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Cognitive Mechanisms of Perspective-Taking Across Adulthood: An Eye-Tracking Study Using the Director Task

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Open Data

Data and analysis code can be accessed on the Open Science Framework using the following link: https://osf.io/2epsu/

Abstract

Perspective-taking plays an important role in daily life, allowing consideration of other people's perspectives and viewpoints. This study used a large sample of 265 community-based participants (aged 20-86 years) to examine changes in perspective-taking abilities – a component of 'Theory of Mind' – across adulthood, and how these changes may relate to individual differences in executive functions at different ages. Participants completed a referential-communication task (the 'Director' task) whilst behavioural responses and eye movements were recorded, along with four measures of executive functions (inhibitory control, working memory, cognitive flexibility, and planning). Results revealed a quadratic fit of age in egocentric errors; performance on the task plateaued between 20 to ~37 years old, but showed a substantial decline from ~38 years onwards (i.e., increased egocentric errors). A similar pattern was established in eye-movement measures, demonstrating that advancing age led to a decrease in efficient attention orientation to a target. In other words, older adults were more distracted by a hidden competitor object (egocentric interference), and were therefore delayed in orienting their attention to the correct target object. Mediation analyses revealed that executive functions partially mediated the effect of age on perspective-taking abilities. Importantly, however, the relationship between age and egocentric bias in task performance remained significant when controlling for changes in executive functions, indicating a decline in social cognition abilities with advancing age that was independent of age-related declines in more domain-general abilities, such as executive functions.

Key Words: social cognition; perspective taking; theory of mind; ageing; eye-movements

Cognitive Mechanisms of Perspective-Taking Across Adulthood: An Eye-Tracking Study Using the Director Task

A critical part of our day-to-day lives is our capacity to communicate, both verbally and non-verbally, by attributing meanings and motivations to other people's actions or words. Human-beings are natural experts at 'mind-reading'; we are able to predict, understand and attribute mental states, such as thoughts, feelings, and desires, to both ourselves and other people, despite lacking explicit access to these intrinsically private, unobservable states (Aune, 1961; Premack & Woodruff, 1978). Given the critical role of these social cognition, or 'Theory of Mind' (ToM), abilities, much prior research has focused on how and when these abilities develop during childhood. However, more recently research has begun to focus on ToM abilities in adulthood. These studies have reliably shown that, even in adulthood, there is a great deal of variability in the successful engagement of perspective-taking capacities, and that individual differences in more general social and cognitive skills can predict this success (e.g., Bradford et al., 2015; Cane et al., 2017; Converse et al., 2008; Ferguson et al., 2014; Ferguson et al., 2015). Moreover, some studies have reported a resilient 'egocentric' tendency when adults engage in mental state attributions, which needs to be explicitly suppressed when instructed to take the perspective of another person (e.g., Back & Apperly, 2010; Bradford et al., 2015; Keysar et al., 2000; Keysar et al., 2003). This suggests that despite possessing fully developed ToM abilities, there may be some limits on ToM use, even in healthy adults. Importantly, studies have also indicated that ToM abilities decline in older-age adults (e.g., Bailey & Henry, 2008; Phillips et al., 2011; German & Hehman, 2006), and that this decline may be comparable to that seen in cognitive abilities (Diamond, 2002; Salthouse, 2009).

In this paper we sought to understand some of the cognitive factors that may influence successful engagement of ToM capacities, and, importantly, how this relationship may change across the adult lifespan. Addressing these questions is critical to further develop our understanding of the mechanisms that underlie ToM, particularly the individual differences that predict ToM performance. Thus, using a continuous age sample of participants between 20 and 86 years old, the present study utilized eye-tracking and behavioural measures to examine how perspective-taking abilities change across adulthood, and how these perspective-taking abilities relate to more general executive functioning capacities (specifically: inhibition, working memory, cognitive flexibility, and planning abilities) at different ages. By using a continuous age sample (as opposed to a dichotomous age group design, comparing 'younger' and 'older' participants), the study also sought to identify the age at which changes in perspective-taking abilities begin to emerge.

Over the last decade or so, an increasing amount of evidence has emerged showing that social cognition performance, specifically understanding the emotional or mental states of others, declines with advancing age (e.g., Bailey et al., 2008; Castelli et al., 2010; Saltzman et al., 2000; Ligneau-Hervé & Mullet, 2005). For example, Phillips et al. (2011) conducted a study in which younger (18-39 years; *M* = 25 years), middle-aged (40-64 years; *M* = 51 years), and older (65-88 years; *M* = 73 years) adults completed different measures of ToM, including video clips and vignettes with true- or false-belief manipulations. Measures of mental state attribution often involve assessment of true/false-belief understanding, in which reality and belief states are mismatched, allowing assessment of an individual's ability to understand that one's own knowledge states may not necessarily reflect current reality states, or the current belief state of another individual. Results from Phillips et al. showed that, across tasks, older adults were impaired in their reasoning about false-beliefs compared to middle-aged and younger adults – i.e., older adults experienced difficulties in accurately considering another person's perspective. In contrast, there was no difference in accuracy across the age groups for true-belief reasoning. These results indicate key changes in social cognition abilities across age, with deterioration in ToM capacities in older age.

Phillips et al. (2011) also included measures of executive functions in their task battery, specifically assessing inhibition and working memory. Executive Functioning (EF) refers to a set of cognitive processes that regulate, control, and manage other cognitive processes, allowing flexible and goal-oriented behaviours to be utilized. These cognitive processes include inhibition, working memory, attention/set shifting, and planning (Burgess et al., 2006; Miyake et al., 2000; Miyake & Friedman, 2012). It is clear that even in healthy adults, EF may be required for the expression of ToM abilities. For example, in a false-belief type event, one would need to *inhibit* one's own perspective, *flexibly switch* to the mindset of another person, and *integrate* all the relevant factors into a coherent picture, whilst using *working memory* to keep each of these different states in mind (Burgess et al., 1998; Saxe et al., 2006). Results from Phillips et al.'s (2011) study indicated that updating information in working memory, but not inhibitory control, partially mediated age differences in false-belief reasoning capacities. Bailey and Henry (2008) demonstrated that older adults (*M* = 72.2 years) show reduced ToM capacities compared to younger adults (*M* = 19.5 years) when demands on inhibition are high, with no significant difference in performance when demands on inhibition are low. Moreover, individual differences in inhibitory control (assessed using a Stroop task) emerged as a significant mediator of ToM task performance. These results are consistent with German and Hehman (2006), who found that when younger (*M* = 20 years) and older (*M* = 78 years) adults engaged in a task requiring them to reason about mental states, both groups performed equally well when inferential demands were held constant (i.e., low inhibitory demands). However, when inhibitory demands were increased, task performance was impaired for both older and younger participants, though this impairment was disproportionately larger for older adults. These results provide further evidence that social cognition capacities decline in older age. Importantly, German and Hehman propose that the impairment reflects age-related declines in executive functioning skills, such as inhibitory control, rather than failures in the mental state representational system itself.

Despite the majority of studies indicating age-related declines in ToM abilities (see Moran, 2013, for a review, and Henry et al., 2013, for a meta-analysis), other studies have found mixed results. Indeed, one of the first studies to examine social cognition in late adulthood, by Happé et al. (1998), found evidence for age-related *improvement* in ToM capacities. In their study, participants (older *M* = 73 years; younger *M* = 21 years) completed the 'Strange Stories' task (Happé, 1994); results showed that older participants performed significantly *better* than younger participants on mentalising trials, with no significant difference in task performance in non-ToM trials. However, a later study by Maylor et al. (2002) failed to replicate these results, finding that older participants (*M* = 81 years) performed significantly *worse* than both young (*M* = 19 years) and young-old participants (*M* = 67 years) on the mentalising stories. Importantly, Maylor et al. found that when memory load requirements were increased, the young participants outperformed both older and young-old participants, indicating a direct effect of working memory on ToM task performance in older age. Other studies have reported no age-differences in ToM task performance (e.g., Keightley et al.,, 2006; MacPherson et al., 2002; Saltzman et al., 2000). An issue with the studies described so far, however, is that they have examined age in distinct groups (typically young *versus* old) rather than utilizing age as a continuous measure. It therefore remains uncertain exactly *when* changes in ToM abilities become apparent, and how executive functions may differentially predict ToM success across this age trajectory.

The developmental link between ToM and EF has been widely documented, particularly in childhood. For instance, Carlson and Moses (2001) suggest that EF development is a necessary requirement for successful ToM acquisition, independent of age and IQ (see also Pellicano, 2007; Perner & Lang, 1999). Among adults, correlations have been observed between EFs and ToM skills, and ToM performance can be impaired when executive demands are increased (e.g., Bernstein et al., 2011; Cane et al., 2017; Charlton et al., 2009; Duval et al., 2011; cf. Maylor et al., 2002), indicating that this robust relationship persists into adulthood. It is now well established that executive functioning abilities decline with advancing age (Allain et al., 2005; Elderkin-Thompson et al., 2008; German & Hehman, 2006; Salthouse et al., 2003). Indeed, where age-related declines in ToM have been observed, many researchers have linked these difficulties to declines in more general executive functioning capacities, rather than impairments in the ToM mechanism itself (e.g., Bailey & Henry, 2008; Duval et al., 2011; Phillips et al., 2011). Martin et al. (2019) compared visual perspective-taking abilities in young (18-36 years) and older (55-80 years) adults. They found that older adults exhibit an impairment in switching from their own perspective to the on-screen avatar's (altercentric) visual perspective, with these age-related differences in visual perspective-taking ability being partially explained by individual differences in working memory capacity and inhibitory control.

An important open question remains as to whether the nature of this relationship between ToM and EF, and the specific components of EF involved, changes across the lifespan. The majority of previous studies have focused on just two key EF abilities (working memory and inhibitory control), and have typically examined the effect of these abilities on social cognition in isolation. Thus, the current study advances previous work by examining the role of *four* different executive functions in mediating ToM task performance, across adulthood, which offers new insights into the different roles that separable EFs may contribute in determining ToM engagement.

The current study builds on previous research by examining how perspective-taking abilities change throughout adulthood, and whether these changes can be reliably predicted by executive functioning abilities, in a large sample of 264 participants aged 20-86 years old.

The study employed an eye-tracked computerised version of the referential communication perspective-taking task (the 'Director' task; Keysar et al., 2000). In Keysar et al.'s original Director task, participants sat at a table opposite a 'director' (a confederate), with a vertical 4x4 grid situated between the two of them (similar to those depicted in Figure 1). Importantly, some slots in the grid were occluded so that only the participant could see the objects inside them, whilst the director was naïve to the contents of these slots. The participant's task was to follow the director's instructions to move objects around the grid. Some objects were easily recognizable, such as '*move the truck one slot down'*, where only one item (visible to both the participant and the director) fit the verbal description. Other objects involved more complex instructions, requiring the participant to consider the director's point of view in order to successfully select the right object. For instance, the grid may contain three different sized candles – small, medium, and large, with the smallest candle occluded from the director's perspective. Here, if the director asked the participant to '*move the small candle one slot up*', the participant would need to infer that the director was referring to the *medium* sized candle, since this is the smallest candle from the director's perspective. Keysar et al. found that healthy young adults were surprisingly prone to egocentric responses, selecting the perspective-inappropriate object in the grid. Moreover, eye-tracking data revealed that even when participants eventually selected the correct object in the grid, they experienced interference from the hidden competitor object, with fixation data showing that they temporarily considered this as a potential solution before realigning their gaze to the correct object in shared view.

Since Keysar's original study, this Director task has been widely used a measure of social functioning (e.g., Cane et al., 2017; Dumontheil et al., 2010; Ferguson & Cane 2017; Meyer et al., 2015; Mills et al., 2015; Santiesteban et al., 2015). The current study compared two key conditions: Listener-Only trials, in which participants needed to take the director's perspective to select the mutually available object, and ignore a competitor object in an occluded slot that fitted the description, and Shared-Perspective trials, in which no hidden competitor object was present in the grid. We recorded response times and accuracy, along with eye movements. To provide a measure of more general cognitive performance, individual differences in four core executive functions were also assessed: inhibition (Stroop task), working memory (Operation-Span task), cognitive flexibility (task-switching task), and planning (Tower of Hanoi). Additionally, Full Scale IQ was assessed to provide a measure of an individual's overall level of intellectual functioning (Lange, 2011). Mediation analyses was then used to assess the degree to which age-related changes in ToM could be predicted by these executive function skills and/or IQ (full-scale).

The current study improves on prior research in numerous ways. First, it includes a large, continuous sample of adults aged 20-86 years old, which allows a high-powered exploration of changes *throughout* the healthy adult lifespan, including the often overlooked middle age period; this is important as it allows more sensitive detection of when changes in social cognitive abilities may emerge, which in turn may provide scope for development of interventions that reduce social cognitive declines when detected early, particularly if this is before typical 'older' age. Second, we have employed sophisticated analysis methods (i.e., regression models, growth curve analysis, and mediation analysis) to track incremental changes in ToM capacities with advancing age, and eye movements over time. In contrast to most studies that aggregate data into dichotomous age groups, our statistical approach models variance for both participants and items, and tests the effects of age while controlling for by-subject variation in the condition effects (Barr et al., 2013). In this way, our analyses can detect in a more sensitive manner *when*, if at all, age-related changes occur in perspective taking. Third, we examine four distinct sub-components of EF (inhibition, working memory, cognitive flexibility, and planning), and how changes in these EF capacities may play a key mediating role in determining changes in perspective taking across adulthood.

In line with prior research, we predicted that increasing age would be associated with an overall increase in response times and error rates. Critically, it was predicted that perspective-taking success (i.e., self-perspective inhibition, successful use of the director's perspective within the task) would decrease with age, indicating that older individuals experience more interference from the egocentric perspective than younger individuals. This effect should be manifest in longer response times (present after controlling for general processing speed) and increased error rates with increasing age, along with delayed fixations on the target object in the Listener-Only condition, compared to the Shared-Perspective condition. This pattern would indicate that older participants continue to (incorrectly) consider the privileged-view object as a potential reference for longer than younger participants (i.e., the small candle). Regarding the role of EFs, it was predicted that inhibition and working memory would be significant mediators/partial mediators of ToM task success, as suggested by prior research. In addition, we predicted that cognitive flexibility and planning would play an important role in predicting ToM task success, however these factors have been less studied previously, so the extent of their mediating contribution is unclear.

Method

Participants

A total of 268 participants completed this experiment as part of a larger task battery; four participants were excluded from analysis (one a non-native English speaker; one due to computer failure; two due to low IQ scores), resulting in a final analysis sample of 264 participants aged between 20-86 years old (187 females, 77 males). All participants were native English-speakers, had normal or corrected-to-normal vision, had no known neurological disorders, and had no mental health or autism spectrum disorder diagnosis. Participants were recruited from a community sample in the local area of Kent, U.K., using a variety of recruitment strategies (e.g., newspaper adverts, contacting local groups, word-of-mouth). Table 1 details the demographic details of the sample (divided into three age groups for illustrative purposes), including IQ (assessed using the Wechsler Abbreviated Scale of Intelligence – Second Edition). Participants' consent was obtained according to the Declaration of Helsinki, and the Ethical Committee of the School of Psychology, University of Kent, approved the study.

Table 1: Participant Demographics

	M **(S.D.)**
Young Adults (20-40 yrs; *N* = 86)	
Gender (m:f)	24:62
Age (years)	29.50 (6.55)
Verbal IQ	106.47 (10.72)
Perceptual Reasoning IQ	106.10 (11.58)
Full Scale IQ	107.13 (9.99)
Middle Adults (41-62 yrs; *N* = 90)	
Gender (m:f)	22:68
Age (years)	52.10 (6.07)
Verbal IQ	106.79 (11.12)
Perceptual Reasoning IQ	106.44 (13.00)
Full Scale IQ	107.60 (11.58)
Older Adults (63-86 yrs; *N* = 88)	
Gender (m:f)	31:57
Age (years)	71.25 (6.24)
Verbal IQ	119.20 (11.49)

Perceptual Reasoning IQ	114.24 (11.33)
Full Scale IQ	119.22 (10.72)

Measures and Design

Referential Communication: 'Director' Task

This study used an avatar version of the referential communication 'Director' task. The perspective-taking task was delivered and controlled using SR Research Experiment Builder software (version 2.1.140). During the task, participants were presented with an image of a room containing a 4 x 4 gridded cupboard, creating 16 slots that could contain objects, and a female avatar (the 'director') standing to the rear right-hand side of the cupboard (see Figure 1). Within the cupboard, the backs of five spaces (different for each trial) were covered so that only the participant could see the contents of these spaces, with the contents of the space occluded from the director's view. Eight objects were randomly placed within the grid slots, two of which were in the occluded positions and six of which could be seen by both the director and the participant. Prior to beginning the task, standardized instructions were presented to participants emphasising that the director had a different perspective of the grid than that of the participant; they were shown an example stimulus, including viewing the shelves from the participant and the director's perspectives (i.e., with the occluded slots blocking view of the objects inside of them from the director's perspective), to ensure all participants understood that the director could not see all the objects.

The experiment included two practice trials, and 24 experimental trials. Each trial consisted of three instructions given by the director to move objects around the grid, resulting in 72 instructions in total (and six instructions across the two practice trials). These audio instructions were presented through headphones. Before the first instruction, participants were given 4000 ms to inspect the grid. Across the three instructions per trial, two were fillers that did not require perspective-taking as they referred to specific items on the shelves (one used a modified description, e.g. 'yellow bucket', and one used a simple description, e.g. 'present') that could be seen by both the participant and the director. These filler trials were not included in the analysis. One instruction in each array was the critical instruction, with 12 appearing in the Listener-Only condition and 12 appearing in the Shared-Perspective condition. Participants could be asked by the 'Director' to move an object up, down, left, or right; in experimental trials, participants were only asked to move the object up or down.

Listener-Only **Shared-Perspective**

Figure 1: Example stimuli from the referential communication task. Participants were presented with a grid such as this, alongside an instruction, e.g. '*Move the small star one slot down*'. The left 'Listener-Only' panel shows an example scene in which the target object is visible to both the director and the participant, but the participant has privileged access to a competitor object; the right 'Shared-Perspective' panel shows an example scene in which the target and competitor objects can be seen by both the director and the participant.

In the Listener-Only condition, participants needed to take the director's perspective to select the mutually available object, and ignore a competitor object in an occluded slot that fitted the description (since it could not be seen by the director). Thus, participants were required to inhibit their own perspective to consider the correct object from the director's point of view. For instance, the participant could be asked to '*Move the small star one slot down*', where the grid contained three stars of different sizes, the smallest of which was occluded from the director. In this example, it would be correct for the participant to select the medium sized star, since this is the smallest star from the director's perspective. In the Shared-Perspective condition the competitor object was replaced by a different (neutral) object that could not be mistaken for the object in the director's instruction. For instance, the participant could be asked to '*Move the small star one slot down*', where the grid contained only two mutually-available stars. Here, it would be correct to select the objectively smallest star, since this matched both the participant's and the director's perspective. The order of filler and critical instructions was counterbalanced across trials, and a new instruction was only given once participants had responded to the previous instruction. Participants responded using the computer mouse to select an object, and drag it to the new location detailed in the verbal instruction. See Figure 1 for a visual depiction of stimuli across Listener-Only and Shared-Perspective conditions.

In the referential communication task, response times (how long it took participants to select the referential object) and accuracy rates (correctly selecting the referential object, taking into account the director's perspective) were recorded. Within each experimental trial, the grid contained eight moveable objects located in different slots of the grid. Participants therefore had a 1-in-8 chance (12.5%) of randomly selecting the correct object. Recording of response times started from when the director's instruction was played, until the participant clicked the mouse to pick up the referential object. Eye movements were recorded during the referential communication task using an EyeLink 1000 Plus desktop mounted SR Research eye-tracker in remote mode, with eye movements sampled at a frequency of 500 Hz. Viewing was binocular, but only one eye was tracked at a time. Stimuli were presented on a 24-inch colour monitor screen, with a screen resolution of 1024 – 768 pixels, approximately 70 cm from the participant. A nine-point calibration was used to calibrate participants' eye movements and a drift correction check (central fixation point on the screen) was displayed at the start of each trial.

Executive Functions

Full details of the executive function battery have been previously reported (see Ferguson, Brunsdon, & Bradford, 2021) and so a summary is presented here. Further details can also be found in supplementary materials.

Stroop Task (Inhibitory Control)

The Stroop colour-word task (Stroop, 1935) was used as a measure of inhibitory control. Participants completed 20 practice trials (ten neutral and ten congruent) in a pseudo-randomised order. They then completed 150 experimental trials, consisting of 50 congruent (e.g., 'RED' printed in red), 50 incongruent (e.g., 'RED' printed in yellow), and 50 neutral (e.g., 'TAX' printed in green) trials, presented in a pseudo-randomised order. Response times were calculated for accurate responses that were made 200ms after stimuli onset, and were within 2.5 S.D.s of each participant's trial mean. The dependent variable was the Stroop congruency effect (incongruent trial mean RT minus congruent trial mean RT). To account for age-related slowing and declines in information processing speed, response times were log-transformed for each trial before calculating the Stroop congruency effect. Internal consistency was excellent (Cronbach's alpha = 0.995) and the average inter-item correlation was ideal (r = .582). Split-half reliability (Guttman split-half coefficient; test halves were composed using the odd-even method) was .80 for the Stroop congruency difference scores used in the mediation analysis, indicating good levels of reliability.

Operation Span (Working Memory)

The Operation Span (OSpan; Unsworth et al., 2005) was used as a measure of working memory capacities. Participants were required to solve maths equations whilst concurrently remembering sequences of letters. Participants completed three practice blocks, followed by three trials at 2 to 7 letter spans each (randomised). This resulted in a total of 18 trials, with 81 maths problems to solve and 81 letters to recall. For analysis, a partial OSpan score was calculated, which is defined as the total number of letters recalled in the correct position. Internal consistency was good (Cronbach's alpha = .864) and the average inter-item correlation was ideal (r = .261).

Task-Switching (Cognitive Flexibility)

The task-switching paradigm (Rogers & Mansell, 1995) was used as a measure of cognitive flexibility. The task was identical to Barenberg et al. (2015). Within the non-switch-trials, there were 16 practice trials and 32 experimental trials per block (two blocks). Participants were asked to identify either the shape (CIRCLE/TRIANGLE) or colour (BLUE/YELLOW) that appeared on the screen. In the switch-trials, there were 16 practice trials, and four blocks of 32 experimental trials. Participants had to consider two rules concurrently: if the shape appeared in the top row, participants must make a TRIANGLE/CIRCLE judgement, but if the shape appeared in the lower row, participants must make a BLUE/YELLOW judgement. Response times were calculated for accurate response that were made 200ms after stimuli onset and were within 2.5 SDs of the trial mean. To provide a measure of cognitive flexibility, a 'switch-cost' was calculated by subtracting the mean reaction times of 'non-switch trials' from the reaction time of 'switch' trials. To account for age-related slowing and declines in information processing speed, trial level reaction times were log-transformed before calculating the switch-cost. Internal consistency was excellent for both the single and mixed-task (both Cronbach's alpha = .986). The average inter-item correlation for the no-switch task (r = .529) and the switch task (r = .367) was ideal. Split-half reliability (Guttman split-half coefficient; test halves were composed using the odd-even method) was .837 for the switch-cost difference scores used in the mediation analysis, indicating good levels of reliability.

Tower of Hanoi (Planning)

The Tower of Hanoi (Humes et al., 1997) task was used to assess planning abilities. Participants were presented with three rods with a number of different disks of different sizes on them. At the top of the screen was an image of the rods with the end-state being sought. Participants were required to move the disks from their current positions at the bottom of the screen to match the provided end state, in a pre-defined number of steps. Participants completed three practice trials and 16 experimental trials. There was only one correct way to complete each trial; if the participant made an error, the trial restarted a maximum of 5 times, before the task ended. The dependent variable was calculated as the sum of all perfectly completed trials (i.e., score of 5 for a trial with 5 steps completed perfectly with no errors). Internal consistency was good (Cronbach's alpha = .820) and the average inter-item correlation was ideal (r = .222).

Procedure

The tasks reported here were completed as part of a larger task battery which lasted approximately 5 hours in total. Participants completed the tasks over one or two days, with regular breaks, and tasks were administered in a counterbalanced order.

Results

Statistical analyses were conducted in R version 3.5.2. The data and code are available at https://osf.io/2epsu/. Behavioural data in the Director task was analysed for the full sample of 264 participants, however the eye-tracking analysis was conducted on a slightly smaller sample (*N*=249) due to calibration difficulties that meant no eye-tracking data was recorded for 15 participants.

To investigate our research questions, egocentric errors, responses times, and eye-tracking data for the referential communication task were analysed separately. Egocentric errors were analysed using Linear Models, response times were analysed using Linear Mixed Effects Models, and eye movement data was analysed using Growth Curve Analysis, which allows for sensitive detection of changes over time (Mirman, 2017; Schuh, Eigsti, & Mirman, 2016). Continuous predictor variables (i.e., age or time) were included in the models as linear, quadratic, and cubic terms to examine the nature of changes in effects (i.e. consistent increase/decrease, increasing/decreasing to a vertex, or increasing/decreasing between two vertexes). To determine the best fitting models, we compared the simpler model against the more complex model using an ANOVA (i.e., linear *vs.* quadratic, quadratic *vs.* cubic). If the *p*-value was greater than .05, then the simpler model was selected as the best fitting model. Full details of each analysis model are provided in the relevant sections below.

Behavioural Results

Egocentric errors

For each participant we calculated the percentage of egocentric errors for trials in the Listener-Only condition (i.e., the percentage of trials on which they selected the competitor object in privileged view, and failed to consider the director's perspective). Egocentric errors in the Shared-Perspective condition were not deemed to be informative since they were at floor (*M*= 0.16%), and were likely to reflect attentional errors rather than any difficulty processing perspective (since the competitor object was not a semantic fit for the instruction). Data was analysed using the lm function. Age (linear, quadratic and cubic terms) was included in the model as a continuous fixed effect. Figure 2 illustrates the pattern of egocentric errors with advancing age.

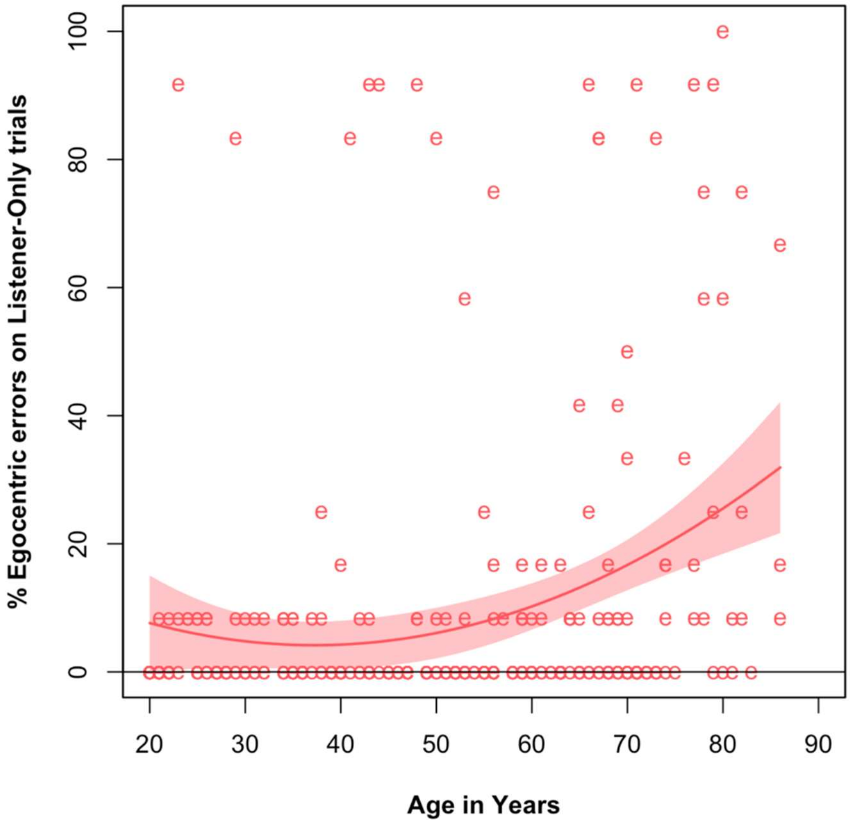

Figure 2: Percentage of egocentric errors (%) in the Listener-Only condition, showing effects over age. The bold line indicates the best-fitting quadratic model, and the shaded area around it indicates the 95% confidence intervals (CIs).

On average, participants made the egocentric response (i.e., selected the hidden competitor object) in the Listener-Only condition on 10.23% of trials. A quadratic[1] model provided the best fit for the effect of age on egocentric errors (*Estimate* = 0.012, *S.E.* = 0.004, p = .009; see also Table 2). Post-hoc analyses to examine each slope of this quadratic model showed no significant changes in the percentage of egocentric errors between 20 to ~37 years old (*Estimate* = -0.086, *S.E.* = 0.32, t = -.266, p = .79), indicating that participants performed at ceiling levels in this task throughout young adulthood. However, from ~38

[1] Analysis was also run excluding participants who made 90% errors or more in Listener trials, resulting in a sample size of 249 participants. For egocentric error rates, this analysis showed that a quadratic model continued to provide the best fit for the effect of age on egocentric errors (*Estimate* = 0.009, *S.E.* = .003, p = .011). Post-hoc analyses to examine each slop on this quadratic model showed, as before, no significant changes in the percentage of egocentric errors between 20 to ~37 years old (*Estimate* = .112, *S.E.* = .229, t = .491, p = .625), indicating that participants performed at ceiling levels in this task throughout young adulthood. However, from ~38 years onwards, results showed a linear increase in egocentric errors (*Estimate* = .378, *S.E.* = .113, t = 3.348, p = .001), indicating that participants become increasingly egocentric across middle and later adulthood.

years onwards results showed a linear increase in egocentric errors (*Estimate* = 0.439, *S.E.* = 0.14, t = 3.05, p = .003), indicating that participants became increasingly egocentric across middle and later adulthood.

Response Times

Analyses tested the effects of age on response times for Listener-Only and Shared-Perspective conditions. Only correct trials were included in the response times analysis, resulting in an average of 6.56% trial loss per participant. Response time was calculated from the onset of the scalar adjective (e.g., “small”) until participants clicked on the target object. These correct response times were log transformed prior to analysis to increase normality in the data due to positively skewed response times (particularly among the older participants), as recommended by Baayen (2008). Statistical analysis used the lmer function in the lme4 package using R (Bates, Machler, Bolker, & Walker, 2015). The model included fixed effects for Condition (Listener-Only *vs.* Shared-Perspective, contrast coded as -.5 *vs.* .5) and Age (linear, quadratic, and cubic terms), and a maximal random effects structure, including random effects for participant and trial, and crossed random slopes for Condition and Age within trial, and a random slope for Condition within Participant (as suggested by Barr, Levy, Scheepers, & Tily, 2013).

On average, participants selected the target object 3178 ms after the onset of the scalar adjective (which approximately corresponds to the auditory instruction offset time; e.g., ‘*Move the small star one slot down*’). A linear[2] model provided the best fit for the data, reflecting the expected positive linear relationship between age and response times (*Estimate* = 0.882, *S.E.* = 0.113, p < .001; see Table 2). Neither Condition (p = .81) or the interaction between Condition and Age (p = .56) was significant, indicating that the effect of Age reflected a general decline in perceptual speed in older age (see Figure 3).

[2] Analysis was also run excluding participants who made 90% errors or more in Listener trials, resulting in a sample size of 249 participants. This analysis showed that a linear model remained the best fit for the response time data, reflecting the expected positive linear relationship between age and response times (*Estimate* = .878, *S.E.* = .116, p < .001). Condition (p = .761) and the interaction between condition and age (p = .579) remained non-significant.

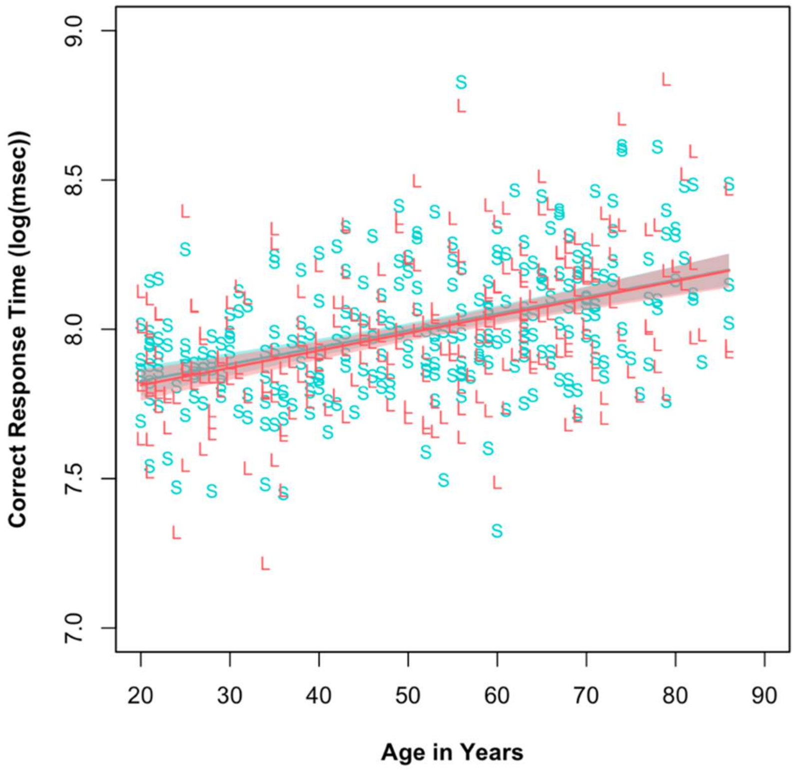

Figure 3: Log-transformed mean correct response times (msec) in the Listener-Only (indicated by 'L') and Shared-Perspective (indicated by 'S') conditions. The bold lines indicate the best-fitting linear models, and the shaded areas around them indicate the 95% confidence intervals (CIs).

Eye-Tracking Results

Data Processing

Eye movements for accurate trials only were time-locked to the onset of the scalar adjective in the auditory instructions from the director avatar (e.g., '*Move the **small** star down*'), and were analysed in a 3000ms period from this scalar onset. Since the average response time was 3178 msec after scalar onset, eye-tracking behaviour in this period indicates listeners' expectations about forthcoming language input and identification of possible referents in the grid. Areas of interest (AOIs) were defined around each object in the 4x4 grid for each visual scene, including the target object (the mutually available object that matched the director's description), and the competitor object (the object in privileged view that was either semantically matched (Listener-Only condition) or did not match (Shared-Perspective condition) the director's description).

Analyses tested whether participants differed in their likelihood of fixating the mutually-available target object or hidden competitor object between the Listener-Only and Shared-Perspective conditions, and whether age influenced the time course of these preferences. To fulfil these aims, fixations during the 3000ms period were broken down into 20ms time bins, and the spatial coordinates were mapped onto AOIs as a function of time. Visual preferences to target or competitor pictures were represented by a binary term in each 20ms time bin, where '1' indicated a fixation on the target/competitor and '0' indicated no fixation. For analysis, data was merged into 100ms time bins, and a 'proportion' score of likelihood to fixate the target *versus* competitor object was calculated (i.e., P(target) – P(competitor)). This calculation produced a single value that takes into account the proportion of fixations to both the target and competitor, and indicates the strength of the bias towards these critical objects in each condition as a function of time. Scores above zero indicate a bias to fixate the target object (values closer to one indicate a stronger preference to fixate the target and positive values closer to zero suggest that the competitor object is interfering with this target preference), scores below zero indicate a bias to fixate the competitor object, and scores around zero indicate no object preference. This data is plotted in Figure 4, collapsed across age.

The resulting data was analysed using mixed models and Growth Curve Analysis (Mirman, Dixon, & Magnuson, 2008), using the 'lme4' and 'eyetrackingR' packages in R. Third-degree orthogonal polynomials, incorporating linear, quadratic and cubic components were used to model the time-course of visual biases over the 3000ms period (see Mirman et al., 2008). Thus, the model included fixed effects for Condition (contrast coded, -.5 *vs* .5) and Age (scaled) alongside the time polynomials, and random effects of participants and items. The final model also included Condition as a random slope within participants and items (other random slopes were dropped due to non-convergence, as recommended by Barr et al., 2013).

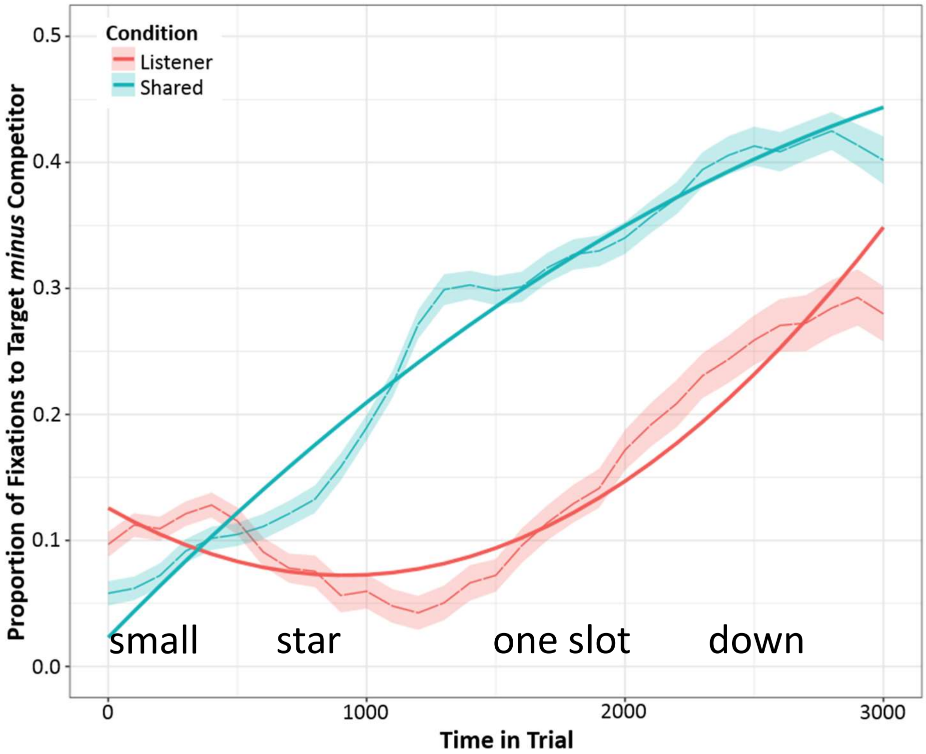

Figure 4: Time course of biases to fixate the target object *versus* competitor object, time-locked to the onset of the scalar adjective, in the Listener-Only and Shared-Perspective conditions.

Time-Course Analysis

The quadratic model provided the best fit for the data. Full details of the statistical effects for this quadratic model are shown in Table 2.

Analyses revealed a significant effect of Time for both the linear fit and quadratic fit, reflecting a general preference for participants to increase fixations on the target object (and decrease fixations on the competitor object) as the auditory instruction progressed in each trial. This effect was further subsumed under a significant interaction between Condition and Quadratic Time. Specifically, in the Shared-Perspective condition, participants showed a consistent and increasing preference to fixate the correct target object following the onset of the scalar adjective. In contrast, in the Listener-Only condition, participants initially showed a reduction in fixations on the target object (i.e., they experienced interference from the competitor object as the reference for the director's instruction up to ~1200ms after scalar onset), then showed a steep and consistent increase in fixations to the target object across the rest of the trial. More importantly, there was a significant effect of Age, indicating that the overall target-bias decreased as age increased. That is, participants became increasingly likely to be distracted by the competitor object with advancing age, which interfered with their ability to fixate the target object.

Table 2: Statistical results from the analysis of egocentric errors (Listener-Only condition), response times, and eye movements, where * *p*<.05, ** *p*<.01, *** *p*<.001.

	Estimate	Std.Error	*t* value	*p*	
Egocentric Errors (Listener-Only)					
Linear Age	-0.868	0.45	-1.91	0.06	
Quadratic Age	0.012	0.00	2.61	0.01	**
Response Times					
Condition	0.003	0.01	0.25	0.81	
Linear Age	0.882	0.11	7.77	<0.001	***
Condition*Linear Age	-0.052	0.09	-0.59	0.56	
Eye Movements					
Condition	0.033	0.03	1.20	0.23	
Age	-0.002	0.00	-5.35	<0.001	***
Linear Time	0.621	0.04	17.55	<0.001	***
Quadratic Time	0.231	0.03	6.63	<0.001	***
Condition*Age	0.002	0.00	3.92	<0.001	***
Condition*Linear Time	0.085	0.05	1.70	0.09	
Condition*Quadratic Time	-0.290	0.05	-5.90	<0.001	***
Age*Linear Time	-0.005	0.00	-7.46	<0.001	***
Age*Quadratic Time	0.001	0.00	0.79	0.43	
Condition*Age*Linear Time	0.005	0.00	5.07	<0.001	***
Condition*Age*Quadratic Time	-0.001	0.00	-1.28	0.20	

There was a significant interaction between Condition and Age, indicating that as age increased, the difference in target/competitor preference between the Listener-Only and Shared-Perspective conditions also increased, with older adults showing a greater condition effect. This effect was further subsumed under a three-way interaction between Condition, Age, and Linear Time. To explore this interaction, post-hoc analyses were conducted separately for Listener-Only and Shared-Perspective trials. Figure 5 plots this data using a tertiary split on Age (young, middle, old) to illustrate the effects. In the Listener-Only condition, the Age x Linear Time interaction was significant (*Estimate* = -.004, *S.E.* < .001; t = -6.10, p < .001), indicating that the linear increase in fixations to the target object over time was significantly steeper among younger participants compared to middle or older-aged participants (i.e., older adults experienced more interference from the hidden competitor object). Scrutinising the data plotted in Figure 5 further suggests that while middle-aged adults showed strong competitor interference in the first 2000ms from the scalar onset, they later recovered to favour the target object; older adults showed consistent competitor interference throughout. In contrast, the Age x Linear Time interaction was not significant in the Shared-Perspective condition (p = .55), indicating that when the competitor object was not a semantic fit with the audio description, the trajectory of looks towards the mentioned target object did not differ by age (i.e., all ages identified the correct object equally quickly).

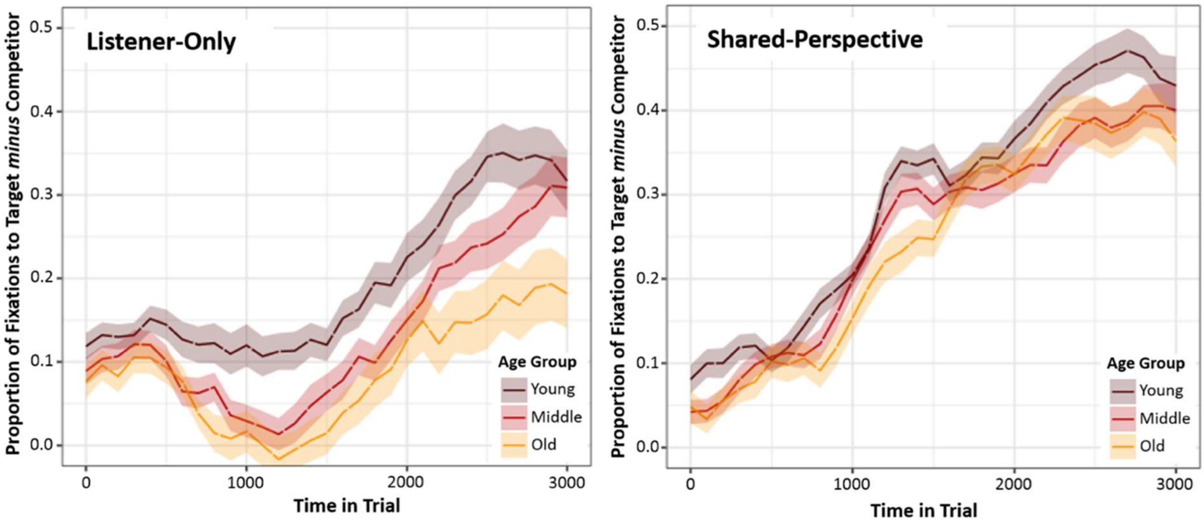

Figure 5: The effect of age on the time course of biases to fixate the target object *versus* competitor object, plotted separately for Listener-Only and Shared-Perspective conditions.

Mediation Analyses: Executive Functions

Mediation analyses tested the degree to which the increasing egocentric effects seen with increasing age on Listener-Only trials (i.e., on egocentric errors, and egocentric bias in looking behaviour) are mediated by age-related changes in EFs. In addition, we included full-scale IQ in the mediation analyses to distinguish any predictive effects that may be due the EFs themselves from more general effects of IQ (which relates to the EF outcome measures). Each mediation analysis included four measures of executive functions: inhibitory control (Stroop task, log transformed), working memory (OSpan, partial score), cognitive flexibility (task-switching, switch cost, log transformed[3]), planning abilities (Tower of Hanoi, absolute score), and IQ scores. Thus, for each model we tested how the relationship between age and perspective-taking might be mediated by each of these executive function capacities and IQ levels independently, as well as the total effect of EF and IQ. The path analysis outcomes are shown in Figure 6; given the different units across our measures, we report the standardized coefficients for each path here. Note that from the 264 participants in the overall dataset (249 in eye-tracking dataset), some data was missing for each of the executive function tasks due to computer failure or participant refusal to complete task: Stroop $N = 3$; OSpan $N = 6$; Task-Switching $N = 14$; Tower of Hanoi $N = 1$.

Egocentric Errors

For the behavioural data, mediation analysis focused on the role of age in predicting the percentage of egocentric errors in the Listener-Only condition.

As illustrated in Figure 6, age significantly predicted *declines* in inhibitory control, working memory, and cognitive flexibility[4]. Age significantly predicted an *increase* in IQ. There was no significant relationship between age and planning abilities. Planning abilities were the only executive function that significantly predicted egocentric errors. In contrast, inhibitory control, working memory, cognitive flexibility, and IQ did not significantly predict egocentric errors in the Listener-Only condition.

Importantly, the total effect of age as a predictor of egocentric errors (i.e., including the executive function and IQ mediators) was significant, and the direct effect of age, controlling for executive function capacities and IQ, continued to significantly predict egocentric errors.

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[3] It is noted that, in the Task Switching paradigm, cognitive flexibility can be assessed using two measures: switch cost and mixing cost. In the context of the current study, switch cost was used as the measure of cognitive flexibility, in line with prior research. We note that mixing costs can also provide valuable insights into cognitive flexibility. Including mixing costs (log transformed) in our mediation analysis did not change the outcomes of the total or direct effects established in the mediation models, both remaining significant in behavioural mediation analysis (Direct Effect: $\beta = .170$, $p = .032$; Total Effect: $\beta = .221$, $p < .001$) and eye-tracking mediation analysis (Direct Effect: $\beta = -0.224$, $p = .005$; Total Effect: $\beta = -0.256$, $p < .001$).

[4] Note that inhibitory control is a positive value as in this measure, a higher score indicated worse inhibitory control (larger congruency difference score), whereas for working memory and cognitive flexibility, a negative value indicated reduced task performance.

Egocentric Bias in Looking Behaviour

For eye-tracking measures, analysis focused on the proportion of looks to the target vs. competitor object (i.e., egocentric bias in looking behaviour) in the Listener-Only condition, exploring the role of age in predicting egocentric looking behaviours.

As illustrated in Figure 6, results showed that age significantly predicted reductions in inhibition, working memory, and cognitive flexibility, but not planning abilities. As previously, age significantly predicted increases in IQ. Planning abilities were the only executive function that significantly predicted egocentric bias in eye movements. Neither inhibition, working memory, cognitive flexibility, or IQ significantly predicted egocentric bias in eye movements.

Most importantly, the combined effects of age and executive function and IQ mediators provided a significant predictor of egocentric looking behaviour, and the direct effect of age on egocentric looking behaviour remained significant once the influence of executive function capacities and IQ was controlled.

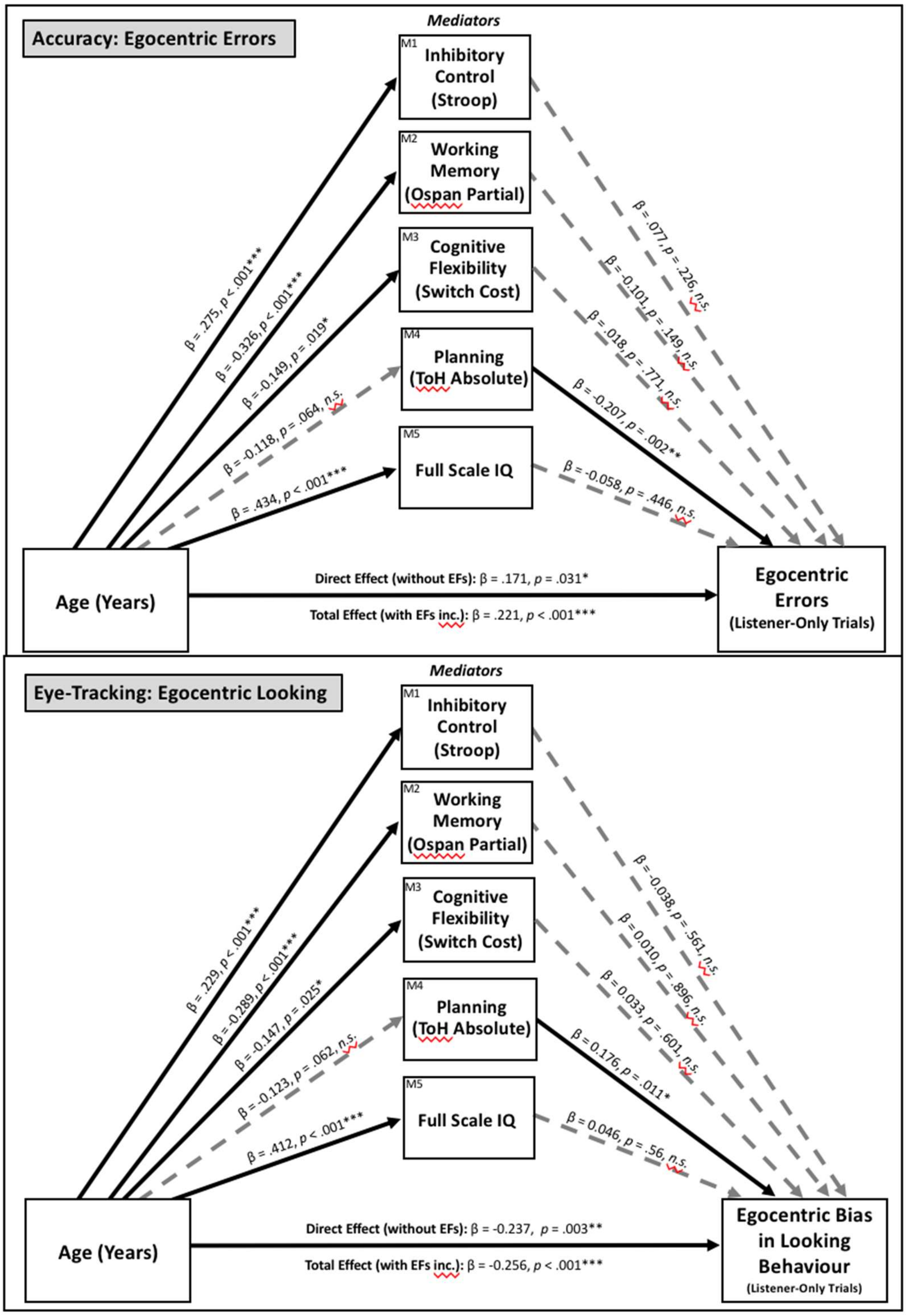

Figure 6: Path diagrams of mediation analyses examining the role of four executive functions (inhibition, working memory, cognitive flexibility, and planning) and IQ (Full-Scale) as possible mediators of age differences in (a) egocentric errors [top panel; 264 participants] and (b) egocentric looking behaviour [lower panel; 249 participants] in the Director task. **p* < .05, ** *p* < .01, ****p* < .001.

Discussion

In recent years, there has been growing interest in how perspective-taking capacities may change across adulthood, and how age-related differences may manifest. Prior research has produced mixed results when examining age-related changes in ToM task performance, although a majority of studies have indicated declines in social cognition abilities with advancing age (e.g., Bailey et al., 2008; Castelli et al., 2010; Ligneau-Hervé & Mullet, 2005; Phillips et al., 2011). In this study, we sought to examine how the ability to engage ToM capacities changes across the adult lifespan, and the degree to which this ability is influenced by individual differences and age-related changes in four executive functioning capacities (inhibition, working memory, cognitive flexibility, and planning). To address these aims, we employed an eye-tracked version of the referential communication perspective-taking task (the 'Director' task) in a large, community-based sample of 264 participants, spanning a continuous age range between 20 and 86 years old.

In line with our hypotheses, behavioural results showed that perspective-taking success declined with advancing age. Reaction times revealed an overall effect, whereby participants became slower to select the correct object as age increased throughout adulthood, in line with prior research indicating slower response times with advancing age (e.g., Bashore et al., 1997; Hultsch et al., 2002). More interestingly, analysis of response errors revealed that participants were increasingly likely to make egocentric errors (i.e., to select the hidden competitor object rather than the mutually available target object) in older age. Between 20 and ~37 years old, participants performed at ceiling levels in the ToM task, making very few egocentric errors. However, from ~38 years onwards, a decline in perspective-taking abilities was shown, with advancing age leading to increased likelihood of responding from an egocentric perspective in Listener-Only trials. These behavioural results support our hypotheses, indicating that older individuals experience more interference from the egocentric perspective than younger individuals. They are also in line with prior research that has shown a decline in social cognition abilities in older age, importantly highlighting that this decline can begin in middle age (from ~38 years onwards), well before the onset of traditional 'old age' (i.e. 65 years old; e.g., Bailey et al., 2008; German & Hehman, 2006; Phillips et al., 2011). Our results indicate that social cognitive abilities appear to undergo a gradual decline across middle and later adulthood that cannot be captured when comparing dichotomous younger and older age categories.

Analysis of online eye movement patterns corroborated this age-related decline in perspective-taking ability (and increase in egocentric interference). Overall, results revealed different time-courses of visual bias to the target/competitor objects in Shared-Perspective (i.e., the perspectives of the participant and director were matched) *versus* Listener-Only (i.e., conflict between the perspectives of the participant and director) conditions. Specifically, in Shared-Perspective conditions, participants showed a consistent and increasing preference to fixate the correct target object as the trial progressed, as expected in trials in which there was no perspective conflict. In contrast, in Listener-Only conditions, participants showed an initial *reduction* in fixations to the correct target object (i.e., they considered the hidden competitor object – *'the small candle'* – as the reference for the director's instruction), before showing a steep and consistent increase in fixations to the target object across the remainder of the trial. These results are consistent with prior literature in showing that even neurotypical adults experience interference from the egocentric perspective when considering another person's more limited perspective (e.g., Back & Apperly, 2010; Bradford et al., 2015; Ferguson et al., 2015; Keysar et al., 2000; Keysar et al., 2003). Importantly, analysis of eye movements revealed an age-related decline in perspective-taking abilities. As age increased, participants became significantly slower to fixate on the mutually available target object, as they experienced more interference from the hidden semantically relevant competitor object, and considered this object as a potential referent for the director's instruction. This effect was larger in the Listener-Only condition, where younger participants showed a significantly steeper increase in fixations to the target object over time compared to middle or older-aged participants (i.e., middle and older adults experienced more interference from the hidden competitor object). In other words, participants experienced greater levels of egocentric interference with advancing age, and took longer to orient their attention to the correct target object in the Director task.

Taken together, our results converge in showing that people become more egocentric across middle and later adulthood, thus demonstrating a much earlier onset of decline in perspective-taking abilities than is evident in prior research that has typically examined dichotomous groups of participants (e.g., younger vs. older adults). This finding fits with recent research that has observed relatively early declines in other social skills, including facial recognition (e.g., Norton et al., 2009), face processing (Germine et al., 2011), and general cognitive functioning (Hartshorne & Germine, 2015). For instance, Norton et al. compared the performance of young (<40 yrs), middle-aged (40-59 yrs), and elderly (>59yrs) adults on a face detection task. They found that the middle-aged group were moderately degraded in performance compared to the young group, with the elderly adults further degraded in task performance, supporting findings that declines in social cognitive abilities may begin in middle adulthood. These results highlight the importance of including middle aged adults when examining ageing effects, to allow understanding of not just whether declines occur with advancing age, but also *when* these declines begin to manifest across different social cognitive skills, and to what extent. The study presented here is one of the first to examine perspective-taking abilities with age as a continuous variable throughout adulthood, enabling a valuable examination of when changes in social cognitive capacities emerge, rather than comparing categorised age groups of participants. It is noted that there are limitations to this approach; longitudinal analysis would be required to assess the extent to which changes seen in the current data are due to age-related differences across individuals rather than cross-sectional differences (e.g., Lindenberger et al., 2011), and future research using a longitudinal sample would be valuable. However, within the scope of this study design, our data provides a more detailed understanding of how social cognition/ToM abilities change with advancing age, and when difficulties in these skills begin to impact processing, which in turn may provide insight into the need for targeted early-interventions to reduce the impact of declines in social cognition capacities across the lifespan.

Another question addressed in this paper was how perspective-taking abilities relate to more general executive functioning capacities (inhibition, working memory, cognitive flexibility, and planning abilities) at different ages. As expected, mediation analyses revealed that all four EFs showed an age-related decline, with task performance reducing in older age. This cognitive decline partially mediated the effect of age on perspective-taking abilities, for both behavioural (egocentric errors) and eye movement measures (egocentric fixation bias). Importantly, however, analyses showed that age remained a significant predictor of egocentric bias in the Director task when changes in EFs and IQ (full-scale) were controlled for, suggesting that, in this study, declines in social cognitive abilities with advancing age were independent of age-related declines in cognitive abilities. This is an important finding, revealing that changes in perspective-taking skills across adulthood may reflect specific declines in social cognition abilities, which are not merely reflective of domain-general declines in cognitive capacities, such as executive functions (c.f. Bailey & Henry, 2008; German & Hehman, 2006; Phillips et al., 2011). However, it is noted that some prior research has indicated limited coherence among tasks measuring ToM abilities (e.g., Warnell & Redcay, 2019); given this, the current results provide preliminary evidence that changes in perspective-taking skills across adulthood, as assessed by the Director task, are driven by effects over and above declines in general cognitive capacities, such as executive functions. Future research examining this the relationship between these executive functions and difference measures of social cognition abilities would further inform the extent to which these results may highlight domain-specific declines in social cognition capacities, versus task-specific declines.

The finding in the current study that inhibition and working memory abilities in particular did not significantly mediate ToM success across adulthood is surprising in light of previous studies that have found a relationship between working memory and inhibition and social cognition capacities (e.g., Bailey & Henry, 2008; Carlson & Moses, 2001; Maylor et al., 2002; Phillips et al., 2011), and recent theoretical models that have proposed a mediating role of EFs in successful social communication (e.g. Apperly & Butterfill, 2009; Butterfill & Apperly, 2013; Carruthers, 2016). It is possible that the Director task used here may not have placed sufficiently large demands on perspective-taking capacities for the mediating relationship between ToM abilities and executive functioning capacities to be captured. Indeed, previous research has demonstrated that egocentric tendencies on this task are elevated when cognitive load is increased by a secondary task (Cane et al., 2017; Mills et al., 2015). Interestingly, performance on the Tower of Hanoi task, a task that has been shown to index planning abilities, was associated with performance on the Listener Only trials of the Director task (i.e., levels of egocentric behavioural responses and eye movements). Frye (2000) proposed that planning capacities play a key role in determining successful ToM activation, in that individuals must reason and ‘plan’ appropriate actions given awareness of differing mental states. Conceptualised in this way, the importance of planning in facilitating participants’ success in the current task is clear (i.e., to identify and select the correct answer object, and move it to a new, specified location, which involves planning of motor actions and spatial configurations). However, as reported in our supplementary materials, a significant positive correlation was found between planning and working memory. This may indicate that the planning task utilized in the current study (Tower of Hanoi task) was tapping into capacities beyond ‘planning’, including elements of working memory. Additionally, previous research has rarely implicated planning in ToM task ability, or found significant relations between the two (e.g., Carlson et al., 2004). It is possible then that the effects of planning seen in the current study reflect task-specific cognitive skills (i.e. manipulating objects in a grid or spatial-reasoning skills involved in both tasks), rather than perspective-taking skills. It would be of interest in future research to examine whether other indices of planning abilities also lead to these outcomes, and whether this relationship extends to other aspects of perspective-taking abilities. In particular, future research would benefit from examining the extent of the potential relationship between planning and perspective-taking abilities, such as by manipulating task complexity and cognitive load, as well as response options.

The aim of the current study was to observe the impact of ‘healthy’ aging on perspective taking abilities, and how potential changes may relate to individual differences in executive functions at different ages. The participants for this study were recruited from a community-based sample, and it is notable that the older age participants (63-82 years) who took part in this study had higher IQ scores (full scale, verbal, and perceptual reasoning) than the younger (20-40 years) and middle (41-62 years) aged participants included in analysis. As is common in research examining healthy aging processes, this higher IQ may reflect that those who are experiencing ‘optimum’ healthy ageing may be more likely to take part in research studies such as the current project. Mediation analysis highlighted that this increased IQ with advancing age was indeed significant; however, despite the higher IQ associated with this group, the current study still established age-related declines in perspective-taking abilities, providing insight into changes in perspective-taking capacities as a part of healthy aging processes. It would be of further interest in future studies to examine age-related changes in individuals with lower IQ scores at these older ages, to provide insight into the extent to which IQ may play a protective role against the extent of age-related declines experienced. Additionally, the current study documents an age-related decline using the Director task as a measure of online perspective-taking abilities. Examination of task performance shows that during early adulthood, participants were performing at optimum levels, making very few errors. Future research into the extent to which age-related declines can be documented across different types of perspective-taking would further our understanding of the structure and development of perspective-taking capacities, including whether specific aspects of perspective-taking are influenced by age-related changes or whether these age-related declines can be differentiated based on the types of tasks used to assess different perspective-taking abilities.

Conclusion

Using a large sample of 264 participants, the current study examined changes in social cognition abilities across adulthood (20-86 years), and how individual differences in executive functions (inhibition, working memory, cognitive flexibility, planning) predict successful engagement of these ToM abilities. Results from the Director task revealed a steady decline in social cognitive abilities, reflected in both egocentric errors and eye movement measures. Importantly, this decline emerged earlier than is typically thought, from age ~38-years onwards. Mediation analysis further revealed that the direct effect of age (i.e., when controlling for age-related changes in executive functioning abilities and IQ) was significant, indicating that social cognitive skills as assessed using the Director task undergo age-related declines that are independent from established declines in executive functioning abilities seen in older age. Future work is needed to understand what factors contribute to these ageing effects – and to what extent they are shown across different measures of social cognition – as well as the implications that the declines seen in social cognition abilities may have on an adult's ToM performance in daily life.

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