strategy when recalling town-related adjectives, compared to self-related adjectives (hypothesis 1). Second, we found a continued age-related improvement in perspective taking abilities between adolescence and early adulthood (hypothesis 2). Finally, measures of the memory domain of self-referential processing (memory sensitivity and response bias) were not significantly related to perspective taking (hypothesis 3). Overall, our findings show age-related decreases of biases in self-referential memory and perspective taking in male adolescents and young adults. However, we found no evidence that these two processes are related.

During adolescence, feedback from the social environment turns into a valuable and salient source of information (e.g., Blakemore & Mills, 2014), used to gain more knowledge about the self (Harter, 2012; Sebastian et al., 2008; Van der Aar et al., 2018; Moses-Payne et al., in press). We speculate that the memory-related findings could be driven by age-related differences in the emotional salience of self-related information (Blakemore & Mills, 2014), possibly coupled with age-related changes in emotion regulation (Silvers et al., 2012). Previous work in young adults demonstrated that emotionally arousing words (vs. less arousing words) are associated with a more liberal response bias (Dougal & Rotello, 2007), thus favoring self-related adjectives. However, in adolescents, heightened emotional arousal of presented adjectives could also result in a conservative bias against less arousing words. For example, given that

adolescents are poorer at regulating their emotions in the presence of emotionally salient stimuli (Silvers et al., 2012), they might be less efficient at dividing their attention between self- (more emotionally salient) and town-related (less emotionally salient) information, resulting in prioritizing self- over town-related information. In other words, self-related information might act as a potential “social-emotional” disruptor, by reorienting attention away from information not related to the self. In line with this interpretation, a neuroimaging study by Magis-Weinberg et al. (2017) found heightened right anterior insula activity (a brain region involved in self-regulatory and reward seeking behaviors) during non-social compared to social relational reasoning in adolescents, relative to adults. To test this social-emotional disruptor hypothesis, future studies should investigate whether young adolescents continue to display a conservative bias against town-related adjectives once such potential social-emotional disruptors are removed (by omitting self-related adjectives).

While we observed age-related differences in response biases, contrary to our predictions, adolescents and adults showed no significant differences in memory sensitivity (i.e., the difference between the proportion of hits and false alarms) for self- vs. town-related information in the self-referential memory task. The discrepancy between the subjective confidence in the accuracy of the memory (i.e., response bias) and the actual memory performance (i.e., memory sensitivity) could be explained by the differential effect of emotions on both types of functioning. Several studies have shown that emotional valence of stimuli impact more on the subjective sense of recollection than on objective memory performance (Dougla & Rotello, 2007; Phelps & Sharot, 2008; Rotello & Macmillan, 2007; Sharot et al., 2004; Talarico & Rubin, 2003). In other words, even though emotional stimuli intensify the (subjective) recollective experience it may not be a reliable indicator of the (objective) accurate recollection of details.

Further support for this argument comes from neuroimaging studies, which have found that the quality of memory, and the confidence with which it is held, rely on dissociable neural mechanisms (Sharot et al., 2004; see Eichenbaum et al., 2007 for a review). For example, Sharot and colleagues (2004) have found that, in adults (aged 20-35 years), recalling “neutral” stimuli was related to enhanced activity in the parahippocampal cortex, whereas recalling “emotional” stimuli was associated with enhanced activity in the amygdala. Our results align with this notion, namely, that confidence in one’s memory and actual memory performance might be subserved by partly distinct cognitive processes.

The results from the Director task in the current sample of male participants replicate previous findings from female samples demonstrating age-related differences in perspective taking abilities (Dumontheil et al., 2010, 2012). In our male sample, we found age-related increases in task accuracy in experimental trials (i.e., trials requiring participants to use information about the director’s perspective) (hypothesis 2). Hence, our results show that the ability to account for someone else’s perspective in order to guide behavior continues to improve throughout adolescence, not only in females but also in males.

Together, our findings suggest that adolescents demonstrate heightened self-referential biases when processing self- and other-oriented information. However, these tendencies do not seem to be driven by the same processes, insofar as they are not significantly correlated (hypothesis 3). Previous studies have suggested that perspective taking abilities can support the formation of a more differentiated self-concept (Cooley, 1983; Tamir & Mitchell, 2010) and these claims were partially supported by studies investigating this relationship in autistic individuals (Toichi et al., 2002; Lombardo et al., 2007). However, the current results indicate no

relationship between self-referential memory and perspective taking in typically developing adolescents and young adults.

Limitations

The findings reported here should be considered in the context of certain limitations. First, the self-referential memory effect has been well replicated and is thought to be robust (D'Argembeau et al., 2007; Gutchess et al., 2007; Mitchell et al., 2006). It is therefore surprising that in the current study participants did not show a difference in memory sensitivity between self- and town-related adjectives. Previous studies, for example Dégeilh et al. (2015), used a greater number of stimuli (target adjectives) and observed greater memory for self-related items. However, due to time constraints that arise when testing in school settings, we employed a reduced number of stimuli. Second, we introduced a modified paradigm to investigate self-referential memory by presenting participants with adjectives in reference to themselves (social information) and London (non-social information). Given that we assessed only one domain of social processing (i.e., the self-referential domain), it is unclear whether the observed age-related changes in response bias are specific to self-related information or apply to social information more generally. Third, we recruited exclusively male participants to test for within-group variation, removing variance that could be accounted for by gender differences in perspective taking development during adolescence (Keulers et al., 2010; Maccoby, 1998; Van der Graaff et al., 2014). Future studies should ideally use a larger number of various social (e.g., self and other) and non-social stimuli (e.g., town) for the self-referential memory task and recruit across genders.

Conclusion

The current findings show that the impact of self-referential biases in memory and perspective taking decreases with age between adolescence and early adulthood. Adolescents displayed an age-related decrease in memory biases when recalling town-related adjectives, compared to self-related adjective. In parallel, we found age-related decreases in egocentric biases in perspective taking from adolescence to early adulthood (i.e., perspective taking abilities improved with age). However, these two self-referential processes were not related to each other, and therefore might be mediated by different cognitive processes.

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Author Contributions

Maximilian Scheuplein: Conceptualization, Methodology, Investigation, Software, Formal Analysis, Visualization, Data Curation, Writing - Original Draft.; **Gabriele Chierchia:** Formal Analysis, Visualization, Data Curation, Writing - Review & Editing; **Saz P. Ahmed:** Investigation, Software, Formal Analysis, Supervision, Writing - Review & Editing; **Lucy Foulkes:** Conceptualization, Supervision, Writing - Review & Editing; **Cait Griffin:** Investigation, Writing - Review & Editing; **Sarah-Jayne Blakemore:** Conceptualization, Supervision, Funding Acquisition, Writing - Review & Editing.

Data and Code Availability

Data and code to reproduce all analyses in the manuscript will be made available on the Open Science Framework (<https://osf.io/8hf9t/>) and will be live upon publication.

Declaration of Competing Interest

The authors report no conflicts of interest.

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Supplemental Material

Table S1

Participant Information

	Adolescents (<i>n</i> = 50; aged 11.2-17.5)			Adults (<i>n</i> = 47; aged 22.2-35.6)		
	<i>M</i>	<i>SD</i>	Range	<i>M</i>	<i>SD</i>	Range
Age (years)	13.96	1.48	11.2-17.5	26.04	3.62	22.2-35.6
% Race						
Asian		6			64	
Black		0			11	
White		82			19	
Mixed		10			2	
Other		2			4	
% Parental highest education attainment	Mother	Father		Mother	Father	
O-Level or GCSE	2	6		13	17	
AS or A-Level	14	12		13	15	
Undergraduate (e.g., BSc)	50	40		45	28	
Postgraduate (e.g., MSc, PhD)	28	36		23	21	
N/A	6	6		2	8	
Don't Know	0	0		4	11	

Note. Descriptive statistics of participants included in the analyses (all male) by age group, race, and parental highest education attainment. Race and parental highest education attainment were reported by adult participants or the primary caregiver of the adolescent participants. M = Mean, SD = Standard deviation.

Table S2*Target and Distractor Adjectives used in the Self-Referential Memory Task*

Self			Town		
Target (<i>n</i> = 20)	Distractor (<i>n</i> = 80)		Target (<i>n</i> = 20)	Distractor (<i>n</i> = 80)	
Kind	Calm	Reliable	Big	Busy	Friendly
Arty	Fair	Sociable	Rich	Cute	Medieval
Happy	Brave	Sensible	Tidy	Cold	Pleasant
Smart	Funny	Tolerant	Cosy	Grey	Relaxing
Eager	Jolly	Truthful	Local	Huge	Stunning
Chatty	Proud	Trustful	Foggy	Safe	Terrific
Joyful	Active	Talented	Green	Tiny	Touristy
Honest	Clever	Pleasant	Pretty	Loud	Peaceful
Healthy	Caring	Confident	Remote	Nice	Beautiful
Relaxed	Giggly	Sensitive	Classic	Clean	Colourful
Cautious	Humble	Talkative	Ancient	Quiet	Enjoyable
Athletic	Modest	Interested	Spacious	Rainy	Energetic
Unafraid	Polite	Optimistic	Friendly	Small	Fantastic
Practical	Sporty	Supportive	Charming	Magic	Industrial
Attentive	Careful	Cooperative	Traditional	Cloudy	Impressive
Emotional	Curious	Hard-working	Thrilling	Famous	Fashionable
Respectful	Helpful	Intelligent	Welcoming	Modern	International
Thoughtful	Patient	Inquisitive	Historical	Amazing	
Imaginative	Cheerful		Adventurous	Crowded	
Warm-hearted	Creative		Multicultural	Elegant	
	Fearless			Popular	
	Generous			Wealthy	

Full Model Specification and Results

For each model described in the manuscript, we report here its full random-effects structure and effect estimates.

Self-Referential Memory

Model A: Memory Sensitivity

We examined how age and condition (self vs. town) influenced memory sensitivity with a linear mixed-effects model. All predictors of interest were included in the model as interacting fixed effects. The model also included random intercepts for each participant. In this model and all subsequent models, age was treated as a continuous variable for which we computed orthogonal polynomials to avoid multicollinearity.

Table A

Memory Sensitivity: Mixed Model Results

	χ^2	<i>df</i>	<i>p</i> -value
Intercept	907.28	1	<.001
Age	0.98	1	.32
Condition	0.68	1	.41
Age x Condition	0.27	1	.60

Model B: Response Bias

We examined how age and condition (self vs. town) influenced response bias with a linear mixed-effects model. All predictors of interest were included in the model as interacting fixed effects. The model also included random intercepts for each participant.

Table B*Response Bias: Mixed Model Results*

	χ^2	<i>df</i>	<i>p</i> -value
Intercept	1.99	1	.16
Age	8.43	1	.004
Condition	14.77	1	<.001
Age x Condition	4.73	1	.03

Model C: Memory Response Times

We examined how age, condition (self vs. town), and category (target vs. distractor adjectives) influenced reaction times (RTs) for recognized adjectives with a linear mixed-effects model. RTs were log-transformed to better approximate normal distribution. All predictors of interest were included in the model as interacting fixed effects. The model also included random intercepts for each participant.

Table C*Memory Response Times: Mixed Model Results*

	χ^2	<i>df</i>	<i>p</i> -value
Intercept	71462.24	1	<.001
Age	2.31	2	.13
Condition	3.10	1	.08
Category	12.32	1	<.001
Age x Condition	0.003	2	.95
Age x Category	0.69	2	.41
Condition x Category	1.90	1	.17
Age x Condition x Category	14.10	2	<.001

Figure S1*Effect of Age on Memory RTs in the Self-Referential Memory Task*

Note. Median RTs (y-axis) are plotted as a function of age (x-axis) for each condition and category. All colored lines and shaded .95 CIs show the linear trends as estimated by the linear mixed-effects models.

Model D: Learning Phase Ratings

We examined how age and condition (self vs. town) influenced learning phase ratings with a linear mixed-effects model. All predictors of interest were included in the model as interacting fixed effects. The model also included random intercepts for each participant.

Table D*Learning Phase Ratings: Mixed Model Results*

	χ^2	<i>df</i>	<i>p</i> -value
Intercept	6469.42	1	<.001
Age	8.75	1	.003
Condition	175.75	1	<.001
Age x Condition	2.28	1	.13

Model E: Recall Phase Ratings

We examined how age and condition (self vs. town) influenced recall phase ratings with a linear mixed-effects model. All predictors of interest were included in the model as interacting fixed effects. The model also included random intercepts for each participant.

Table E*Recall Phase Ratings: Mixed Model Results*

	χ^2	<i>df</i>	<i>p</i> -value
Intercept	10393.18	1	<.001
Age	3.27	1	.07
Condition	7.31	1	.007
Age x Condition	6.34	1	.01

Figure S2*Learning- and Recall Phase Ratings in the Self-Referential Memory Task*

Note. (A) Effect of age on learning phase descriptiveness ratings. Mean learning phase descriptiveness ratings (y-axis) are plotted as a function of age (x-axis) for each condition. (B) Effect of age on recall phase confidence ratings. Mean recall phase confidence ratings (y-axis) are plotted as a function of age (x-axis) for each condition. Across age, participants were

similarly confident in recalling self-related target adjectives. However, young adolescents were less confident in recalling town-related target adjectives than adults. All colored lines and shaded .95 CIs show the linear trends as estimated by the trial-level linear mixed-effects models. * $p_{\text{Bonf}} < .05$.

Perspective Taking

Model F: Perspective Taking Accuracy

We examined how age and trial type (experimental vs. control) influenced perspective taking accuracy with a generalized linear mixed-effects model. All predictors of interest were included in the model as interacting fixed effects. The model also included random intercepts for each participant and allowed for different slopes across trial type.

Table F

Perspective Taking Accuracy: Mixed Model Results

	χ^2	df	p -value
Intercept	62.52	1	<.001
Age	1.03	1	.31
Trial type	122.84	1	<.001
Age x Trial type	8.54	1	.003

Model G: Perspective Taking Response Times

We examined how age and trial type (experimental vs. control) influenced perspective taking RTs with a linear mixed-effects model. All predictors of interest were included in the model as interacting fixed effects. The model also included random intercepts for each participant.

Table G*Perspective Taking Response Times: Mixed Model Results*

	χ^2	<i>df</i>	<i>p</i> -value
Intercept	12170.89	1	<.001
Age	0.57	1	.45
Trial type	21.83	1	<.001
Age x Trial type	0.04	1	.84

Interrelation between Self-Referential Memory and Perspective Taking***Model H: Relation between Memory Sensitivity and Perspective Taking Accuracy***

With a linear regression, we examined how age and perspective taking accuracies related to memory sensitivity difference scores.

Table H*Relation between Memory Sensitivity Difference Scores and Perspective Taking Accuracy:**Regression Results*

	<i>F</i>	<i>df</i>	<i>p</i> -value
Intercept	1.54	1	.22
Age	0.28	1	.60
Experimental accuracy	1.04	1	.31
Age x Experimental accuracy	1.00	1	.32

Model I: Relation between Response Bias and Perspective Taking Accuracy

With a linear regression, we examined how age and perspective taking accuracies related to response bias difference scores.

Table I*Relation between Response Bias Difference Scores and Perspective Taking Accuracy:**Regression Results*

	<i>F</i>	<i>df</i>	<i>p</i> -value
Intercept	9.07	1	.003
Age	1.89	1	.17
Experimental accuracy	0.92	1	.34
Age x Experimental accuracy	0.16	1	.69

Autistic Traits**Table S3***Participant Information (AQ)*

	Adolescents			Adults			<i>t</i> -value	<i>p</i> -value
	<i>(n</i> = 50; aged 11.2-17.5)			<i>(n</i> = 47; aged 22.2-35.6)				
	<i>M</i>	<i>SD</i>	Range	<i>M</i>	<i>SD</i>	Range		
AQ	17.18	5.63	4-30	18.68	6.79	6-35	-1.19	.24

Note. Descriptive statistics of participants included in the analyses (all male) by Autism Quotient (AQ) score. M = Mean, SD = Standard deviation.

Model J: Relation between AQ and Perspective Taking Accuracy

With a linear regression, we examined how perspective taking accuracy (i.e., mean percentage errors on experimental trials in the Director task) and age relate to individual AQ scores. We observed a significant main effect of Age, $F(1, 89) = 4.29$, $p = .04$, indicating that the abilities being measured by the AQ change across adolescence into adulthood. Additionally, we observed a marginally significant Age x Perspective taking accuracy interaction, $F(1, 89) = 3.81$, $p = .05$,

indicating that perspective taking accuracy predicted individual AQ scores marginally more at younger ages.

Table J

Relation between AQ and Perspective Taking Accuracy: Regression Results

	<i>F</i>	<i>df</i>	<i>p</i> -value
Intercept	230.18	1	<.001
Age	4.29	1	.04
Experimental accuracy	1.05	1	.31
Age x Experimental accuracy	3.81	1	.05

Model K: Relation between Memory Sensitivity and AQ

With a linear regression, we examined how age and individual AQ scores related to memory sensitivity difference scores. We observed a marginally significant main effect of AQ, $F(1, 89) = 4.04$, $p = .05$, indicating that changes in memory sensitivity performance were marginally related to differences in AQ scores.

Table K

Relation between Memory Sensitivity Difference Scores and AQ: Regression Results

	<i>F</i>	<i>df</i>	<i>p</i> -value
Intercept	2.62	1	.10
Age	0.08	1	.77
AQ	4.04	1	.05
Age x AQ	0.13	1	.72

Model L: Relation between Response Bias and AQ

With a linear regression, we examined how age and individual AQ scores related to response bias difference scores. Main and interaction effects were non-significant.

Table L

Relation between Response Bias Difference Scores and AQ: Regression Results

	<i>F</i>	<i>df</i>	<i>p</i> -value
Intercept	4.94	1	.03
Age	2.17	1	.14
AQ	1.01	1	.32
Age x AQ	0.52	1	.47