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Personal interests amplify engagement of language regions in the brains of children with and without autism.

Anila M. D'Mello[†1,2,3,4], Halie A. Olson[†1,5], Kristina T. Johnson[†6,7], Shruti Nishith[1], Isabelle R. Frosch[1,8], John D.E. Gabrieli[1,5].

[1]McGovern Institute for Brain Research, Massachusetts Institute of Technology, Cambridge, MA 02139, [2]Department of Psychiatry, University of Texas Southwestern Medical Center, Dallas, TX 75390, [3]Peter O'Donnell Jr. Brain Institute, University of Texas Southwestern Medical Center, Dallas, TX 75390, [4]Department of Psychology, University of Texas at Dallas, Richardson, TX 75080, [5]Department of Brain and Cognitive Sciences, Massachusetts Institute of Technology, Cambridge, MA 02139, [6]Media Lab, Massachusetts Institute of Technology, Cambridge, MA 02139, [7]Department of Neurology, Boston Children's Hospital, Harvard Medical School, Boston, MA 02114 [8]Department of Psychology, Northwestern University, Evanston, IL 60208

[†]Authors share joint first authorship.

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Abstract

Behavioral investigations have found that personal interests can profoundly influence language-relevant behaviors; however, the influence of personal interest on language processing in the brain is unknown. We measured brain activation via functional magnetic resonance imaging (fMRI) in 20 children while they listened to personalized narratives written about their specific interests, as well as to non-personalized narratives about a neutral topic. Multiple cortical language regions, as well as select cortical and subcortical regions associated with reward and salience, exhibited greater activation for personally-interesting than neutral narratives. There was also more overlap in activation patterns across individuals for their personally-interesting narratives than neutral narratives, despite the personalized narratives being unique to each individual. These results replicated in a group of 15 children with autism, a condition characterized by both specific interests and difficulties with communication, suggesting that personally-interesting narratives may impact neural language processing even amidst challenges with language and social communication. These findings reveal that engagement with topics that are personally interesting can significantly affect activation in the neocortical and subcortical regions that subserve language, reward, and salience in the brains of children.

Introduction

Human language is informed by our personal experiences, backgrounds, intrinsic motivations, and interests. However, when studying language processing in the laboratory, researchers typically use impersonal and generic stimuli with the assumption that idiosyncrasies and personal relevance merely introduce noise (Van Lancker, 1991). Crucially, failing to consider the effects of individual differences in interest may affect brain activation in unknown ways and potentially obscure some of the functionality of the language network.

Personal interests can be powerful motivators of language comprehension and communication (Krapp, Hidi, & Renninger, 1992). Interesting materials increase reading comprehension performance, allowing children to better comprehend materials beyond their established reading level (e.g., Shnayer, 1968), and children are more likely to play with and be generous towards individuals who share similar interests (e.g., Sparks, Schinkel, & Moore, 2017). Perhaps most strikingly, interest can improve performance in populations that typically struggle with language. For example, case studies of children with autism, a condition characterized by communication difficulties as well as a high prevalence of specific interests (Klin, Danovitch, Merz, & Volkmar, 2007), find positive impacts of scaffolding sociolinguistic interactions around topics of personal interest (e.g., Harrop, Amsbary, Towner-Wright, Reichow, & Boyd, 2019). Notably, few studies have extended personal interests into the brain. This may be in part due to a reluctance to use idiosyncratic stimuli and thereby give up experimental control. Prior studies have, however, personalized stimuli to the individual when studying certain phenomena – such as food cravings or memories – based on the intuition that personalization (e.g., a favorite food, or a video of a specific memory) might be the most effective and ecological way to elicit neural responses (e.g., Bainbridge & Baker, 2022; Tomova et al., 2020).

Despite the effects of interest on linguistically-relevant behavior, and the intuitive use of personalization to study brain activation in other domains, no studies have examined how topics of personal interest modulate language activation in the human brain. We recruited children (n=20, 6.98-12.01 years) with highly specific interests for an individually-tailored functional magnetic resonance imaging (fMRI) experiment in which they listened to personalized narratives written about their interests. We compared brain responses to these narratives with responses to non-personalized, control narratives about nature that were the same across all children. We hypothesized that personally-interesting narratives would elicit higher activation than neutral narratives in language regions. We also explored whether personal interests would affect language network function in a group of children with autism (n=15, 8.18-13.27 years).

Results

Personally-interesting narratives increased activation in language regions. To determine whether personally-interesting narratives modulated activation in language regions, we extracted functional responses from *a priori* left frontal, temporal, parietal, and right cerebellar regions of interest (ROIs) canonically associated with language processing (Fedorenko, Hsieh, Nieto-Castañón, Whitfield-Gabrieli, & Kanwisher, 2010). Across language regions, activation was higher for personally-interesting narratives than for non-personalized "neutral" narratives (main effect of condition: Interest>Neutral: Est.=0.47, S.E.=0.04, t-value=11.69, p<0.001; **Figure 1A**).

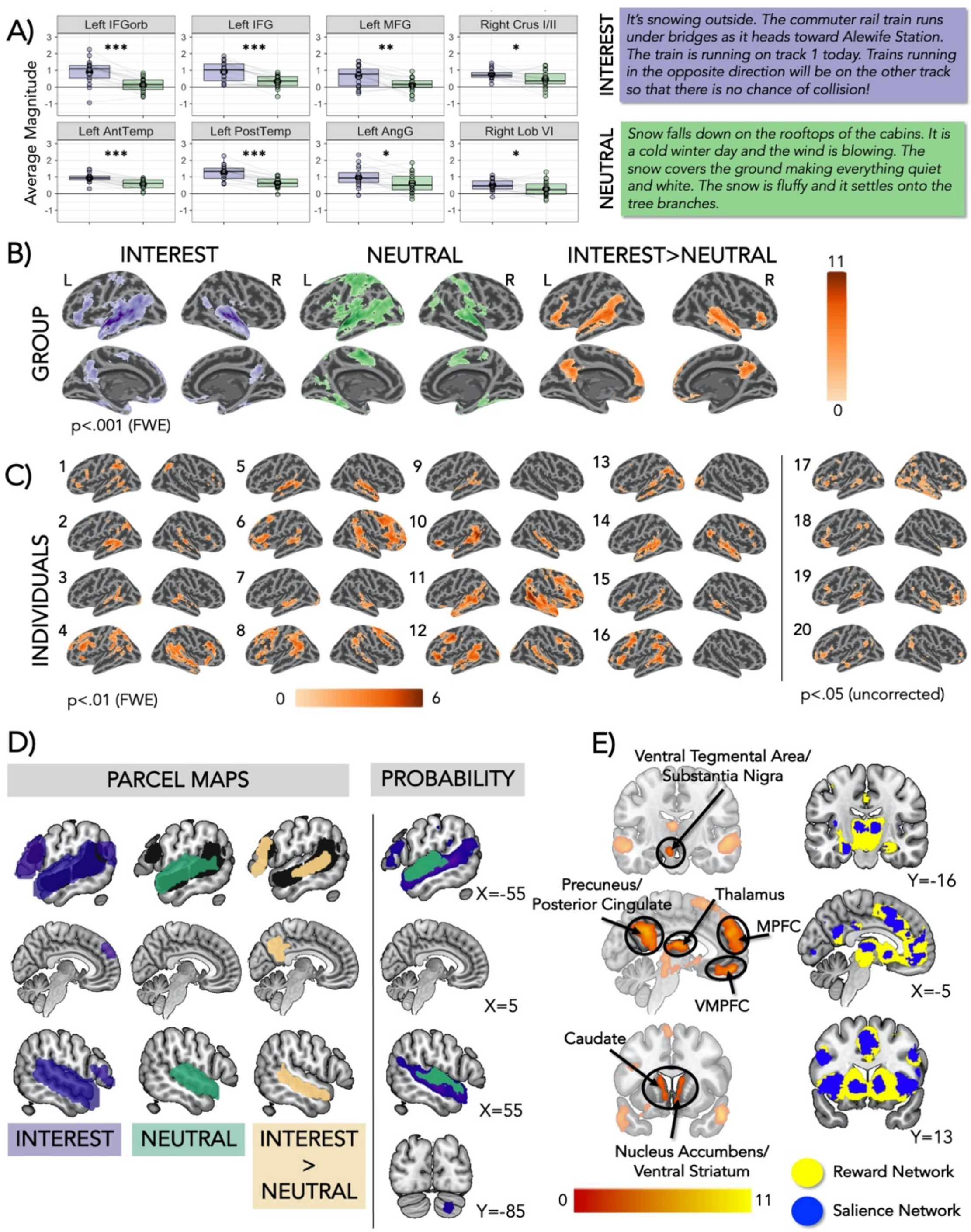


Figure 1. (A) Boxplots show average BOLD response to personally-interesting and neutral narratives within 8 language ROIs (right: example narratives). Black circle = mean; gray lines connect individual participants. *p<0.05, **p<0.01, ***p<0.001 (uncorrected). **(B)** Group average for Interest>baseline, Neutral>baseline,

and Interest>Neutral ($p<0.001$, FWE cluster $p<0.05$). **(C)** Individual whole-brain responses to Interest>Neutral language visualized at $p<0.01$, FWE cluster $p<0.05$. Participants who did not show suprathreshold voxels at this threshold or in surface space are visualized at $p<0.05$ uncorrected. **(D) Left**: Parcels within which >80% of participants show significant activation, overlaid on language ROIs (black). **Right**: Overlay of probability maps for interest (purple) and neutral (green), each thresholded for 25% overlap at the voxel level**. (E) Left**: Group-level activation for Interest>Neutral in classical reward/salience regions. **Right**: Neurosynth uniformity maps for "reward" and "salience"; FDR corrected 0.01.

Given that the personally-interesting narratives feature each child's favorite topic, it was possible that they would indiscriminately increase activation across large swaths of the brain. Instead, a whole-brain analysis revealed that increased cortical activation for personally-interesting narratives was mostly constrained to language regions (e.g., bilateral superior and middle temporal gyri and inferior frontal gyrus), both at the group level (**Figure 1B**) and at the level of individual children (**Figure 1C**). This result was made all the more striking by the fact that the contrast (Interest > Neutral) presumably controlled for language processing, suggesting that language areas were *specifically sensitive to interest*.

A concern with personalization is that using different stimuli will give rise to discrepant patterns of activation across individuals. Using a data driven approach, we identified large regions (i.e., "parcels") wherein over 80% of subjects showed significant activation. More parcels were identified for personally-interesting than neutral narratives, and these parcels roughly recapitulated canonical language regions, suggesting that idiosyncratic stimuli did not lead to more discrepant activation patterns (**Figure 1D, left**). We also examined intersubject overlap at the voxel level, finding more overlapping voxels for personally-interesting than neutral narratives (**Figure 1D, right**). These results suggest that despite the fact that stimuli were idiosyncratic, ranging in topic from train lines to video games, activation patterns for personally-interesting narratives were *more* consistent across participants than activation patterns for neutral narratives. Finally, the whole-brain analysis revealed higher activation for personally-interesting narratives in regions implicated in reward and salience processing, such as the caudate, nucleus accumbens, ventral tegmental area/substantia nigra, ventromedial and medial prefrontal cortex (VMPFC and MPFC, respectively), and precuneus/posterior cingulate (**Figure 1E**). Several of these regions are involved in narrative processing (Silbert, Honey, Simony, Poeppel, & Hasson, 2014), as well as processing of self-referential, autobiographical (Bainbridge & Baker, 2022), or personally relevant materials (Abraham & Cramon, 2009).

Personally-interesting narratives increased activation in language regions in autistic children. Finally, we investigated whether the potentiating effects of personally-interesting narratives generalized to autism. We scanned 15 autistic children with specific interests and challenges with social communication. As in neurotypical children, personally-interesting narratives elicited higher activation than neutral narratives in language ROIs (main effect of condition: Interest>Neutral: Est.=0.52, S.E.=0.07, t-value=7.27, $p<0.001$; **Figure 2A**) and in the whole brain (**Figure 2B-C, E**). Autistic children also showed more consistent activation patterns for personally-interesting than neutral narratives (**Figure 2D**).

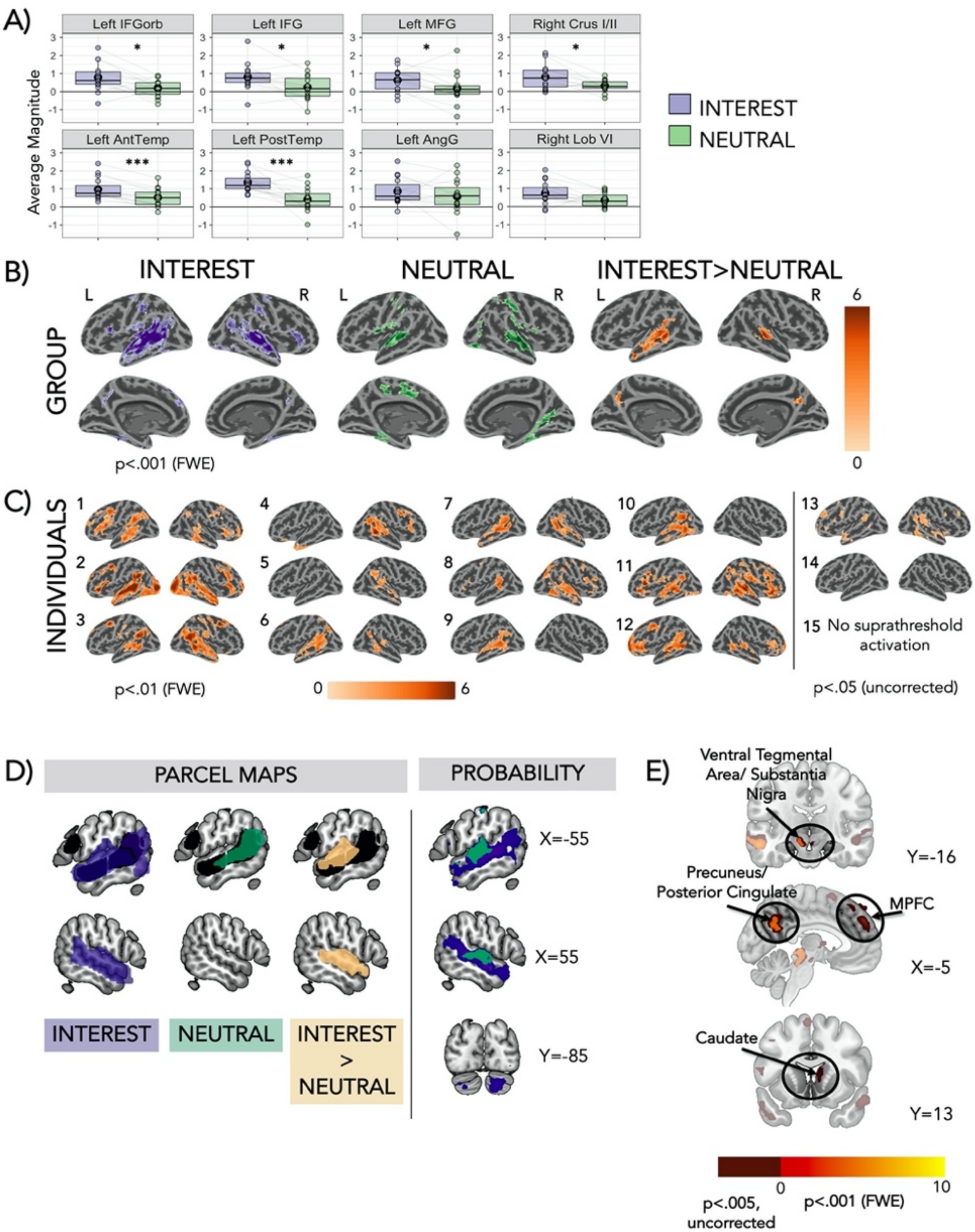


Figure 2. (A) Average BOLD responses to personally-interesting and neutral narratives within language ROIs. **(B)** Group averages for each condition. **(C)** Individual whole-brain responses to Interest>Neutral, visualized as in Figure 1. **(D) Left**: Data-driven parcels, overlaid on language ROIs (black). **Right**: Probability maps for interest (purple) and neutral (green), thresholded at 25% overlap at the voxel level**. (E)** Group-level activation in classical reward/salience regions.

Discussion

For the first time, we show that personal interest led to higher activation in children's language regions, as well as select subcortical regions, during passive listening to narratives. The use of personalized spoken passages highlights the power of intrinsically motivating content on the functions of the language network for both neurotypical and autistic children.

Several factors may have contributed to higher responses for personally-interesting narratives in the disparate regions we observed, such as increased attention and arousal, higher intrinsic motivation, and greater personal relevance of and familiarity with the topic. Similar engagement of canonical language regions alongside medial (MPFC, precuneus) and subcortical (e.g., caudate) regions has been associated with processing highly-relevant personalized language stimuli (i.e., greater activation for mothers' voices than unfamiliar voices, Abrams, Mistry, Baker, Padmanabhan, & Menon, 2022), and auditory narrative processing more generally, which may involve similar component processes (Silbert et al., 2014). Another possibility is that the neutral narratives may have elicited lower-than-expected activation due to the context of the task, in which those narratives were interleaved with highly salient, personally-interesting narratives.

A limitation of personalized experiments is that the gain in ecological validity is associated with a loss of stimulus control. In the present study, the content of the personalized narratives differed between participants based on their interests. While it is not feasible (or necessary) to personalize stimuli in every neuroimaging experiment, it might be an important consideration for 1) populations in which personalization will increase engagement in the paradigm, and 2) studies in which inferences about group or individual differences may be confounded by differing levels of attention to the stimuli materials (e.g., young children, individuals with language or attention disorders). In support of this, some neuroimaging studies in autistic children found that using personalized stimuli (e.g., mother's faces and special interests) led to higher activation in regions that otherwise appeared "underactive" (relative to neurotypical peers) when using non-personalized stimuli (e.g., Foss-Feig et al., 2016; Kohls, Antezana, Mosner, Schultz, & Yerys, 2018; Pierce & Redcay, 2008).

In sum, this study highlights the potential of personally-interesting material to modulate language function in the brains of neurotypical and autistic children, and the feasibility of personalization to evoke consistent brain responses. Future studies might consider personal interest as a powerful tool for maximally probing the scope and functionality of brain networks.

Materials and Methods

Methods Summary

All participants (total n=35, n=15 autistic) were screened for the presence of a strong interest and provided links to online videos depicting this interest. Based on these materials, researchers wrote and recorded personalized narratives for each child. In the MRI scanner, all children listened to narratives in three conditions: personally-interesting, neutral, and backwards-language. We compared BOLD activation for personally-interesting and neutral narratives in *a-priori* language regions of interest and across the whole brain, and evaluated intersubject consistency across conditions at the voxel level and within larger regions. Parents provided informed consent, and children provided assent to participate. This protocol was approved by the MIT Committee on the Use of Humans as Experimental Subjects. Data and materials are available on OSF (https://osf.io/dh3wq/).

Participants. Data were analyzed from 20 neurotypical children (ages 6.98-12.01 years, mean(SD)=9.35(1.52), 5 female/15 male) and 15 autistic children (ages 8.18 – 13.27 years, mean(SD)= 11.17(1.62), 3 female/11 male/1 nonbinary). All children were native speakers of English, had normal or corrected-to-normal hearing and vision, had no contraindications for MRI (e.g., metal in the body), and had a qualifying special interest (see **Personal interest screening** below). Additional exclusion criteria for the neurotypical children included diagnosis of major neurodevelopmental or psychiatric disorders and language difficulties. In n=9 autistic children scanned prior to the onset of the Covid-19 pandemic, autism diagnosis was confirmed via the Autism Diagnostic Observation Schedule (ADOS) administered by a research-reliable clinician

(Lord et al., 2000). Data presented in the current manuscript are a subset of 54 children who were originally recruited for participation (n=27 neurotypical, n=27 autistic). N=19 of the original recruited sample were excluded due to: refusal to participate in the fMRI scan or inability to stay in the scanner past the initial T1 (n=5), excessive motion for the language task (n=12), incidental findings (n=1), and incomplete data (n=1). One participant in the autism group returned post-pandemic since no usable functional data was collected on the first attempt.

Personal interest screening. Parents expressed interest in the study via an online screening survey. If a child was potentially eligible (i.e., appropriate age, no exclusions based on the criteria listed above, and parent-reported presence of a significant interest, hobby, passion, or affinity), a member of the research team conducted a phone screening and discussion with parents to (1) confirm eligibility, and (2) ask follow-up questions about the child's interest. Criteria for the presence of a personal interest were as follows: (1) the child must engage with the interest for at least an hour per day on average (or would engage with that interest for the specified amount of time if there were no restrictions in place, e.g., screen time limits), (2) the child must have had the same interest for at least the last two weeks, and (3) the interest had to have associated videos that could be used in the fMRI experiment. Parents, in collaboration with their children, were then asked to provide video clips pertaining to their child's interest, which were then used to create personalized narratives for the fMRI experiment (see **Personalized Stimuli Creation**).

Group	NT	ASD
Age (years)	9.35(1.52) range = 6.98 – 12.01	11.17(1.62) range = 8.18 – 13.27
KBIT Matrices (standard score)	118.65(15.39) range = 87.00 – 140.00	114.93(7.92) range = 104.00 – 133.00
KBIT Verbal Composite (standard score)	121.00(12.99) range = 98.00 – 142.00	107.57(12.70) range = 77.00 – 119.00
SRS Communication (T score)	46.00(6.07) range = 37 – 55	78.93(15.99) range = 51 – 114
Autism Quotient (raw score)	42.47(12.39) range = 19 – 66	95.87(15.20) range = 55 – 124
Age of first word (months)	11.61(3.11 range = 6 – 20.41	14.00(8.32) range = 8 – 42
Age of first sentence (months)	20.41(6.60) range = 12 – 36	23.00(7.78) range = 12 – 42
Age for understanding command (months)	12.18(3.75) range = 6 – 18	14.93(9.64) range = 3 - 36
Interests	• Soccer (n=3) • Baseball and football (n=2) • Basketball • Fishing • Fortnite • Minecraft (n=3) • Pokémon • Lego Marvel superheroes • Animals from *Firefly* PBS show • Baking shows • Musicals • Harry Potter • Art tutorial YouTube channel • Calm paint brushing art videos • Transit Systems	• Soccer • Tennis • Computers • Fortnite • Minecraft • Pokémon • Among Us video game • Lego Ninjago (n=2) • Cartoon voices • Dragons from *How to Train Your Dragon* • Fighting insects • Puppies • Hurricanes/Extreme weather • Trains (local commuter line)

Demographic Table*. Table shows Mean(Standard Deviation) and range. Age=age at scan,* *KBIT=Kaufman Brief Intelligence Test (Kaufman & Kaufman, 2004), SRS=Social Responsiveness Scale (Constantino & Gruber, 2005), Autism Quotient (Auyeung, Baron-Cohen, Wheelwright, & Allison, 2008). Age of first word, first sentence, and understanding command were asked via parent report.*

Experimental Protocol. Participants completed 1-2 study sessions, which involved behavioral testing and a neuroimaging session. The neuroimaging session included an anatomical scan, a functional run of a task involving watching the participants' selected interest videos and nature videos (not discussed in this paper), a functional run of the personal interest language task (discussed in this paper, see **Personal Interest Narrative Task** below), and optional additional scans that varied between participants. These options included a resting state scan, neural adaptation tasks involving faces, objects, and auditory words, a separate language task, a diffusion scan, and additional runs of the personal interest tasks. Parents completed a set of questionnaires about their child during the visit including questions about demographic and developmental histories (e.g., language onset), the Autism Quotient (AQ, Auyeung et al., 2008), and the Social Responsiveness Scale (SRS, Constantino & Gruber, 2005). Parents provided informed consent, and children provided assent to participate. This protocol was approved by the MIT Committee on the Use of Humans as Experimental Subjects.

Personalized Stimuli Creation. Parents, in collaboration with their child, provided links to online video clips (e.g., YouTube) that captured their child's personal interest, including timestamps for their child's favorite parts of the videos. We cut seven 16-second clips from the provided videos (capturing each child's favorite part of the videos if provided), and wrote short narratives of the scenes from the selected video clips. A female experimenter (HAO) recorded the descriptions in a sound-proof booth, and the audio files were trimmed to be exactly 16 seconds. Language narratives were approximately matched between participants by avoiding personal pronouns (e.g., "I" or "you"), using simple vocabulary (allowing for interest-specific terms), and using short sentences. Due to the unique nature of personal interests, the personal-interest narratives tended to have more specific nouns — e.g., "Alewife Station" or "Lionel Messi" — than the neutral narratives. Both the personally-interesting and neutral narratives included action verbs and sensorially evocative descriptions. See OSF (https://osf.io/dh3wq/) for the neutral and personally-interesting narrative transcripts for all children with usable data. Total word count, number of words per sentence, number of syllables per word, and number of sentences per narrative were approximately matched between neutral and personally-interesting conditions (Total word count: M(SD)=39.92(4.21) for personal-interesting across all participants and M=45.14 for the neutral narratives [same across all participants], Number of words per sentence: M(SD)=7.40(1.15) for personally-interesting and M=7.74 for neutral; Number of syllables per word: M(SD)=1.40(.10) for personally-interesting and M=1.23 for neutral, and Number of sentences: M(SD)=5.49(.83) for personally-interesting and M=6.0 for neutral).

Behavioral Measures. Nonverbal cognitive reasoning was assessed via the matrices subtest of the Kaufman Brief Intelligence Test, 2nd edition (KBIT-2, Kaufman & Kaufman, 2004). Language skills were assessed via the verbal composite score of the KBIT-2, including the vocabulary and riddles subtests.

Personal Interest Narrative Task. Participants were asked to passively listen to spoken narratives presented binaurally via MRI-compatible headphones using a block-design paradigm. The task consisted of three conditions: personal interest, neutral, and backwards narratives. In the personal interest condition, participants listened to the personalized narratives about their specific interests. In the neutral condition, participants listened to non-personalized narratives describing nature scenes. Nature content included in the neutral narratives was similarly familiar to all children and unrelated to any child's personal interest. In the backwards condition, participants listened to backwards versions of the neutral narratives in order to account for lower-level auditory features of the narratives. Children listened to 7 narratives (16-seconds each) in each condition. Each narrative was followed by an inter-stimulus rest block of 5 seconds (total of 21 narratives across three conditions and 22 rest blocks). To confirm that children were attending to the task without imposing significant physical or cognitive demands, we included a low-demand attentional check following each narrative. An image of a panda appeared on the screen directly after the narrative for 1.5 seconds, followed by a blank screen for 0.5 seconds. Children were instructed at the beginning of the study to press a button using their pointer finger via an MRI-compatible button box that they held in their hand every time they saw a picture of a panda. Task order was fixed across participants in the following pattern: personal interest, rest, neutral, rest, backwards, rest, etc. [ABCABC…]. Total task time was 8min 8s.

Acquisition. Data were acquired from a 3-Tesla Siemens Prisma scanner located at the Athinoula A. Martinos Imaging Center at the McGovern Institute at MIT, using a 32-channel head coil. T1-weighted structural images were acquired in 176 interleaved slices with 1.0mm isotropic voxels (MPRAGE; TA=5:08; TR=2530.0ms; FOV=256mm; GRAPPA parallel imaging, acceleration factor of 3). Functional data were acquired with a gradient-echo EPI sequence sensitive to Blood Oxygenation Level Dependent (BOLD) contrast in 3.0mm isotropic voxels in 40 near-axial slices covering the whole brain (EPI factor=70; TR=2500ms; TE=30ms; flip angle=90 degrees; FOV=210mm; TA=7:47).

Preprocessing and Statistical Modeling. fMRI data were preprocessed using fMRIPrep v1.1.1 (Esteban et al., 2019). fMRIPrep is a pipeline developed by the Center for Reproducible Neuroscience that includes motion correction, correction for signal inhomogeneity, skull-stripping, spatial normalization to the Montreal Neurological Institute (MNI)-152 brain atlas, segmentation, and co-registration. Preprocessed images were smoothed in SPM12 at 6mm FWHM. First level modeling was performed using SPM12. Individual regressors for each condition (interest, neutral, backwards, and button press) were included in the model. Individual TRs were marked as outliers if they had greater than 1mm of framewise displacement. We included one regressor per outlier volume in the first level model, and we excluded participants with > 20% outlier volumes. The critical contrast (interest > neutral) was created to examine regions showing greater activation for personally-interesting than neutral narratives.

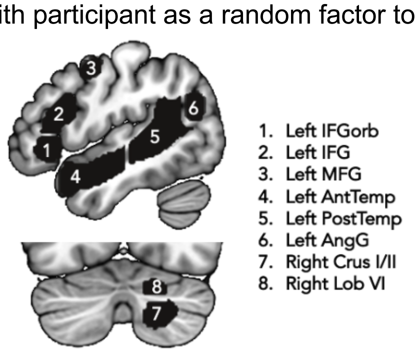
Region of Interest Analyses. To determine whether personal interest activated language regions specifically, parameter estimates for each condition were extracted from *a priori* regions of interest (ROIs) known to be important for language processing (Fedorenko et al., 2010). These ROIs are based on an atlas comprised of functional data from 803 participants during language tasks and reflect regions wherein a high proportion of those participants showed overlap in activation patterns (Lipkin et al., 2022). To capture responses in canonical language-selective regions, we selected eight parcels that are commonly associated with language (Fedorenko et al., 2010): left IFGorb, left IFG, left MFG, left AntTemp, left PostTemp, left AngG, right cerebellum lobule VI, and right cerebellum Crus I/II (**see below**). Linear mixed-effects models were run in R using the lme4 package. To determine if there was an effect of condition (interest, neutral) across the "language network", we used:

$$Y_{BOLDfromROI} \sim X_{condition} + X_{(1|ROI)} + X_{(1|participant)}$$

with participant and ROI as random factors to account for repeated measures. Second, to visualize effects of condition within each language ROI separately, we then used:

$$Y_{BOLDfromROI} \sim X_{condition} + X_{(1|participant)}$$

with participant as a random factor to account for repeated measures.



Group Whole Brain Analysis. Group-level modeling was performed using SPM12. One-sample t-tests were used to determine regions for which activation in each condition of interest (neutral, interest, interest > neutral) was greater than baseline. Group maps were thresholded at an uncorrected voxel p<0.001, with a cluster correction for multiple comparisons (FWE<0.05). For comparison, Neurosynth uniformity maps thresholded at FDR<0.01 (Yarkoni, Poldrack, Nichols, Van Essen, & Wager, 2011) for keywords “reward” and “salience” are presented in Figure 1E.

Overlap Analyses. A group-constrained subject specific (GCSS) approach was used to assess consistency and spatial overlap in activation patterns across different conditions (Fedorenko et al., 2010). For each contrast of interest, each participant’s statistical parametric map was thresholded voxelwise at $p<0.001$ (uncorrected) and binarized. Binarized maps were overlaid to create a probability map of regions engaged by the contrast of interest, which was then smoothed at 6mm FWHM and thresholded voxelwise at n=2 subjects. Probability maps reflect the number of participants showing overlap in a particular voxel. Secondly, a watershed algorithm from the SPM-SS toolbox was applied to detect local probability maxima from probability maps and extend them spatially to create functionally-defined “parcels”. To identify regions within which a large number of participants showed significant activation, we retained parcels which contained significant voxels from 80% or more of participants.

Preregistration. The main hypotheses for the current study were included as part of a broader preregistration in 2018 for a study investigating the neural correlates of personal interest in visual, reward, and language domains in neurotypical and autistic children: https://osf.io/nr3gk. Though beyond the scope of the current study, the planned study included additional groups (e.g., a neurotypical group with general but not specific interests), as well as a video task and associated analyses that are not presented here. For the analysis of the personal interest language task, we deviated from the preregistration by not using subject-specific functional ROIs (neutral>backwards), as this would have precluded a comparison between our conditions of interest (personal interest vs. neutral). Instead, we used *a priori* ROIs and whole brain analyses. The following hypotheses were tested and confirmed: 1) All children will show greater activation in the language network for personally-interesting than neutral narratives, and 2) All children will show greater activation in the reward network for personally-interesting than neutral narratives. We did not test hypotheses related to group differences between neurotypical and autistic children, nor associations with behavioral measures, due to smaller than anticipated sample sizes as a result of the COVID-19 pandemic and subsequent data/personnel limitations.

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