Attentional biases in free viewing of complex scenes in preschoolers and adults

Marcel Linka[1*], Özlem Sensoy[2], Harun Karimpur[1], Gudrun Schwarzer[2], Benjamin de Haas[1]

[1] Department of Experimental Psychology, Justus-Liebig-Universität Giessen, 35394 Giessen, Germany

[2]Department of Developmental Psychology, Justus-Liebig-Universität Giessen, 35394 Giessen, Germany

Corresponding author:

***Marcel Linka**

Justu- Liebig-Universität Giessen

Department of Experimental Psychology

35394 Giessen

Germany

marcel.linka54@gmail.com

Abstract

Adult gaze behaviour towards naturalistic scenes is highly biased towards semantic object information. Little is known about the ontological development of these biases, nor about group-level differences in gaze behaviour between adults and pre-schoolers. Here, we let pre-schoolers (*n* = 34, 5 years) and adults (*n* = 42, age 18-59 years) freely view 40 complex scenes containing objects with different semantic attributes to compare their fixation behaviour. Results show that preschool children allocate a significantly larger proportion of dwell time towards *Faces*, *Touched* objects, *Hands* and objects with implied *Motion*, but significantly less on *Text*. Interestingly, fewer first fixations of pre-schoolers landed on either *Faces* or *Text*, but more on *Touched* objects, *Hands* and *Bodies*. Follow up analyses excluding *Text* fixations revealed attentional biases towards *Touched* objects and *Hands* in children vs. adults. These findings suggest a developmental antagonism between text and touched objects-hand salience, which would resonate with recent findings regarding ‘cortical recycling’. We discuss this and other potential mechanisms driving salience differences between children and adults.

Introduction

To process visual information at high resolution, we constantly have to move our eyes. The periphery of the visual field suffers from crowding and lack of acuity, implying the need to prioritise certain areas in a scene over others[1,2]. How does the oculomotor system decide these priorities? Does it learn them over time? And if so, how do they change across the lifespan?

Visual salience in adults

The past 25 years have seen extensive attempts to predict adult gaze behaviour based on the content of a visual scene. Two types of scene features have emerged as particular relevant, namely low-level features such as the local contrast in orientation, intensity and color[3,4] and high-level features such as faces and text[5]. High-level features have been found to be substantially more predictive of gaze behaviour towards natural scenes than their low-level counterparts. For instance, objects[6,7] as well as Faces, Text, Touched objects and Motion[5, 8] are highly salient for adult observers, outweighing low-and mid-level features in complex scenes[5,9]. These shared attentional biases towards certain semantic features are complemented by large and reliable individual differences in their degree [10,11]. Moreover, some gaze biases seem to be particularly pronounced among observers with specific perceptual abilities or challenges. For instance, patients with autism spectrum disorder (ASD) spend less time fixating faces and social features compared to controls[12,13]. And super-recognizers - people with exceptional abilities for processing facial identity information - spend more time fixating faces and less time focussing on touched objects and text[14].

The development of visual salience

While high-level salience of semantic features has been studied extensively for adults, much less is known about its development. A notable exception is face salience. Infants show a visual preference for face-like dot patterns over inverted patterns very early on[15,16]. In fact, recent evidence points to increased behavioural responses to such face-like stimuli by human foetuses during the third trimester of pregnancy[17]. This contributes to a long-standing debate on the question whether human attentional biases towards faces are driven by innate mechanisms[16,18]. In the course of infancy, this attentional bias develops into a more differentiated preference for faces over mere face-like stimuli[19] and non-face objects in complex scenes[20-22]. Aside from faces, infants also show gaze biases towards other socially relevant stimuli. For example, Frank, Vul, & Saxe let 3-30-month-old infants freely view videos of complex social scenes and found that infants spent a larger proportion of dwell time fixating hands when a depicted scene turned socially complex[23]. This effect was positively correlated with age, suggesting that throughout infancy, gaze allocation becomes increasingly tuned to socially relevant visual information. This bias for social information might go hand in hand with an early visual sensitivity for biological motion in (new born) infants[24]. More recent work shows that a visual preference for implied motion in static stimuli might emerge already at around 5 months of age[25,26]. As with adults[10, 27], the degree of attentional biases towards social information varies reliably among infants and school-aged children and is highly heritable[12,28].

Fewer studies have investigated the development of attentional biases beyond three years of age. Açık et al. have looked at free-viewing behaviour towards complex scenes across three age groups (7-9-year-old children, 19-27-year-old adults, and >72-year-olds) and showed a drop of low-level saliency with age[29]. Further, Helo et al. compared free-viewing behaviour of adults with those of children between 2-10 years and found that saccadic amplitudes increased and fixation duration decreased as a function of age[30]. These studies suggest that gaze behaviour towards complex scenes changes from preschool/school age to adulthood, shifting from fixating more local, low-level features like luminance contrasts and orientation, to more global, explorative viewing behavior. However, more recent work predicting gaze behaviour in children (age 6-14) and adults showed that a face-based model outperformed (low-level) saliency models in predicting gaze towards complex scenes, even in the youngest age group. The face-based model however was more predictive for gaze behaviour of adults than children[31]. This suggests that gaze behavior is more attracted to faces than to low-level features and that this face preference increases with age. Whether and to which degree children in this age group show visual preferences towards other semantic features which are highly salient for adults (i.e. text, touched objects and implied motion) is largely unclear.

Taken together, we know of distinct semantic information that guides viewing behaviour in adults and infants. Gaze behaviour in older children seems to differ significantly from adults in terms of low-level salience and oculomotor traits, such as saccadic amplitudes and fixation duration[29, 30]. However, just as for adults, the gaze behaviour of children is better predicted by high-level semantic information compared to low-level features[5, 31]. Although we know of qualitative differences in semantic salience in adults and infants, it is unclear whether and how gaze behaviour towards semantic information differs between preschool children and adults. The relevance of this question is underscored by the finding that selective attention develops significantly during later childhood, especially between 4 and 7 years of age[32].

Understanding whether and how gaze behaviour in children is drawn towards semantic content can have important implications. Abnormal gaze behaviour towards faces has been found in infants and children with ASD[33,34]. Insights on semantic gaze biases in healthy children may help establishing a normative baseline to test the diagnostic potential of gaze behaviour for neurodevelopmental disorders. Moreover, given the increasing exposure of children to screen-based education, understanding their attentional biases may help in the design of efficient learning material.

The present study

In the present study we investigated gaze behaviour towards 40 complex scenes in 5-year-old pre-schoolers and adults. In particular, we tested whether and to what extend children compared to adults differ in their proportions of (1) dwell time and (2) first fixations towards objects of multiple semantic categories depicted in these scenes, namely *Faces*, *Text*, *Motion* and *Touched objects*. Here, first fixations refer to the landing position of the first saccade after image onset. We chose these dimensions because of their importance for predicting adult gaze behaviour. Moreover, we have previously found that individual gaze tendencies along these dimensions can be tested reliably with this small stimulus set[5, 10, 11]. The very recent publication of additional pixel masks and meta data for this stimulus set[35] further allows the quantification of fixation biases towards *Bodies* and *Hands* depicted in the scenes.

Results

First, we investigated whether children vs. adults show differences in their proportions of cumulative dwell time spent on *Faces*, *Text*, *Touched* objects and objects with implied *Motion*. Figure 1 shows example heatmaps of cumulative dwell times for both groups. Figure 2 shows the distributions of cumulative dwell time proportions for children and adults respectively for each of the four semantic dimensions.

Dwell time towards semantic categories between children and adults

Results showed that children spent a significantly larger proportion of their dwell time on *Faces*, $t(74) = 2.06$, $p = 0.043$, and objects with implied *Motion*, $t(74) = 3.37$, $p = 0.002$, compared to adults. Further, we found that the proportion of cumulative dwell time children spent on *Text* was reduced fivefold compared to adults $t(74) = -14.59$, $p < 0.001$. Finally, children spent a significantly larger proportion of dwell time on *Touched* objects than adults, $t(74) = 4.30$, $p < 0.001$.

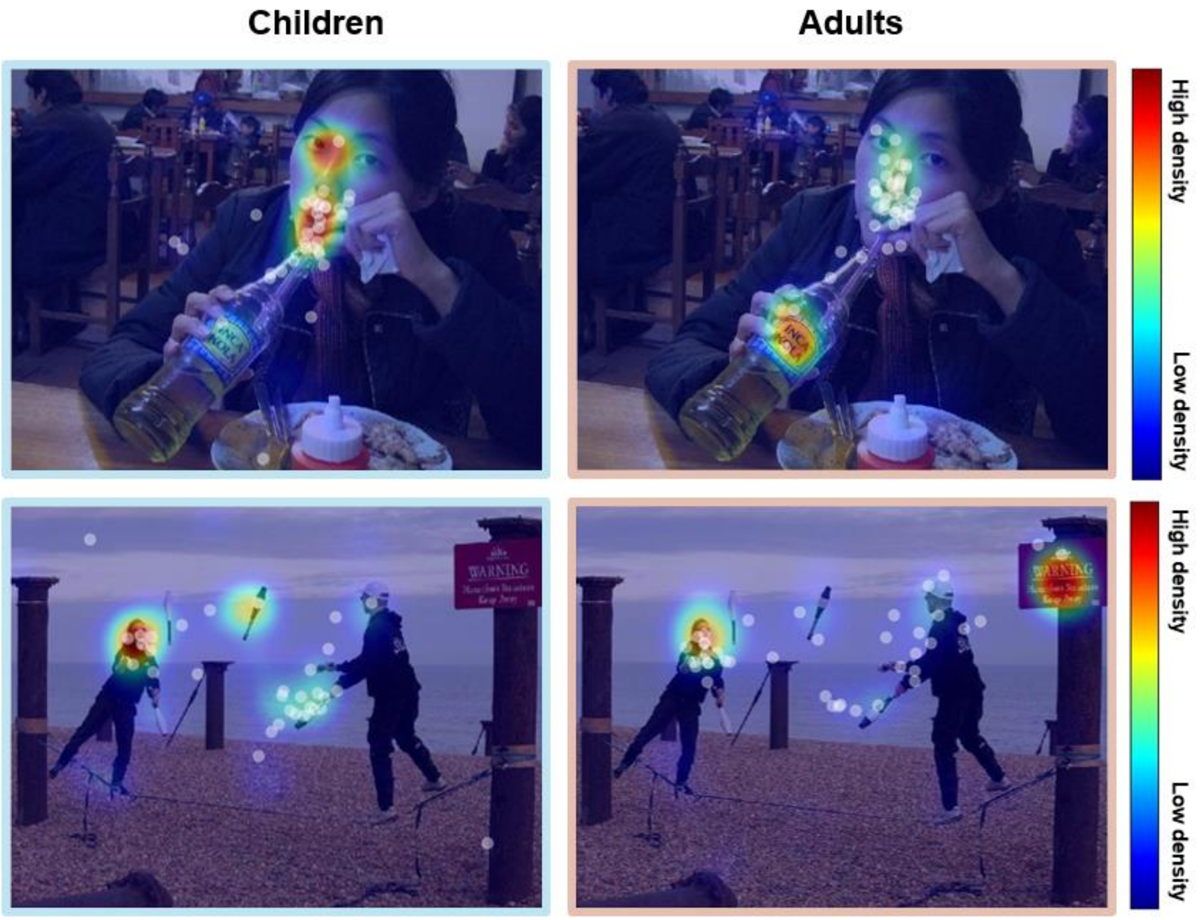

Figure 1**. Heat maps showing group-wise fixations for two example images**. Heat maps on the left-hand side show duration weighted fixation data from children, maps on the right-hand side show fixations from adults. The transparent white scatters show all first fixations towards the image by all subjects of the respective group.

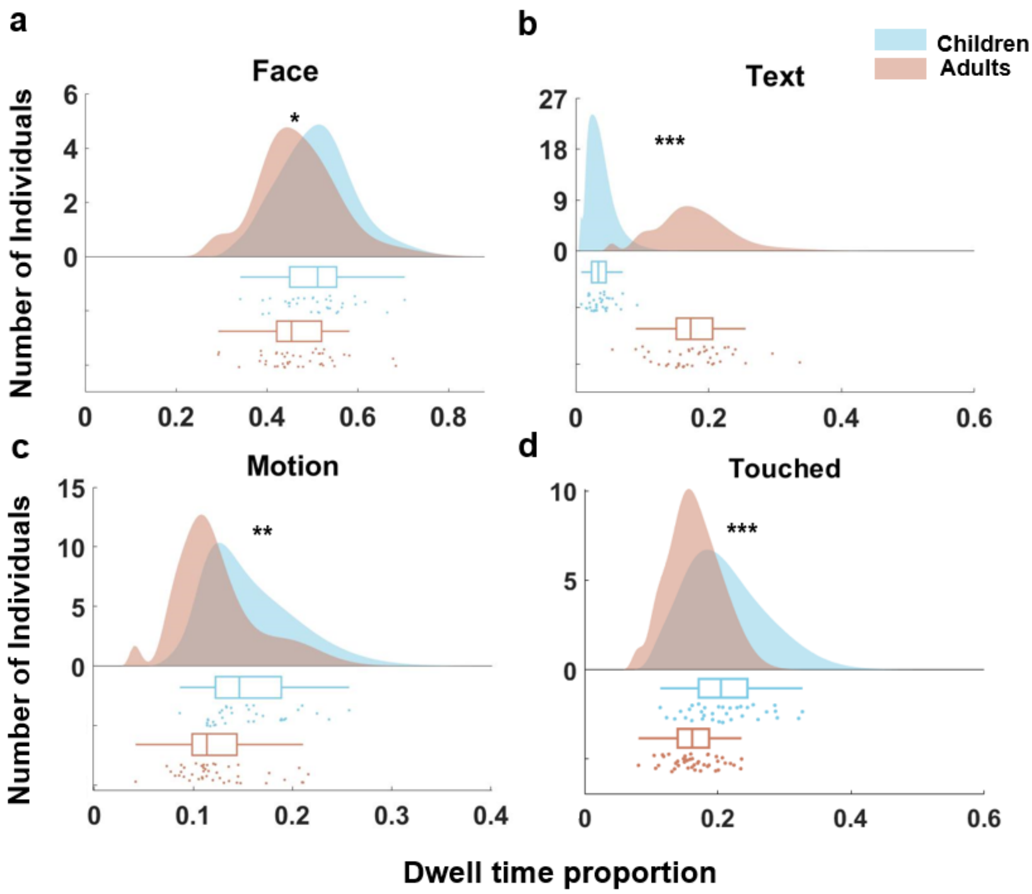

Figure 2. **Differences in visual saliency between children and adults.** Density plots showing the probability distribution of cumulative dwell time proportion towards objects of the dimensions *Face* (a), *Text* (b), *Motion* (c) and *Touched* (d) respectively for children (blue) and adults (red). Data points below the distributions indicate the individual dwell time proportion. Box plots depict the summary statistics for each dimension and group. For a respective box plot, the vertical line indicates the mean cumulative dwell time proportion. The left side of the box indicates the 25th percentile and the right side the 75th percentile. The whiskers represent the minimum and maximum values. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$ (Holm-Bonferroni corrected; see Methods)

First fixations towards semantic categories between children and adults

Moreover, we tested whether children and adults differ in their proportion of *first* fixations towards *Faces*, *Text* and *Touched* objects, that is the proportion of saccades immediately after image onset landing on objects from these categories. Previous results have shown that this tendency cannot be reliably estimated for *Motion* using our stimulus set[11] and we therefore dropped this dimension for this analysis. Figure 3 shows the distributions of first fixation proportions for children and adults. Findings show that children directed a significantly smaller proportion of first fixations towards *Faces*, $t(74) = -3.05$, $p = 0.003$ and *Text*, $t(74) = -5.75$, $p < 0.001$. Further, children directed a significantly larger proportion of first fixations towards *Touched* objects, $t(74) = 4.53$, $p < 0.001$.

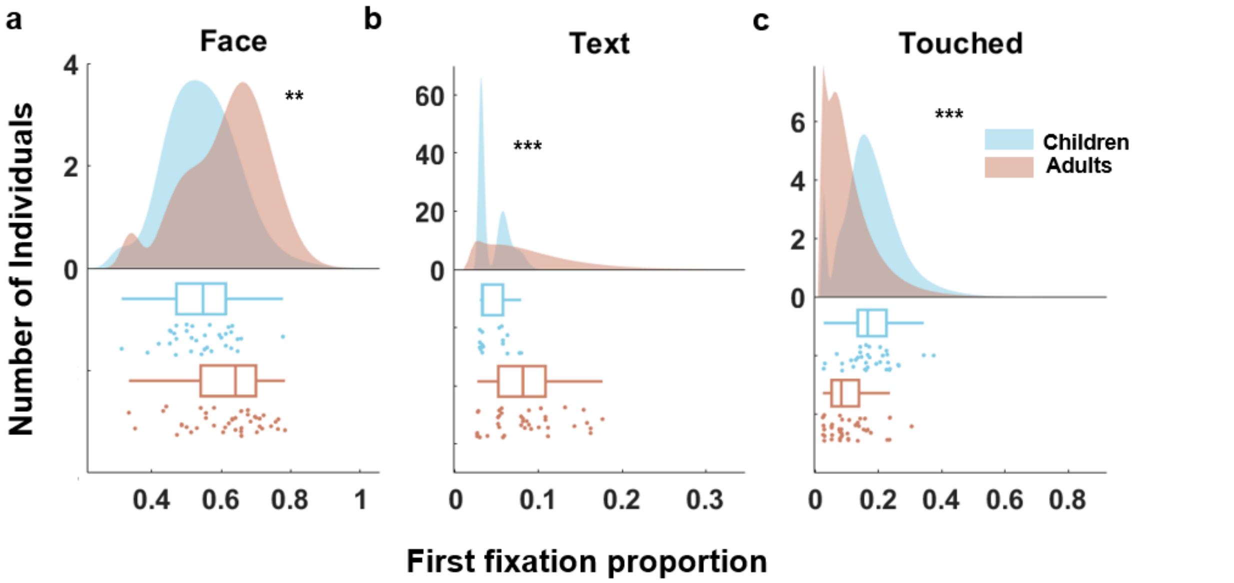

Figure 3. **Differences between children and adults in first fixation proportion for semantic dimensions.** Density plots show the probability distribution of first fixation proportion towards *Faces* (a), *Text* (b) and *Touched* objects (c) respectively for children (blue) and adults (red). Box plots below show an overview of the summary statistics for each group and semantic dimension; the vertical line within a respective box represents the mean value. The left side of a box indicates the 25th percentile and the right side the 75th percentile. The whiskers represent the minimum and maximum values. Data points represent the individual corresponding first fixation proportions. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$ (Holm-Bonferroni corrected; see Methods)

Visual salience towards hands and bodies

Given enhanced fixation tendencies towards *Faces* and *Touched* objects in children and recent findings on fixation tendencies in adults[35], we additionally tested whether similar effects would emerge for *Hands* and *Bodies* (with the latter excluding hands). Figure 4 shows the distributions of cumulative dwell time (a, b) and first fixation (c, d) proportions spent on *Hands* and *Bodies* for children and adults. Children did not differ from adults in the proportion of dwell time spent on *Bodies*, $t(74) = 0.75$, $p = 0.458$), but spent a significantly larger proportion of dwell time on *Hands* ($t(74) = 2.79$, $p = 0.013$). Moreover, children spent a larger proportion of first fixations on *Hands* and *Bodies* compared to adults (*Hands*: $t(74) = 2.83$, $p = 0.012$, *Bodies*: $t(74) = 2.40$, $p = 0.018$).

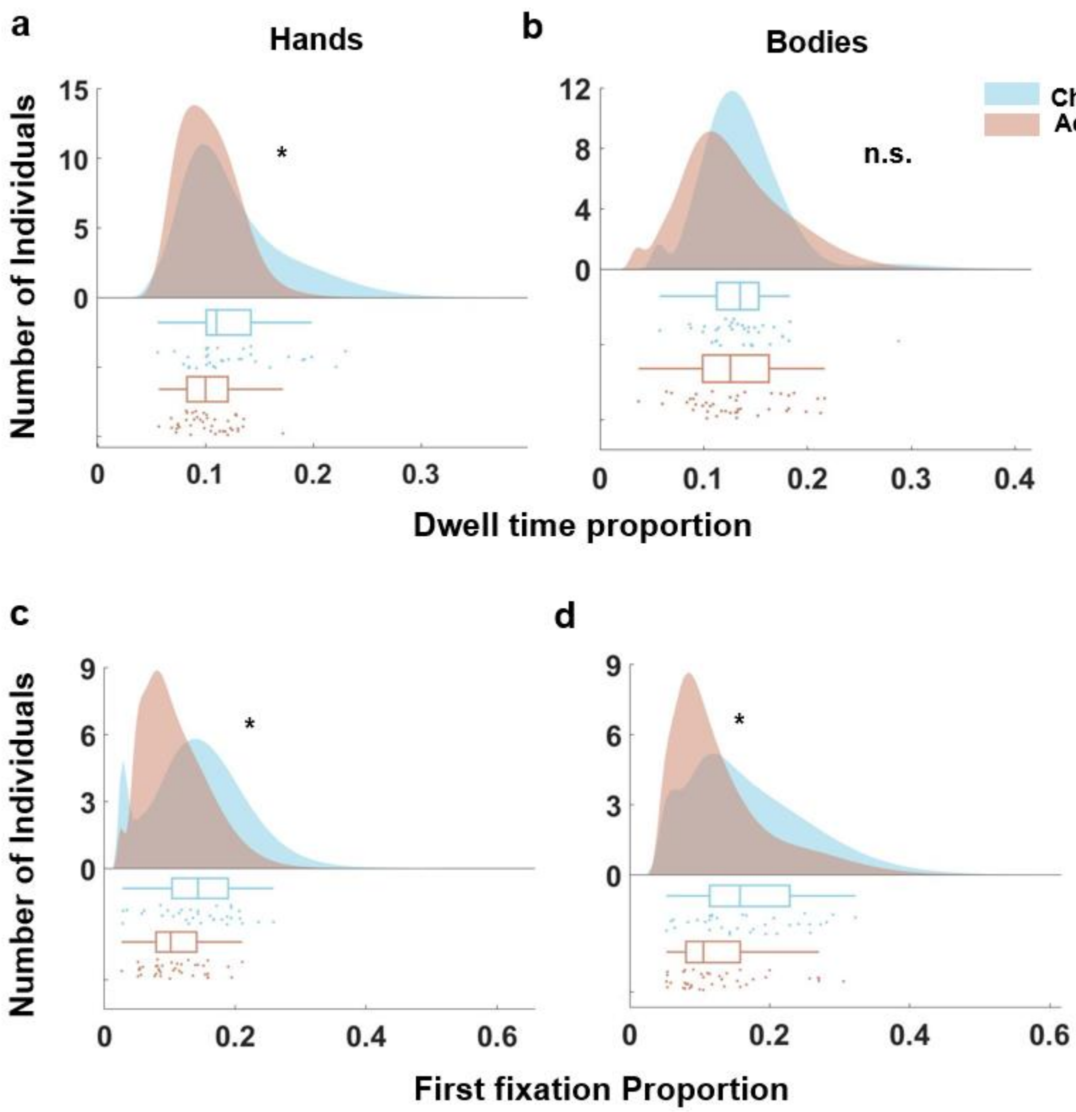

Figure 4. **Group differences in visual salience for hands and bodies.** Density plots showing the probability distributions of cumulative dwell time (a,b) and first fixation proportion (c,d) towards objects of the dimensions *hands* (a,c) and *bodies* (b,d) for children (blue) and adults (red). Data points depicted below indicate the individual dwell time and first fixation proportion towards the respective dimension. Corresponding box plots above the data points show an overview of the summary statistics for each group and semantic category; the vertical line within a box represents the mean value. The left side of a box indicates the 25th percentile and the right side the 75th percentile. The whiskers represent the minimum and maximum values. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$ (Holm-Bonferroni corrected; see Methods)

Testing group differences excluding text fixations

Enhanced salience for the dimensions *Faces*, *Touched*, and *Motion* in children may be a by-product of the much more pronounced bias towards *Text* in adults vs. children. That is, the lower salience of text in (pre-literate) children may imply larger proportions of fixations to spend on other categories, but the distribution of these fixations among other categories may not differ from that of adults. To test whether and how reported attentional biases differ between groups when controlling for differences in *Text* salience, we re-analysed the data ignoring all text fixations. That is, we computed the proportion of dwell time and first fixations of all fixations excluding those landing on *Text* before analysing group differences. These controlled analyses yielded no significant group differences in dwell time proportion for *Faces* ($t(74) = -0.80$, $p = 0.494$), *Motion* ($t(74) = 1.67$, $p = 0.299$) and *Hands* ($t(74) = 1.168$, $p = 0.493$) between children and adults. Children still showed larger dwell time proportions for *Touched* objects, $t(74) = 2.20$, however this effect did not survive Holm-Bonferroni correction, $p = 0.122$. Regarding first fixations, children spent a significantly larger proportion on *Touched* objects ($t(74) = 4.14$, $p < .001$) and *Hands* ($t(74) = 2.43$, $p = 0.018$ and a significantly smaller proportion of first fixations on *Faces*, $t(74) = -4.15$, $p < .001$.

Discussion

Adult gaze behaviour towards complex scenes is strongly biased towards semantic object categories[5] and individual observers show large and reliable differences in the magnitude of these biases[10]. Similarly, infants show early looking preferences for faces[15], hands[23] and (implied) motion[24-26]. Less is known about gaze behaviour towards complex scenes in pre-school children.

Our findings show substantial differences in attentional biases between children and adults. Children spent a larger proportion of dwell time on *Faces*, *Touched* objects, objects with implied *Motion* and *Hands* when freely viewing complex scenes. Most significantly, children spent a lot less time fixating *Text* compared to adults and most other dwell time differences seemed to be explicable by this effect. Moreover, we found that children compared to adults placed significantly fewer first fixations on *Faces* and *Text*, but more on objects being *Touched*, *Hands* and *Bodies*.

These findings contribute to our understanding of how human attention changes across the lifespan. Already very early in life our gaze becomes increasingly drawn towards distinct semantic information[23].Our findings show that these tendencies change between pre-school childhood and adulthood, to include text, at the expense of salience for implied *Motion*, *Hands*, *Bodies* and objects being *Touched*. This suggests substantial differences in how adults and children perceive the same complex scenes, which in turn seems tied to the acquisition of reading. Interestingly, most of these changes in semantic attention extend to the first saccade after image onset. Thus, semantic salience appears the result of an interaction between image content, individual differences and developmental status.

This may explain why heritability estimates for gaze behaviour towards social scenes are substantially higher for infants[12] compared to older children (9 - 14 years[28]). Individual differences at the beginning of life seem dominated by genes, but may be modulated substantially by later experience, such as the acquisition of reading.

We hypothesize that reduced text saliency in children is due to limited literacy. Our pre-school sample had not yet acquired formal education in reading and text features consequentially are uninformative to them. With age and improving reading ability, gaze behaviour may increasingly be tuned towards text at the expense of other semantic information. However, we did not assess reading ability so cannot exclude the possibility that at least some children already acquired reading skills before entering school.

Our findings further suggest that children spent significantly more dwell time on faces. This is in part inconsistent with evidence showing that face-based models are more successful in predicting gaze behaviour in adults compared to children[31]. At the same time other work showed enhanced attentional biases in children towards social information when memorising a scene[36]. Interestingly however, for the proportion of first fixations adults showed enhanced gaze behaviour towards faces compared to children. This may point towards two separate visual processes driving these biases in adults and children; one that is largely uncontrolled and bottom-up, guiding attention immediately after stimulus onset and showing a stronger, possibly more matured bias towards faces in adults. This may reflect more accurate and faster face processing abilities in adults[37], enabling them to saccade towards faces in the periphery very rapidly[38]. Dwell times may be under more top-down control and reflect the stronger competition of text with other semantic categories in adults for our stimuli. This is underscored by the finding that no significant differences remain between adults and children when excluding *Text* fixations from dwell time comparisons (only a tendency for a higher fixation tendency towards *Touched* objects in children). Interestingly, children still showed stronger attentional preferences for *Touched* objects and *Hands* when doing the same for the proportion of first fixations. In a recent study, Nordt et al. showed that from young childhood to teen age, expanding word selective regions in ventral temporal cortex are directly linked to decreases in limb selectivity[39]. These findings are interpreted as evidence of cortical recycling of limb-selective areas for the visual word form area, emerging during reading acquisition. It is tempting to speculate that such effects of cortical recycling may be linked to the matching changes in visual salience we report here, that is, a salience shift from limbs to text in adults compared to children.

Another candidate hypothesis for why children spent more of their dwell-time on *Touched* objects and *Hands* is a possible immaturity of social processing abilities. Critical social skills like reasoning about other people's thoughts (theory of mind; ToM) likely continue to develop beyond 5 years of age[40-42]. Children may compensate for limited social processing abilities by allocating more dwell time towards hands and touched objects to extract the information necessary for making sense of goals and behaviours of people depicted in the scenes. This may be particularly pronounced for briefly presented complex scenes including multiple objects, people and their interactions.

Further, there is evidence that children are embodied learners, that is, they seem to build their knowledge more strongly on sensorimotor experiences compared to adults[43]. It is possible, that attentional preferences in children for hands and objects being touched reflect such tuning towards physical and motor experiences.

Finally, children's enhanced attentional biases towards touched objects and hands may be related to their distinct drive to explore why and how things in the world interact as they do. Children seem to have a strong preference for understanding the causal structures surrounding them. For instance, when exposed to events that are inconsistent with their prior knowledge, preschool children seek causal explanations[44].Moreover, pre-schoolers most frequently asked questions about functions and causal properties when they encountered novel objects[45,46]. This preference for causal information seems to be particular pronounced in pre-schoolers[47]. Children's attentional biases towards objects being touched and hands could be a consequence of this early drive to understand cause and effect and the functionality of objects.

Future studies could test this hypothesized relationship between causal inference and corresponding eye movements in pre-school children in controlled experiments, juxtaposing stimuli with well-known and novel functions for children. Further, one could compare gaze behaviour towards semantic information in pre-schoolers and children who have already experienced formal education to test the effect of literacy on attention and specifically whether it is gradual or sudden. Given recent evidence for cortical recycling during childhood[39], future research could also examine whether a shift from cortical selectivity for limbs towards enhanced selectivity for words co-occurs with corresponding attentional biases. Finally, future research could probe visual salience in preschool children towards more naturalistic stimuli, like videos of everyday scenes. This could reveal whether salience differences - especially those for objects with implied motion - also hold for dynamic scenes.

Taken together, we report evidence for attentional biases in pre-school children along multiple semantic dimensions. Children spent less dwell time on *Text* and more on *Faces*, objects with implied *Motion*, *Touched* objects and *Hands*. For the dimensions *Text*, *Touched* and *Hands*, these biases could be shown as early as for first fixations after image onset. For the dimension *Faces,* children showed a significantly smaller proportion of first fixation compared to adults. Further analyses excluding text fixations, showed that reported attentional biases for *Touched* objects and *Hands* in children are not exclusively due to the stronger competition between *Text* and other dimensions (but others are).

These findings suggest that semantic salience is substantially depending on age. Children and adults seem to perceive the same visual environment in qualitatively different ways. We discuss potential roles of reading ability, socio-cognitive development and cortical recycling for these developmental differences. Future research examining the relationship between these factors and visual attention in pre-schoolers can inform theories on the development of human visual attention.

Methods

Subjects

In total, n = 78 subjects with normal or normal-to corrected vision took part in the study. All subjects provided written informed consent before participation. For children, parents gave written informed consent. The study was approved by the local ethics committee and adhered to the declaration of Helsinki.

Children (n = 34; M_{age} = 5,7; range = 5.1-5.9; SD = 0.17; 19 females) were recruited as part of a larger study based on a local data base of parents, who indicated their interest in child development studies. No child in the sample attended school at the time of the study. All children completed several other tasks and questionnaires which were not related to the present study. Subjects received no financial reimbursement for participation. Children were rewarded with a certificate of participation and a small gift.

Adults (n = 42; M_{age} = 24.4; range = 18-59; *SD* = 7.05; 31 females) were recruited as part of a larger study and completed other tasks which were unrelated to the present study. Adult participants were compensated with money (7€/hr) or course credit for participation.

Apparatus

The free viewing task was created and implemented using Psychopy 2020.1.2[48] in Python version 3.6.10[49]. Stimuli were shown on a Lenovo ThinkPad X230 with a screen resolution of 1366 x 768 pixels. The stimuli were presented with a size of 1000 x 750 pixels, roughly corresponding to 21 x 16 degrees visual angle. Eye movements were recorded from both eyes using a Tobii 4c Eye Tracker (Tobii AB, Danderyd, Sweden) at 90 Hz.

Stimuli and procedure

We used the OSIE40[11,5] dataset, which includes 40 complex everyday scenes and corresponding pixel masks for 364 objects with binary labels for 12 semantic object dimensions. Additionally, we used pixel masks for bodies and hands recently published by Broda and de Haas[35]. We recently showed that individual salience tendencies could be estimated reliably with 40 images[11]. As in previous analyses[11], the 12 labels for the semantic dimensions were modified in order to reduce overlap between them in the following way: The *Face* label was removed from all objects with the *Emotion* label; the *Smell* label was removed from all objects with a *Taste* label; and the *Operable* and *Gazed* label were removed from objects with a *Touched* label. The *Watchable* label was removed from all objects with the label *Text*. Finally, we removed the label hands from all objects labelled *Bodies.*

On average, subjects sat at a distance of ~ 54 cm away from the screen. After completing a child-friendly 5-point calibration and validation procedure, subjects were instructed to freely view 40 images. Each image was presented centrally on the screen for 3 s, with a fixation cross in between trials. A trial could only be initiated if a subject's gaze did not deviate 2 d.v.a. from the fixation cross for 1 s. Images were presented in the same order across subjects

Data Processing

All pre-processing steps and statistical analyses were computed using MATLAB R2019B (MathWorks). Fixations were extracted from raw eye tracking data by applying a saccade threshold of 30 d.v.a/s and a spatial inter-sample distance threshold of 2 d.v.a. Further, we used the median x and y position of fixation samples to determine the respective fixation location. Fixations with a duration < 100 ms as well as onset fixations (< 100 ms onset time) were not considered.

Fixation tendencies across four semantic dimensions

First, we tested differences in fixation tendencies along four semantic dimensions (*Faces*, *Text*, *Motion* and *Touched*) between children and adults. We chose these four dimensions, because adult gaze behaviour has been shown to reliably vary along them for the stimuli used in the present study (OSIE40)[11]. We first calculated the individual cumulative dwell time across all fixations towards all labelled objects depicted in the scenes. In a next step, we then determined the proportion of cumulative fixation time for a given object category (cumulative dwell time proportion) for each subject. Following the same procedure, we additionally tested differences in gaze behaviour towards hands and bodies (for which Broda and de Haas recently documented reliable individual differences among adults[35]). We further determined the proportion of first fixations after image onset which landed on *Text*, *Faces*, *Touched* objects for each participant (first fixation proportion). Note, we did not include the dimension *Motion* here, because earlier work indicated that the present stimulus set of 40 images is insufficient to reliably estimate individual differences in the proportion of first fixations towards objects with implied motion. An additional control analysis followed the same procedure described above, but excluded all *Text* directed fixations before calculating proportions of dwell time and first fixations for other dimensions. Group differences were tested with two-sample *t*-tests between children and adults for each semantic dimension and cumulative dwell time as well as first fixation proportions. The corresponding *p*-values were

Holm-Bonferroni corrected for 4 (cumulative dwell time analysis) and 3 dimensions (first fixation proportion analysis), respectively. All group comparisons (Figure 2-4) are visualized using Raincloud Plots[50].

References

1. Strasburger, H., Rentschler, I., & Jüttner, M. (2011). Peripheral vision and pattern recognition: A review. *Journal of Vision, 11*. https://doi.org/10.1167/11.5.13
2. Rosenholtz, R. (2016). Capabilities and limitations of peripheral vision. *Annual Review of Vision Science*, *2* (1), 437–457. https://doi.org/10.1146/annurev-vision-082114-035733
3. Harel, J., Koch, C., & Perona, P. (2006). Graph-based visual saliency. In Schölkopf, B., Platt, J. C., & Hoffman, T. (Eds.), *Proceedings of the 19th International Conference on Neural Information Processing Systems* (pp. 545–552) Cambridge, MA: MIT Press.
4. Itti, L., & Koch, C. (2000). A saliency-based search mechanism for overt and covert shifts of visual attention. *Vision Research, 40*, 1489-1506. https://doi.org/10.1016/S0042-6989(99)00163-7
5. Xu, J., Jiang, M., Wang S., Kankanhalli, M. S., & Zhao, Q. (2014). Predicting human gaze beyond pixels. *Journal of Vision, 14*(1), 1-20, https://doi.org/10.1167/14.1.28.
6. Einhäuser, W., Spain, M., & Perona, P. (2008). Objects predict fixations better than early saliency. *Journal of Vision*, *8*, 18–18. https://doi.org/10.1167/8.14.18
7. Stoll, J., Thrun, M., Nuthmann, A., & Einhäuser, W. (2014). Overt attention in natural scenes: Objects dominate features. *Vision research*, *107*, 36-48. https://doi.org/10.1016/j.visres.2014.11.006
8. Wang, H. C., & Pomplun, M. (2012). The attraction of visual attention to texts in real-world scenes. *Journal of Vision*, *12*, 26–26. https://doi.org/10.1167/12.6.26
9. Kümmerer, M., Wallis, T. S. A., Gatys, L. A., & Bethge, M. "Understanding low- and high-level contributions to fixation prediction" in *2017 IEEE International Conference on Computer Vision (ICCV)* (IEEE, 2017), pp. 4799–4808.

10. de Haas, B., Iakovidis, A. L., Schwarzkopf, D. S., & Gegenfurtner, K. R. (2019). Individual differences in visual salience vary along semantic dimensions. *Proceedings of the National Academy of Sciences, 116*, 11687. https://doi.org/10.1073/pnas.1820553116

11. Linka, M., & de Haas, B. (2020). OSIEshort: A small stimulus set can reliably estimate individual differences in semantic salience. *Journal of Vision*, *20*, 13-13. https://doi.org/10.1167/jov. 29 20.9.13

12. Constantino, J.N., Kennon-McGill, S., Weichselbaum, C., Marrus, N., Haider, A., Glowinski, A.L., …, Jones, W. (2017). Infant viewing of social scenes is under genetic control and is atypical in autism. *Nature, 547*, 340–344. https://doi.org/10.1038/nature22999

13. Amestoy, A., Guillaud, E., Bouvard, M. P., & Cazalets, J.-R. (2015). Developmental changes in face visual scanning in autism spectrum disorder as assessed by data-based analysis. *Frontiers in Psychology*, *6*, 989. https://doi.org/10.3389/fpsyg.2015.00989

14. Linka, M., Broda, M. D., Alsheimer, T. A., de Haas, B., & Ramon, M. (2022, March 29). Characteristic fixation biases in Super-Recognizers. Retrieved from osf.io/bdafk

15. Johnson, M. H., Dziurawiec, S., Ellis, H., and Morton, J. (1991a). Newborns' preferential tracking of face-like stimuli and its subsequent decline. *Cognition*, *40*, 1–19.

16. Johnson, M. H., Senju, A., & Tomalski, P. (2015). The two-process theory of face processing: Modifications based on two decades of data from infants and adults. *Brain, Memory and Development: The Imprint of Gabriel Horn*, *50*, 169–179. https://doi.org/10.1016/j.neubiorev.2014.10.009

17. Reid, V. M., Dunn, K., Young, R. J., Amu, J., Donovan, T., & Reissland, N. (2017). The human fetus preferentially engages with face-like visual stimuli. *Current Biology*, *27*, 1825-1828.e3. https://doi.org/10.1016/j.cub.2017.05.044

18. Reynolds, G. D., & Roth, K. C. (2018). The Development of Attentional Biases for Faces in Infancy: A Developmental Systems Perspective. *Frontiers in Psychology*, *9*. https://www.frontiersin.org/article/10.3389/fpsyg.2018.00222
19. Chien, S. H.-L. (2011). No more top-heavy bias: Infants and adults prefer upright faces but not top-heavy geometric or face-like patterns. *Journal of Vision*, *11*, 13–13. https://doi.org/10.1167/11.6.13
20. Gluckman, M., & Johnson, S. (2013). Attentional capture by social stimuli in young infants. *Frontiers in Psychology*, *4*. https://www.frontiersin.org/article/10.3389/fpsyg.2013.00527
21. Gliga, T., Elsabbagh, M., Andravizou, A., & Johnson, M. (2009). Faces attract infants' attention in complex displays. *Infancy*, *14*, 550–562. https://doi.org/10.1080/15250000903144199
22. Kelly, D. J., Duarte, S., Meary, D., Bindemann, M., Pascalis, O. (2019). Infants rapidly detect human faces in complex naturalistic visual scenes. *Developmental Science*, *22*, e12829. https://doi.org/10.1111/desc.12829
23. Frank, M.C., Vul, E. and Saxe, R. (2012), Measuring the development of social attention using free-viewing. *Infancy*, *17*, 355-375. https://doi.org/10.1111/j.1532-7078.2011.00086.x
24. Simion, F., Regolin, L., & Bulf, H. (2008). A predisposition for biological motion in the newborn baby. *Proceedings of the National Academy of Sciences*, *105*, 809. https://doi.org/10.1073/pnas.0707021105
25. Shirai, N., & Imura, T. (2014). Implied motion perception from a still image in infancy. *Experimental brain research*, *232*, 3079–3087. https://doi.org/10.1007/s00221-014-3996-8

26. Shirai, N., & Imura, T. (2016). Emergence of the ability to perceive dynamic events from still pictures in human infants. *Scientific reports, 6*, 37206. https://doi.org/10.1038/srep37206

27. Guy, N., Azulay, H., Kardosh, R., Weiss, Y., Hassin, R. R., Israel, S., & Pertzov, Y. (2019). A novel perceptual trait: Gaze predilection for faces during visual exploration. *Scientific Reports*, *9*, 10714. https://doi.org/10.1038/s41598-019-47110-x

28. Kennedy, D.P., D'Onofrio, B.M., Quinn, P.D., Bölte, S., Lichtenstein, P., & Falck-Ytter, T. (2017). Genetic influence on eye movements to complex scenes at short timescales. *Current Biology*, *27*, 3554-3560.e3.

29. Açık, A., Sarwary, A., Schultze-Kraft, R., Onat, S., & König, P. (2010). Developmental changes in natural viewing behavior: Bottom-up and top-down differences between children, young adults and older adults. *Frontiers in Psychology*, *1*. https://www.frontiersin.org/article/10.3389/fpsyg.2010.00207

30. Helo, A., Pannasch, S., Sirri, L., & Rämä, P. (2014). The maturation of eye movement behavior: scene viewing characteristics in children and adults. *Vision research*, *103*, 83–91. https://doi.org/10.1016/j.visres.2014.08.006

31. Rider, A. T., Coutrot, A., Pellicano, E., Dakin, S. C., & Mareschal, I. (2018). Semantic content outweighs low-level saliency in determining children's and adults' fixation of movies. *Journal of Experimental Child Psychology*, *166*, 293–309. https://doi.org/10.1016/j.jecp.2017.09.002

32. Hanania, R., & Smith, L. B. (2010). Selective attention and attention switching: towards a unified developmental approach. *Developmental science*, *13*, 622–635. https://doi.org/10.1111/j. 1467-7687.2009.00921.x

33. Jones, W., Carr, K., & Klin, A. (2008). Absence of preferential looking to the eyes of

approaching adults predicts level of social disability in 2-year-old toddlers with autism spectrum disorder. *Archives of general psychiatry*, *65*, 946–954. https://doi.org/10.1001/archpsyc.65.8.946

34. Klin, A., & Jones, W. (2008). Altered face scanning and impaired recognition of biological motion in a 15-month-old infant with autism. *Developmental Science*, *11*, 40–46. https://doi.org/10.1111/j.1467-7687.2007.00608.x

35. Broda, M. D., & de Haas, B. (2022, February 16). Individual differences in looking at persons in scenes. Retrieved from osf.io/ynujz

36. Doherty, B. R., Fraser, A., Nobre, A. C., & Scerif, G. (2019). The functional consequences of social attention on memory precision and on memory-guided orienting in development. *Developmental Cognitive Neuroscience*, *36*. https://doi.org/10.1016/j.dcn.2019.100625

37. De Sonneville, L. M. J., Verschoor, C. A., Njiokiktjien, C., Op het Veld, V., Toorenaar, N., & Vranken, M. (2002). Facial identity and facial emotions: Speed, accuracy, and processing strategies in children and adults. *Journal of Clinical and Experimental Neuropsychology*, *24*, 200–213. https://doi.org/10.1076/jcen.24.2.200.989

38. Crouzet, S. M., Kirchner, H., & Thorpe, S. J. (2010). Fast saccades toward faces: face detection in just 100 ms. *Journal of Vision*, *10*, 16-16. https://doi.org/10.1167/10.4.16

39. Nordt, M., Gomez, J., Natu, V. S., Rezai, A. A., Finzi, D., Kular, H., & Grill-Spector, K. (2021). Cortical recycling in high-level visual cortex during childhood development. *Nature Human Behaviour*, *5*, 1686-1697. https://doi.org/10.1038/s41562-021-01141-5

40. Golarai, G., Ghahremani, D. G., Whitfield-Gabrieli, S., Reiss, A., Eberhardt, J. L., Gabrieli, J. D., & Grill-Spector, K. (2007). Differential development of high-level

visual cortex correlates with category-specific recognition memory. *Nature neuroscience*, *10*, 512-522. https://doi.org/10.1038/nn1865

41. Osterhaus, C. and Koerber, S. (2021), The development of advanced theory of mind in middle childhood: a longitudinal study from age 5 to 10 years. *Child Development*, *92*, 1872-1888. https://doi.org/10.1111/cdev.13627
42. Saxe, R.R., Whitfield-Gabrieli, S., Scholz, J. and Pelphrey, K.A. (2009), Brain regions for perceiving and reasoning about other people in school-aged children. *Child Development*, *80*, 1197-1209. https://doi.org/10.1111/j.1467-8624.2009.01325.x
43. Wellsby, M., & Pexman, P. M. (2014). Developing embodied cognition: Insights from children's concepts and language processing. Frontiers in Psychology, *5*. https://www.frontiersin.org/article/10.3389/fpsyg.2014.00506
44. Legare, C. H., Gelman, S. A., & Wellman, H. M. (2010). Inconsistency with prior knowledge triggers children's causal explanatory reasoning. *Child development*, *81*, 929–944. https://doi.org/10.1111/j.1467-8624.2010.01443.x
45. Greif, M. L., Nelson, D. G. K., Keil, F. C., and Gutierrez, F. (2006). What do children want to know about animals and artifacts? Domain-specific requests for information. *Psychological Science, 17,* 455-459. doi: 10.1111/j.1467-9280.2006.01727.x
46. Kemler Nelson, D.G., Egan, L.C., & Holt, M.B. (2004). When children ask, ‘‘What is it?’’what do they want to know about artifacts? *Psychological Science*, *15*, 384–389. https://doi.org/10.1111/j.0956-7976.2004.00689.x
47. Booth, A. E., & Alvarez, A. (2015). Developmental Changes in Causal Supports for Word Learning. *Language Learning and Development*, *11*, 80-92. https://doi.org/10.1080/15475441.2014.888900
48. Peirce, J. W., Gray, J. R., Simpson, S., MacAskill, M. R., Höchenberger, R., Sogo,

H., Kastman, E., Lindeløv, J. (2019). PsychoPy2: experiments in behavior made easy. *Behavior Research Methods.* 10.3758/s13428-018-01193-y

49. Van Rossum, G., & Drake, F. L. (2009). *Python 3 Reference Manual*. Scotts Valley, CA: CreateSpace.

50. Allen, M., Poggiali, D., Whitaker, K., Marshall, T. R., & Kievit, R. A. (2019). Raincloud plots: a multi-platform tool for robust data visualization. *Wellcome open research*, *4*, 63. https://doi.org/10.12688/wellcomeopenres.15191.1

Acknowledgements

We would like to thank Amelie Benner and Nele Zscherper for data collection. ML and BdH are supported by ERC Starting Grant 852885 INDIVISUAL. BdH and GS are further supported by Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) Project No. 222641018–SFB/TRR 135 TP C9 and C3 and ÖS is supported by DFG Forschergruppe 2253 Crossing the Borders, and BdH and GS by "The Adaptive Mind", funded by the Excellence Program of the Hessian Ministry of Higher Education, Science, Research and Art. Finally, we would like to thank Xu et al. as well as Broda & de Haas for making their stimuli, pixel masks and metadata publicly available[5, 35].

Author contributions

ML and BdH designed and implemented the experiment in collaboration with HK, ÖS and GS. ÖS conducted the experiment. ML analysed the data and prepared the initial draft of the manuscript in collaboration with BdH. GS and BdH administered and supervised the project. All authors provided comments and/or revisions and approved the final article.

Data availability statement

Anonymized data and code to reproduce the presented findings and figures are available at osf.io/78aqf/.

Additional Information

The Authors declare no conflict of interest.

Keywords: scene viewing, visual salience, pre-schoolers, development