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Tracking developmental differences in real-world social attention across adolescence, young adulthood and older adulthood

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Abstract

Detecting and responding appropriately to social information in one's environment is a vital part of everyday social interaction. We report two pre-registered experiments that examined how social attention develops across the lifespan, comparing adolescents (10-19 years old), young (20-40 years old) and older (60-80 years old) adults. In two real-world tasks, participants were immersed in different social interaction situations – a face-to-face conversation and navigating an environment – and their attention to social and non-social content was recorded using eye-tracking glasses. Results revealed that, compared to young adults, adolescents and older adults attended less to social information (i.e. the face) during face-to-face conversation, and to people when navigating the real-world. Thus, we provide evidence that real-world social attention undergoes age-related change, and these developmental differences might be a key mechanism that influences Theory of Mind among adolescents and older adults, with potential implications for predicting successful social interactions in daily life.

Keywords

Real-life social interactions; social attention; theory of mind; ageing; eye-movements

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M.D.L contributed to study design, data collection, data analysis and interpretation, drafting and revising the manuscript; R.F contributed to data collection and data coding; M.C.F contributed to data collection and data coding; A.S contributed to data collection and data coding; E.E.F.B contributed to drafting and revising the manuscript; C.W-H contributed to data collection; H.J.F conceived of the study, designed the study, data analysis and interpretation, and led on drafting and revising the manuscript. All authors gave final approval for publication.

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The authors declare no competing interests.

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Introduction

The ability to detect and respond appropriately to social information in one's environment is a vital first step towards social interaction. Successful social interaction requires us to make rapid inferences about others' mental states, such as their intentions, emotions, desires and beliefs, and is therefore contingent on theory of mind (ToM), perspective-taking and empathy, all of which are predictors of social competency, well-being and mental health[1,2, 3]. For example, detecting subtle changes in the facial expression of a conversation partner provides important information about how the interaction is going; monitoring these signals allows us to rapidly adapt our own behaviour to ensure that the intended message is understood. Social attention therefore lays the foundations for reciprocal social interaction[4] and may be a real-world indicator of ToM. Research has revealed that some basic attentional functions have an extended period of development into young adulthood, and deteriorate in older age in a way that cannot easily be explained by mere generalized cognitive slowing. For example, adolescents and older adults are slower and less accurate than young adults in performing visual-search tasks (e.g. [5, 6]) and are more susceptible to distracting information than young adults (e.g. [7, 8, 9]). These developmental differences in attentional functions are likely to have a significant impact on peoples' ability to understand their social world and the people within it, since disrupted attention restricts the available domain of information. In this paper, we use eye-tracking in immersive real-world environments to examine how social attention develops across the lifespan, from adolescence through to young and older adulthood.

ToM abilities show a steep developmental trajectory during early childhood, with the ability to distinguish self and other mental states emerging between the ages of 2 and 7 years old[10] and more complex reasoning for social communication developing around 9 years old (e.g. [11, 12, 13]). More recently, researchers have established that ToM continues to develop throughout adolescence and well into our twenties (e.g. [14, 15, 16, 17]) due to ongoing structural changes in the brain[18] and functional improvements in cognitive control[19, 20]. Thus, adolescents appear more egocentric (i.e. biased towards their own perspective) compared to young adults. Interestingly, adolescence is a period marked by particular sensitivity to the social environment[21], most notably an attentional shift in social orientation from family members to their same-aged peers[22] and increased self-awareness[23, 24]. To date no studies have examined how social attention is allocated during adolescence, and whether this differs from adulthood.

In contrast, social cognitive skills show a general decline in older age (e.g. [25, 26, 27, 28, 29]), with older adults experiencing particular difficulty attributing mental states to others[30]. Similar to adolescents, older adults show greater interference from their own knowledge than young adults, prioritising the egocentric perspective during perspective computation and experiencing particular difficulty switching away from this default view[31, 32, 33]. In addition, older adults use different visual scanning patterns for emotional faces compared to young adults[34, 35] and are not as sensitive to social gaze cues as young adults[36, 37]. These differences might impair older adults' ability to interpret others' mental states appropriately and therefore identify socially relevant information to guide communication[38]. However, it

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is not known how these difficulties with ToM might be reflected in a different allocation of real-world social attention in older age compared to young adulthood.

It is important to note that the majority of studies that have examined the development of social cognitive processing have been conducted in relatively tightly-controlled lab-based settings, in which individual participants merely observe other people in static images or dynamic videos; participants are not physically co-present in a social interaction[39, 40]. Although these lab-based designs have strengths in providing experimental control over stimuli, they are limited in ecological validity. Real-world social interaction and everyday use of social cognition is richer in detail and more nuanced than passively presented stimuli are able to convey[41, 42]. Moreover, some studies have revealed inconsistencies in social behaviours when they are tested in a typical lab-setting versus an unconstrained real-world social interaction (e.g. [43]). It is therefore unknown whether the difficulties that adolescents and older adults show in lab-based social cognition tasks are magnified in real-world situations due to the complex and dynamic cues available, or whether the situational context scaffolds more successful use of social interaction processes. Over the last decade, technologies have advanced with methods that allow us to assess social interaction in everyday, real-life situations.

In this paper we explore whether social attention differs across development, testing whether social attention shows the same patterns of impairment seen in ToM among adolescents and older adults compared to young adults. We adapted two tasks that have examined social attention in real-world interactive situations, using mobile eye-tracking technology. Freeth, Foulsham, and Kingstone[44] (see also[45]) monitored looking behaviours while young adult participants engaged in a semi-structured one-to-one conversation with an experimenter. Participants took turns with the experimenter to ask and respond to questions about general topics, such as plans for the weekend, and eye movements to the face, body and background were analysed while participants were speaking or listening. Results revealed a general preference to look at the experimenter's face, however social attention (i.e. fixations on the face) was higher when participants were listening compared to speaking, and attention to the non-social information (i.e. the background) was higher when speaking than listening. This pattern is interpreted as evidence that interlocutors found speaking more cognitively demanding than listening, and used gaze aversion as a means of reducing these processing costs to avoid distracting social information in the face (e.g. [46, 47, 48, 49]). Gaze also provides important cues to regulate interaction by signalling turn-taking[50, 51]. In another study, Foulsham, Walker and Kingstone[52] recorded young adult participants' gaze while they walked through a busy university campus. Contrary to lab-based studies that have shown a human predisposition to preferentially attend to social information[53, 54], the results from this naturalistic setting revealed that relatively few fixations were directed towards people (~22%) compared to other non-social information in the environment. This study therefore provides further evidence that social attention is reduced when participants are under additional cognitive demands (e.g. route-finding). Moreover, people were even less likely to be fixated when they were close to the participant, suggesting that participants adjusted their attentional focus as a means to deter social interaction (see also[55]).

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To date, no research has examined the lifespan developmental differences of social attention while people actively participate in real-world interactive situations. Nevertheless, some insights can be gained from studies that have eye-tracked young and old adults while they watch videos of other people interacting. For example, Vicaria, Bernieri and Isaacowitz[56] and Grainger, Steinvik, Henry, and Phillips[57] compared older and younger adults' gaze as they watched videos of two people discussing a controversial topic, then judged the rapport between the two protagonists or their mental states. Both studies showed that older adults spent less time fixating on the protagonists' faces compared to young adults, though this did not influence their ability to correctly judge rapport or understand their mental states. However, while the dynamic video stimuli and eye-tracking methods used by Vicaria et al. [56] and Grainger et al. [57] provide richer detail on changes in social attention with age, and identify some of the underlying mechanisms, they are still limited since participants are not actively engaged in a real-life social interaction. Moreover, none of these studies have included an adolescent group to assess early development.

The current study employed a pre-registered design with two real-world tasks that immersed participants fully in different social interaction situations. In the first task, participants engaged in a face-to-face conversation with an experimenter, similar to Freeth et al. [44], and in the second task, participants navigated through a busy building, similar to Foulsham et al. [52]. In both tasks, we recorded attention to social and non-social content of the environment unobtrusively using eye-tracking glasses. Crucially, we compared social attention in a large sample (N=268) across three age groups: adolescents (aged 10-19 years old), young adults (aged 20 to 40 years old) and older adults (aged 60 to 80 years old). Thus, the goal of the study was to test the general hypothesis, based on previous lab-based studies, that young adults would show enhanced social attention compared to both adolescents and older adults. Specifically, in the face-to-face conversation task we expected to replicate the basic effects from Freeth et al. [44]; overall participants would preferentially attend to social content in the environment, and this would be modulated by phase of the conversation (i.e. more looks to the experimenter's face while listening, and to the background while speaking). We also predicted that adolescents and older adults would make fewer fixations towards their social partner compared to young adults. In the navigation task we expected to replicate the basic effects from Foulsham et al. [52]; overall participants would make more fixations on non-social content (i.e. objects, map, path) than social content (i.e. people) in the environment. We also predicted that older adults would make fewer fixations towards people compared to adolescents and young adults, and instead would look more at non-social content. The enhanced social attention in adolescents relative to older adults was predicted in this task due to heightened awareness of the social environment and the people in it during adolescence.

In the face-to-face conversation task we included an additional measure of social attention by displaying three posters directly behind the experimenter, which either depicted social scenes including people (with either averted or direct gaze) or non-social scenes depicting nature. Previous lab-based research suggests that humans spontaneously attend to social content in scenes- that is, people like to look at other people[58, 59]. Thus we predicted that overall participants would make more fixations to the background posters depicting social scenes compared to the poster depicting a non-social scene. Moreover, research has distinguished social attention effects when agents in the scene use direct gaze (i.e. maintained eye contact with the participant) *versus* averted gaze, suggesting that direct gaze impairs concurrent cognitive processing (e.g. [60, 61, 62, 63]). Based on this research, we predicted that participants would be more likely to fixate the poster depicting a social scene with averted than direct gaze as a means of protecting cognitive resources. The current research provides an unusual test for the proposal that people/faces capture attention in real-life scenes, since these static images are presented alongside a real-life social partner, which is likely to disrupt normal social attention towards the posters.

Results

All analysis procedures were pre-registered, and the full datasets and analysis scripts are available on the Open Science Framework web pages (https://osf.io/fnd8h/). All statistical analyses were conducted in R version 3.6.1.

Face-to-face conversation

For the main analysis, fixations were analysed using a 3 x 2 x 3 mixed design ANOVA, crossing the between-subjects factor Age Group (adolescents vs. young adults vs. older adults) with the within-subjects factors Condition (speaking vs. listening) and AoI (face vs. body vs. background). Full statistical effects are reported in Table 1. Note that the main effects of Group and Condition, and the Group x Condition interaction are not meaningful in this analysis because proportions of fixations for each participant/condition summed to 1.

Results revealed a main effect of AoI, indicating that overall, participants distributed their attention differently towards the three AoIs. Follow-up analyses showed that participants spent a greater proportion of time fixating the experimenter’s face (M = .60) compared to either the background (M = .24; t(267) = 13.87, p < .001, d = 1.53) or the body (M = .15; t(267) = 17.55, p < .001, d = 1.94).

As expected, the Condition x AoI interaction was significant, showing that participants allocated their attention around the AoIs differently when speaking and listening. Follow-up analyses used t-tests to compare fixations for speaking and listening conditions separately for each AoI. As predicted, participants spent longer fixating the background while speaking (M = .36) compared to listening (M = .13, t(267) = 15.40, p < .001, d = .97), but spent longer fixating the experimenter’s face while listening (M = .71) comparing to speaking (M = .50, t(267) = 11.44, p < .001, d = .65). In addition, participants spent longer fixating the experimenter’s body while listening (M = .17) compared to speaking (M = .14, t(267) = 2.25, p = .03, d = .13).

Importantly, the Group x AoI interaction was significant, and was further subsumed under a 3-way interaction between Group, Condition and AoI. Follow-up analyses showed that the Group x AoI interaction was significant both while speaking, F(4, 530) = 3.81, p = .005, η_p^2 = .03, and listening, F(4, 530) = 6.24, p < .001, η_p^2 = .05. Therefore, we conducted separate 1-way ANOVAs for each AoI to compare fixations between age groups. Results for both listening and speaking conditions showed a significant difference between age groups on fixations to the experimenter’s face [listening: F(2, 265) = 8.24, p < .001, η_p^2 = .06;

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speaking: $F(2, 265) = 5.18$, $p = .006$, $\eta_p^2 = .04$] and the background [listening: $F(2, 265) = 9.06$, $p < .001$, $\eta_p^2 = .06$; speaking: $F(2, 265) = 4.52$, $p = .01$, $\eta_p^2 = .03$], but no effect of age group on fixations to the experimenter's body, Fs < .89, ps > .4. Planned contrasts showed that young adults looked longer at the experimenter's face compared to both older adults [listening: t(177) = 4.04, p < .001, d = .61; speaking: t(177) = 2.10, p = .04, d = .32] and adolescents [listening: t(186) = 2.69, p = .008, d = .41; speaking: t(186) = 3.34, p < .001, d = .48]. Young adults subsequently spent less time looking at the background compared to both older adults (this effect while speaking was only marginally significant) [listening: t(177) = 4.33, p < .001, d = .65; speaking: t(177) = 1.95, p = .053, d = .29] and adolescents [listening: t(186) = 2.79, p = .006, d = .43; speaking: t(186) = 3.17, p = .002, d = .46].

Posters

Fixations to the three posters were analysed using a 3 x 2 x 3 mixed design ANOVA, crossing the between-subjects factor Age Group (adolescents vs. young adults vs. older adults) with the within-subjects factors Condition (speaking vs. listening) and AoI (direct gaze vs. averted gaze vs. neutral). Full statistical effects are reported in Table 1.

Results revealed a main effect of AoI, showing that overall, participants distributed their attention differently between the three posters. Follow-up analyses showed that participants spent a greater proportion of time fixating the neutral poster (M = .03) compared to both the averted gaze poster (M = .02; t(267) = 2.59, p = .01, d = .22, and the direct gaze poster (M = .02; t(267) = 2.80, p = .005, d = .24). Thus, in contrast to research that shows attention capture by social information, participants here preferentially attended to posters that depicted non-social scenes compared to social scenes. The main effect of Condition confirmed that participants looked longer at the posters while speaking (M = .03) compared to listening (M = .01). Finally, the main effect of Group was significant, showing that young adults spent less time looking at the posters (M = .015) compared to both older adults (M = .024; t(177) = 2.19, p = .03, d = .33) and adolescents (M = .03; t(186) = 3.11, p = .002, d = .45). None of the interactions were significant. Figure 1 shows the proportion of time spent fixating each AoI in the speaking an listening condition during the face-to-face conversation task.

Navigating an environment

Fixations were analysed using a 3 x 4 mixed design ANOVA, crossing the between-subjects factor Age Group (adolescents vs. young adults vs. older adults) with the within-subjects factor AoI (map vs. objects vs. path vs. people). Full statistical effects are reported in Table 2. Note that the main effect of Group is not meaningful in this analysis because proportions of fixations for each participant summed to 1.

Results revealed a main effect of AoI. Follow-up analyses compared the proportion of fixations on social (i.e. people) vs. non-social stimuli (i.e. path, objects and map). Participants looked less at people in their environment (M = .05) compared to any of the other AoIs: path (M = .65; t(270) = 68.88, p < .001, d = 6.25), objects (M = .11; t(270) = 12.15, p < .001, d = .98), map (M = .19; t(270) = 15.61, p < .001, d = 1.52).

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The interaction Group x AoI was significant, and in line with our pre-registered analysis plan we conducted four one-way ANOVAs, testing for differences between the three age groups, separately for each AoI. These analyses showed that fixations to people were modulated by Age Group, $F(2, 268) = 5.67$, $p = .004$, $\eta_p^2 = .04$, as young adults spent more time looking at people ($M = .06$) compared to both older adults ($M = .04$, $t(180) = 2.80$, $p = .006$, $d = .42$) and adolescents ($M = .04$, $t(188) = 2.85$, $p = .005$, $d = .41$). Age Group also modulated the time spent fixating the map, $F(2, 268) = 4.40$, $p = .01$, $\eta_p^2 = .03$, as young adults spent less time looking at the map ($M = .17$) compared to older adults ($M = .22$, $t(180) = 2.99$, $p = .003$, $d = .45$), but did not differ compared to adolescents ($M = .19$, $t(188) = 1.53$, $p = .13$, $d = .22$). The effect of Group was not significant for any of the other AoIs ($ps > .05$). Figure 2 shows the proportion of time spent fixating each AoI in the navigation task.

Finally, given that the number of people encountered during the navigation task naturally varied between participants, and in fact showed a consistent difference across age groups (mean duration of people present, adolescents = 55.3sec, young adults = 84.5sec, older adults = 87.5sec), we conducted an exploratory analysis of fixations to people that took into account the time that people were visible in the environment. In other words, we recoded the scene camera video for each participant to determine the sum duration that people were visible in the scene, then calculated the proportion of time that each participant spent fixating people relative to their availability in the scene (i.e. sum duration of fixations to people / sum duration of people recorded by scene camera). We then analysed the data using a one-way ANOVA with the between-subjects factor Age Group (adolescents vs. young adults vs. older adults). Results, as shown in Figure 3, revealed that the three age groups differed in the time they spent fixating people, $F(2, 268) = 8.23$, $p < .001$, $\eta_p^2 = .06$. Post-hoc comparisons showed that young adults spent more time looking at people ($M = .11$) compared to older adults ($M = .05$, $t(180) = 3.92$, $p < .001$, $d = .54$), but did not differ compared to adolescents ($M = .11$, $t(188) = .27$, $p = .79$, $d = .04$). This finding suggests that the reduced attention to people among adolescents in the main analyses reflected a reduced availability of people in the environment, and that once this was controlled for, adolescents were comparably aware of their social environment and the people in it as young adults. Figure 3 shows the proportion of time spent fixating people in each age group in the navigation task, controlling for the time that people were visible in the environment.

Discussion

In this paper we sought to examine how social attention develops across the lifespan, from adolescence (aged 10-19 years old) through to young (aged 20 to 40 years old) and older (aged 60 to 80 years old) adulthood, by immersing participants in real-life social interaction situations and recording their eye movements using mobile eye-tracking glasses. In the first task, participants engaged in a face-to-face conversation with an experimenter, similar to Freeth et al. [44], and in the second task, participants navigated through a busy building, similar to Foulsham et al. [52]. This paper employs such ecologically valid methods to study real-world social interaction with physically co-present others across development, and directly compares social attention in adolescents and older adults with young adults.

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As such, the results provide insights into a potential mechanism for the diminished social cognitive abilities seen among adolescents and older adults compared to young adults.

In the face-to-face conversation task we replicated the basic effects from Freeth et al. [44] by showing that overall, participants preferentially attended to social content in the environment (i.e. the experimenter's face), but this was modulated by phase of the conversation (i.e. more looks to the experimenter's face while listening, and more looks to the background while speaking). More importantly, adolescents and older adults made fewer fixations towards their social partner's face compared to young adults, and in turn spent more time fixating the background compared to young adults. This reduced social attention to faces among adolescents and older adults is likely to be linked to more general reductions in social cognitive functioning, however it is also possible that the context of the face-to-face conversation task exacerbated these differences (discussed below). In addition, our incidental measure of social attention showed relatively few looks to the background posters (~7% of total fixation time); participants made more fixations to the poster depicting a non-social scene compared to either of the posters depicting social scenes (i.e. people with averted or direct gaze). This finding contrasts with previous lab-based research showing that humans spontaneously attend to static scenes that contain social content (i.e. faces/people; [58, 59]). Instead, it suggests that these basic attentional biases are overruled when a real-life social partner is prioritized for attention, and reinforces the notion that social attention effects in non-interactive settings do not necessarily generalize to real-world interactive settings. Moreover, the finding that young adults spent less time looking at all types of background posters compared to both adolescents and older adults reflects the young adult preference to fixate the experimenter's face, and suggests that the posters did not hold any special status for attention allocation in this live conversation context.

In the navigation task the main analyses replicated the basic effects from Foulsham et al. [52], showing that overall participants made more fixations on non-social content (i.e. objects, map, path) than social content (i.e. people) in the environment. More importantly, adolescents and older adults made fewer fixations towards people compared to young adults, and instead spent more time looking at the map. This pattern therefore complements results from the face-to-face task by providing further evidence that social attention is enhanced among young adults compared to both adolescents and older adults. However, our exploratory analyses took account of the time that people were available in the visual field and found that once availability of people was controlled for, only the older adult group exhibited reduced attention to people; adolescents and young adults were comparable. This difference is likely to reflect reduced availability of people in the environment when the adolescents completed the task, since many were restricted to out-of-school hours or school holidays when the University campus was less busy. Though this pattern requires further support in more controlled environments (i.e. where the number of people is held relatively constant across age groups), it provides valuable real-world evidence that adolescents are particularly sensitive to their social environment[21] and orient their attention to similar-aged peers[22].

The finding that real-world social attention peaked in young adulthood is consistent with lab-based studies that have observed an extended period of development through

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adolescence and an older-age decline in ToM abilities (e.g. [14, 26, 28, 29, 31, 64]). This could suggest that younger adults are more motivated to seek out people in their environment and understand their mental states. Lab-based research has also revealed that older adults experience a specific difficulty attending to social information when observing other people interacting[25, 56]. We show that this difficulty remains in older adults and adolescents when they are actively participating in a social interaction situation. Given that detecting social information in our environment and maintaining attention on it is an essential first step towards inferring other people's mental states, it is possible that social attention influences success in social interaction, and therefore diminished social attention may contribute to the impaired ToM seen in adolescents and older adults compared to young adults. Interestingly, the age-related differences in social attention seen here are relatively small in magnitude, with adolescents and older adults spending ~12% less time looking at the experimenter's face in the conversation task and ~2% less time looking at people in the navigation task compared to young adults. However, the impact of these small reductions in social gaze in adolescence and older adulthood is likely to be cumulative in dynamic social interaction situations. Attending less to people and their faces means that adolescents and older adults miss important cues about other peoples' mental states (e.g. their emotions, intentions, beliefs etc) that guide successful communication, and therefore may lead to larger impairments in social interaction, or less opportunities to engage in social interaction with others. Age-related difficulties in ToM mediate a substantial decline in social participation, which in turn leads to isolation, loneliness and poor health[65, 66]. It is therefore critical to further understand how social interaction develops across the lifespan.

These findings also mirror previous research in showing that people use social attention as a means of managing the cognitive effort involved in social interaction situations (e.g. [46, 47, 48, 49]). Here, participants reduced their attention to social aspects of the environment when processing costs were high; they looked less at the experimenter's face (and more at the background) when speaking (vs. listening), and spent a relatively low proportion of time (~5%) fixating people when navigating around an unfamiliar environment. This deliberate attenuation of social attention is further evidenced by looks to the background posters in the conversation task, where participants showed a clear preference to fixate the non-social neutral poster compared to either of the social scene posters, suggesting that when they allocated attention away from the experimenter's face they did so to avoid distracting social information.

Importantly, the finding that adolescents and older adults exhibited reduced social attention in both tasks, and instead were more likely to attend to non-social aspects of the environment, suggests that they experienced greater difficulty managing the cognitive effort of maintaining the conversation or route-finding compared to young adults. Since this pattern was observed both while speaking and listening in the conversation task, we can infer that even when cognitive load was reduced (i.e. while listening), adolescents and older adults found the social situation challenging to maintain and were therefore more likely to avoid the social information of the face than young adults. Indeed, previous research has shown that contextual information has a greater influence on social attention among older than younger adults (even when the context is irrelevant), which is interpreted as reflecting difficulty inhibiting information in older age[35, 67]. Thus, the age-related difficulties found

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in the current tasks are likely due to developing or declining cognitive control at each end of the lifespan (e.g. [68, 69, 70, 71]). It is notable that as a group, the older adult participants had higher IQ scores (full scale, verbal, and performance) than either the adolescent or young adult groups. These older adults were recruited from the local community, and it is likely that the cohort who were willing to take part in our research study were experiencing 'healthy' aging, and therefore had a higher IQ (as seen in[72]). Nevertheless, the fact that social attention showed significant declines in older age in both our tasks, despite preserved or even enhanced IQ, shows that IQ does not hold a protective role against age-related declines in social attention.

It is important to acknowledge some potential non-social factors which might have contributed to the reduced social attention observed here among older adults. First, it is possible that data quality and precision systematically differed across the three age groups, with data loss being particularly affected in the older adult group, and this resulted in differences in gaze behaviour without this actually being the case (see[73] for a similar argument and analyses comparing infants and young adults). Second, it is possible that the older participants experienced more difficulty walking (due to reduced motor capacities; [74]) or using the map to navigate[75], which in turn forced their attention away from the social environment and onto the path and map in front of them.

Although ecological validity is a strength of the current study, employing such unconstrained methods also raises some limitations. For example, people might alter their real-world looking behaviour while wearing eye-tracking glasses, as knowing that their gaze is being monitored makes them feel more self-conscious about where they are looking. The effect of being watched is likely to have a particular impact in looks to social content in our tasks, as participants avoid staring at other people to conform with cultural norms and as a means of reputation management. In line with this, Canigueral and Hamilton[76] revealed an 'audience effect' whereby people were less likely to look at their conversation partner, but more likely to act pro-socially, when they believed they were being watched live by the other person. In addition, we note that the number of people that participants encountered during the navigation task, and the context in which they appeared (e.g. individuals vs. groups), differed between participants due to factors such as time of day, stage of the academic year etc. We tried to control for these differences in our exploratory analyses that calculated fixation time on people relative to their availability in the scene, however since the scene camera on the eye-tracking glasses only records what is in the participants' direct field of vision (i.e. directly in front of them) it is not known whether more people were available in the environment but participants did not choose to orient their head to look at them. As such, it remains possible that lack of availability may have contributed to the overall low proportion of time spent fixating people in this task. Foulsham et al. [52] recorded social attention in an outdoor University setting and reported ~22% of gazes were on people, compared to ~5% in the indoor University setting here. Nevertheless, both studies showed the same general pattern that people made fewer fixations to people compared to either objects or the path.

More generally, it is likely that characteristics of the people in our real-world environments elicited in/out-group effects on social attention[77, 78, 79], and that these biases may have

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influenced age group effects. Specifically, the experimenters who led the face-to-face conversation were young adult females (aged ~25 years old), and the majority of people encountered in the navigation task were young adult students due to the campus University setting. Previous research has shown that an own-age bias enhances performance in a range of social perception tasks (e.g. [80, 81, 82, 83]), including heightened attention towards faces that are in the same age category as the perceiver (e.g. [80]), superior memory for faces of one's own age group[83], and enhanced eye-gaze following for own-age faces[82, 84]. Indeed, young adults may be more susceptible to these in-group biases than older adults[82]. In addition, age effects in social tasks have been shown to be moderated when older adults feel motivated to engage with age-relevant stimuli (e.g. [85, 86]). Previous research has also shown that social rank can influence attention to faces, as people direct their attention away from a higher-ranking person's eyes when they believe they are being watched[87]. Social rank effects might therefore have a particular influence on adolescents during the face-to-face conversation task due to the perceived higher social rank of the experimenter (i.e. older and more educated). Thus, further research is needed to systematically vary the social context to explore whether young adults' increased likelihood to fixate on the experimenter's face during the face-to-face conversation or to people in the navigation task reflects a general social processing advantage in this young adult group, or a more specific preference to look at people from one's own age group. Moreover, it will be important to understand whether social attention is allocated differently among adolescents and older adults when more own-age people are available in the environment. This is an especially interesting question during adolescence since this is marked as a normative period of social reorientation as adolescents establish greater independence and self-awareness, and are exposed to increasingly complex socio-emotional environments[22, 23, 24, 88, 89]. Understanding the factors that influence real-world social attention is a vital next step.

In conclusion, we have presented two pre-registered experiments, with a large sample, that immersed participants in real-life social interaction situations to examine developmental changes in social attention, from adolescence through to young and older adulthood. Results converged to show that social attention is enhanced among young adults compared to both adolescents and older adults; young adults spent more time looking at their conversation partner's face and more time looking at people in their environment, while adolescents and older adults attended more to non-social content. These results raise the possibility that developmental differences in social attention may be a key mechanism that leads to impaired ToM in adolescence and older adults, and suggest that these groups use gaze aversion as a means of managing the high cognitive demands of real-world social interaction. Critical questions remain over how the social context influences social attention and interaction.

Methods

All methodological procedures were pre-registered on the Open Science Framework (OSF) web pages (https://osf.io/qwz8m, https://osf.io/ktc8j) on 06.9.2018.

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Participants

A total of 293 participants, aged between 10-80 years old, were recruited for this study and tested throughout a two year period. Of this total sample, nine were excluded for having Montreal Cognitive Assessment (MoCA) scores below 23. In addition, in the face-to-face conversation task ten participants were excluded due to insufficient eye-tracking data and six participants were excluded due to technical issues. In the navigation task six participants were excluded due to insufficient eye-tracking data and seven participants were excluded due to technical issues. This resulted in a final sample of 268 participants in the face-to-face conversation task and 271 in the navigation task, each divided into three age groups (see Supplementary Appendix C, Supplementary Table 1 for participant details): adolescents (aged 10-19 years), younger adults (aged 20-40 years), and older adults (aged 60-80 years). We note that these sample sizes exceed those planned at pre-registration (i.e. N=240 for each task, 80 in each age group). This is because the data was collected as part of a larger longitudinal project, where a higher number of participants was required to reach the total desired sample size (due to drop outs at later stages of the project). We analysed the full available sample here to maximise the data from these valuable populations. Nevertheless, when the pre-registered sample size was used for analysis (i.e. only including the first N=80 per age group who completed the tasks), the patterns of results were replicated and none of the statistical results changed substantively (i.e. no p value changed from significant to non-significant)- see Supplementary Appendix C, Supplementary Tables 2, 3, 4, 5.

Participants completed these eye-tracking tasks as part of a larger task battery and were paid £50 for their time. All participants had English as their first language, vision that was normal or corrected-to-normal, and no diagnoses of neurological disorders, mental health or autism spectrum disorder. Participants were recruited from the local community using media adverts, word-of-mouth, and the Kent Child Development Unit. Sample size was pre-registered based on previous research, and constraints to complete the PhD. The Ethical Committee of the School of Psychology, University of Kent, U.K., approved the study, and informed consent was obtained for all participants.

Participant details, including mean age and gender balance for each of the three age groups, are presented in Supplementary Appendix C, Supplementary Table 1. There was a higher proportion of females vs. males in all age groups since they were likely to volunteer. Participants (if aged over 18) or parents of participants (if aged under 18) reported on their level of education, household income, and occupation (job title and industry) to produce a measure of socio-economic status (SES), with lower scores indicating lower SES. Occupational class was coded using the derivation tables provided by the Office for National Statistics (ONS, 2017). In addition, IQ was assessed using the Wechsler Abbreviated Scale of Intelligence – Second Edition (WASI; [90]), cognitive dysfunction was screened using the Montreal Cognitive Assessment (MoCA; [91]), and autistic traits were screened using the Autism Quotient-10 (AQ-10; [92]). Two participants in the young group did not complete the WASI assessment, therefore these scores are not reported in Supplementary Appendix C, Supplementary Table 1.

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Face-to-face conversation

In this task, participants engaged in a semi-structured conversation with the experimenter while wearing the eye-tracking glasses, similar to Freeth et al. [44]. The conversation tapped general topics, such as plans for the weekend or hobbies. In the first part, the experimenter asked four questions (e.g. “Tell me about some things that you did last weekend and some things that you plan to do next weekend” or “Describe a few things you consider to be typically English and a few things you consider to be typically American”) that were designed to prompt the participant to speak for approximately 30s (see Supplementary Appendix A for the full set of questions); this was defined as the Speaking phase. The experimenter prompted the participant to continue talking if necessary and responded naturally to participants’ responses to facilitate the flow of conversation. In the second part, the participant and experimenter switched roles, and the participant now asked the same questions to the experimenter and listened to their answers; this was defined as the Listening phase. Replicating the protocol from Vabalas and Freeth[45] the Speaking phase was always followed by the Listening phase. The experimenter sat in a chair opposite the participant, approximately one metre away, and tried to engage naturally with the participant while speaking and listening (i.e. made direct eye contact, used hand gestures, etc). Verbal responses were recorded through a microphone integrated into the glasses. This task lasted ~10 minutes on average.

As an additional measure of social attention, we displayed three posters directly behind the experimenter (see Supplementary Appendix B). Two of these posters depicted social scenes- a group of young adults either with averted gaze (i.e. looking at each other) or direct gaze (i.e. looking towards the participant), and one poster depicted a non-social scene (i.e. a scene from the local area with no people). All posters were the same size and their position on the wall was counterbalanced across the participants. Two sets of images were used for each condition (please contact the authors for the full set of images).

This resulted in a mixed design, crossing the between-subjects factor Age Group (adolescents vs. young adults vs. older adults) with the within-subjects factors Condition (speaking vs. listening) and AoI (face vs. body vs. background) for eye movements during the face-to-face conversation. In a separate analysis, eye movements towards the background posters were tested in a mixed design that crossed the between-subjects factor age Group (adolescents vs. young adults vs. older adults) with the within-subjects factors Condition (speaking vs. listening) and AoI (direct gaze vs. averted gaze vs. neutral). Analyses were conducted on the proportion of fixations on each AoI during this conversation task, separately for face-to-face AoIs and for the background posters.

Navigating an environment

This task adapted the real-world navigation task used in Foulsham et al. [52]. Participants were asked to complete a short independent task, to walk from the lab to College reception to collect a leaflet, and walk back. They were given a map of the building and some basic instructions to ensure that they walked through similar environments, but were told they could take the route of their choice (see Supplementary Appendix B). This task involved

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a walk of 5-10 mins inside a building environment that featured objects, signs, and other people. The experimenter followed participants from a distance.

This resulted in a mixed design that crossed the between-subjects factor Age Group (adolescents vs. young adults vs. older adults) with the within-subjects factor AoI (map vs. objects vs. path vs. people). Analysis was conducted on the proportion of fixations on each AoI during this navigation task.

Eye-tracking recording and analysis

Real-life eye movements were recorded using SMI mobile eye-tracking glasses. These glasses include a front-facing camera to record a video of the scene from the participant's perspective (field of view: 60° horizontal, 46° vertical; resolution: 1280 x 960pixels). Binocular eye movements were recorded at a sample rate of 60Hz (with 0.5° accuracy). If necessary, corrective prescription lenses could be attached to the eye-tracking glasses. Participants were fitted with the eye-tracking glasses and completed a 3-point calibration and validation procedure before each real-world task.

SMI BeGaze analysis software (3.7.59) was used to manually code the fixation data for analysis on a frame-by-frame basis. Since the scene camera view changed every time the participant moved their head, areas of interest (AoIs) were dynamic and defined by the experimenter for the fixation on every frame, rather than based on static AoIs on a single scene. This allowed us to calculate a sum duration of fixations on each AoI (excluding saccades and blinks), then calculate the proportion of time spent fixating each AoI relative to the sum duration of time spent fixating all AoIs for that participant/task. Calculating the proportion of fixation times rather than sum fixation times controls for differences in total task duration across participants (e.g. some participants might talk for longer than others during the face-to-face conversation, which increases the time available to fixate social content in the scene). Indeed, examining the recording duration for each age group showed that adolescents, young adults and older adults differed in the average time they took to complete the face-to-face conversation task (Ms = 10.99 mins vs. 10.55 mins vs. 11.51 mins respectively) and the navigation task (Ms = 9.24 mins vs. 8.63 mins vs. 9.52 mins respectively). For completeness, mean duration of fixations to each AoI (i.e. the absolute data) are provided in Supplementary Appendix C, Supplementary Tables 6, 7 and 8.

For the face-to-face conversation task, fixations during the verbal responses were assigned to one of six AoIs: the experimenter's face, body, background, direct gaze poster, averted gaze poster, neutral poster (see Supplementary Appendix B). We note that our pre-registration proposed to code fixations on face features separately from other face parts. We chose to combine these AoIs into a single face area since i) our predictions did not distinguish effects on these two parts of the face, ii) defining fixations on face features vs. other face parts was often subjective as the experimenter and participant's head moved during the conversation, and iii) previous studies have coded the face as one AoI (e.g. [44]). The background AoI was defined as any area in the scene except for the experimenter; fixations to the three posters were added to the background AoI for the main analysis and analysed in isolation for the poster analysis. For the navigation task, fixations were assigned to one of four areas of interest (AoIs): path, map, objects, people (see Supplementary Appendix B). The path

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was defined as the ground and walls ahead of the participant, the map was the printed map participants were given to guide their route, objects included signs and leaflets, and people included looks to the experimenter and any other people that participants encountered on route.

Since assigning fixations that are made on a boundary of two AoIs can be a subjective decision for the coder, we conducted an additional analysis in which 10% (N=27) of the eye-tracking data was double coded by two independent coders (blind to each others' coding). Pearson's correlations were used to estimate inter-coder reliability on the proportion of fixation time allocated to each AoI in each task (irrespective of age group or condition). This analysis revealed a very strong correlation between coders on both the face-to-face conversation task (rs > .93, ps < .001) and the navigation task (rs > .86, ps < .001), thus demonstrating the high reliability of AoI assignment in our data.

Finally, eye-tracking data was analysed to check that data quality was comparable across the three age groups. To this end we calculated two measures of data quality by summing 1) the total number of fixations and 2) the total duration of fixations recorded for each participant in each task (collapsed across AoIs). We then ran one-way ANOVAs to assess whether group differences existed in the number of missing data points or quality of data. These analyses confirmed that the three age groups did not differ in the total number of fixations or the total duration of fixations (see Supplementary Appendix C, Supplementary Table 9), and therefore suggest that data quality was comparable between age groups.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Data availability

Data are available on Open Science Framework (OSF) web pages (https://osf.io/fnd8h/).

Code availability

Data analysis was conducted using R (v.3.6.1). Code are available on Open Science Framework (OSF) web pages (https://osf.io/fnd8h/).

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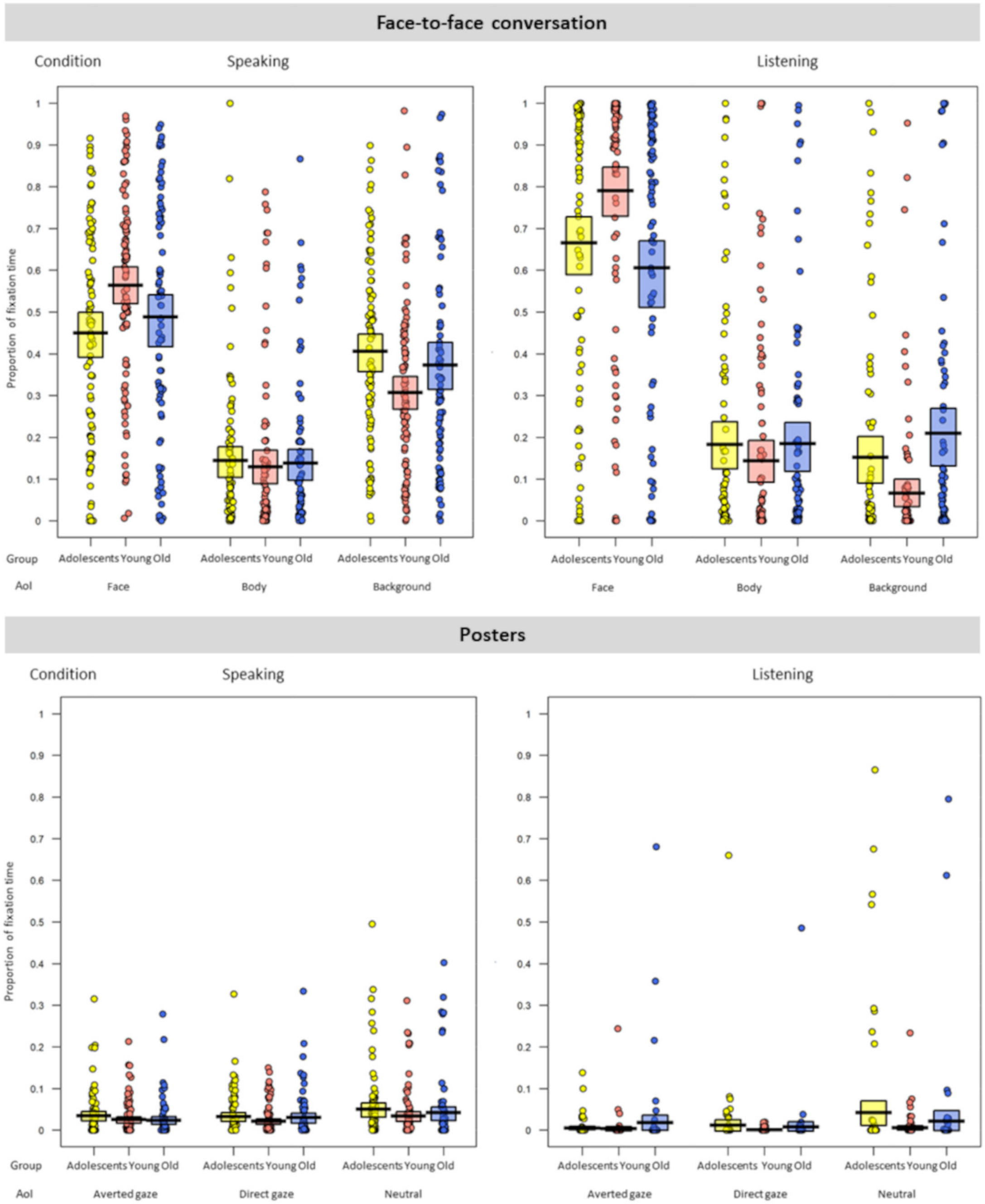

Figure 1. The proportion of time spent fixating each AoI in each condition and age group in the face-to-face conversation task.

The plots show raw data points, a horizontal line reflecting the condition mean, and a rectangle representing the Bayesian highest density interval. The top panels show the proportion of time spent fixating face features, body and background in the main analysis, and the bottom panels show the proportion of time spent fixating posters depicting averted gaze, direct gaze and a neutral (non-social) scene.

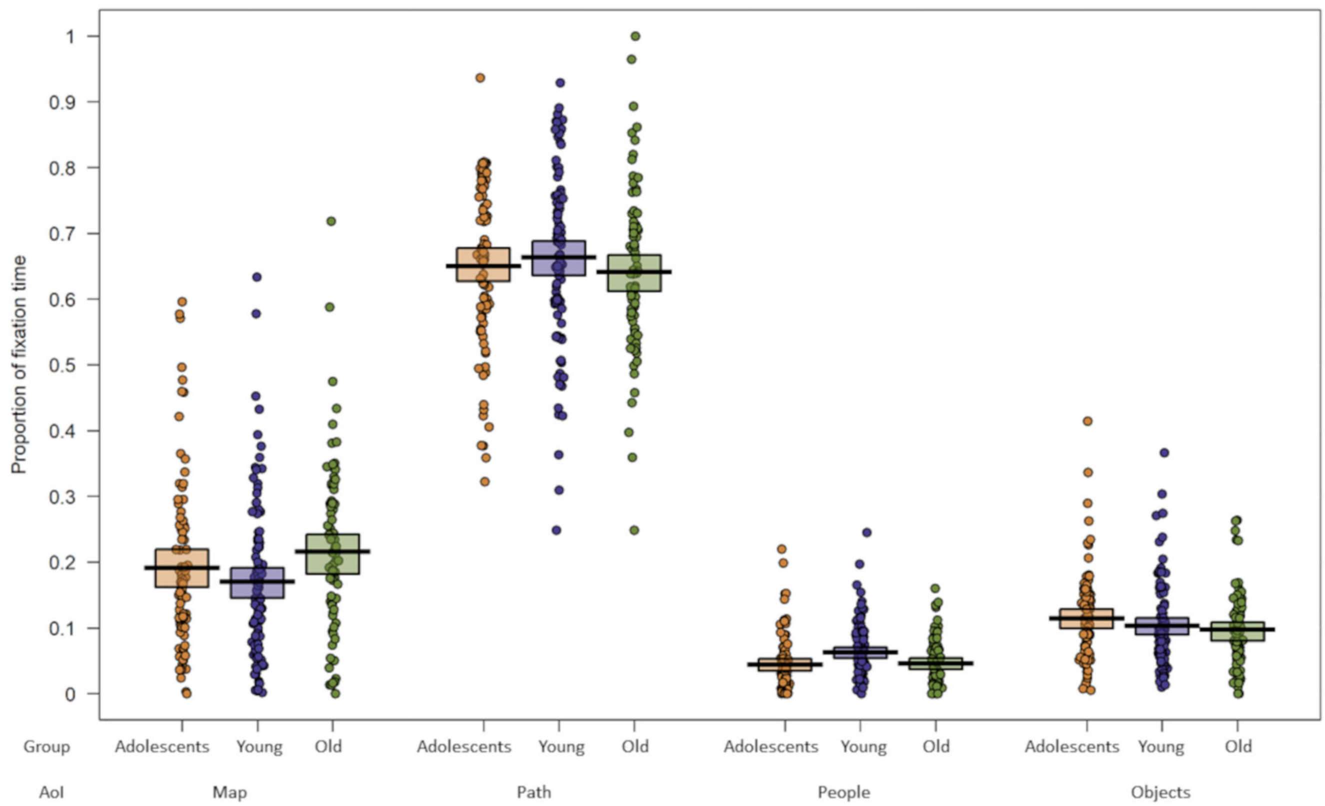

Figure 2. The proportion of time spent fixating each AoI in each age group in the navigation task.

The plot shows raw data points, a horizontal line reflecting the condition mean, and a rectangle representing the Bayesian highest density interval.

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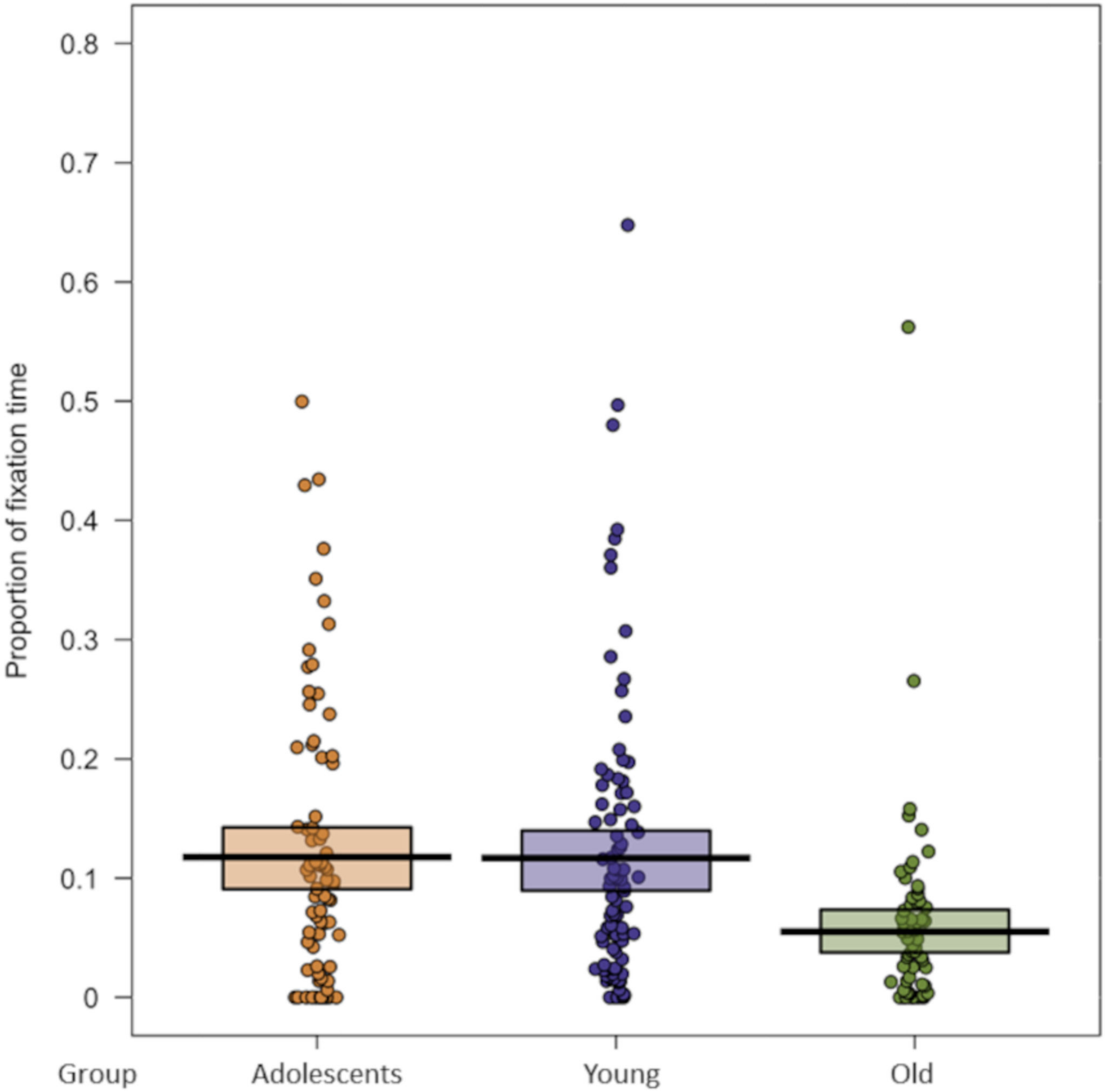

Figure 3. The proportion of time spent fixating people in each age group in the navigation task, controlling for the time that people were visible in the environment.

The plot shows raw data points, a horizontal line reflecting the condition mean, and a rectangle representing the Bayesian highest density interval.

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Table 1

Statistical effects for proportion fixation durations in the main face-to-face conversation task and to the posters. Asterisks show significance of effects, where * p < .05; ** p < .01; *** p < .001.

	Df	F	p	η_p^2
Face-to-face conversation				
Group	(2, 265)	<.001	1	< .001
Condition	(1, 265)	<.001	1	< .001
AoI	(2, 530)	203.62	< .001***	.44
Group x Condition	(2, 265)	< .001	1	< .001
Group x AoI	(4, 530)	5.98	< .001***	.04
Condition x AoI	(2, 530)	128.71	< .001***	.33
Group x Condition x AoI	(4, 530)	3.18	.01**	.02
Posters				
Group	(2, 265)	4.73	.01*	.03
Condition	(1, 265)	47.60	< .001***	.15
AoI	(2, 530)	6.28	.002**	.02
Group x Condition	(2, 265)	.52	.59	< .01
Group x AoI	(4, 530)	.98	.42	< .01
Condition x AoI	(2, 530)	.07	.93	< .01
Group x Condition x AoI	(4, 530)	1.88	.11	< .01

Table 2

Statistical effects for proportion fixation durations in the navigation task. Asterisks show significance of effects, where ** p < .01; *** p < .001.

	Df	F	p	η_p^2
Group	(2, 268)	.01	1	< .01
AoI	(3, 804)	1494.41	< .001***	.85
Group x AoI	(6, 804)	3.01	.006**	.02

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