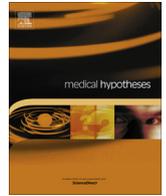


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Causation model of autism: Audiovisual brain specialization in infancy competes with social brain networks

Karen Frankel Heffler*, Leonard M. Oestreicher

Society for the Study of ASD & Social-Communication, 3540 Joerg Ave, Merced, CA 95340, USA

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ABSTRACT

Earliest identifiable findings in autism indicate that the autistic brain develops differently from the typical brain in the first year of life, after a period of typical development. Twin studies suggest that autism has an environmental component contributing to causation. Increased availability of audiovisual (AV) materials and viewing practices of infants parallel the time frame of the rise in prevalence of autism spectrum disorder (ASD). Studies have shown an association between ASD and increased TV/cable screen exposure in infancy, suggesting AV exposure in infancy as a possible contributing cause of ASD.

Infants are attracted to the saliency of AV materials, yet do not have the experience to recognize these stimuli as socially relevant. The authors present a developmental model of autism in which exposure to screen-based AV input in genetically susceptible infants stimulates specialization of non-social sensory processing in the brain. Through a process of neuroplasticity, the autistic infant develops the skills that are driven by the AV viewing. The AV developed neuronal pathways compete with preference for social processing, negatively affecting development of social brain pathways and causing global developmental delay. This model explains atypical face and speech processing, as well as preference for AV synchrony over biological motion in ASD. Neural hyper-connectivity, enlarged brain size and special abilities in visual, auditory and motion processing in ASD are also explained by the model. Positive effects of early intervention are predicted by the model. Researchers studying causation of autism have largely overlooked AV exposure in infancy as a potential contributing factor. The authors call for increased public awareness of the association between early screen viewing and ASD, and a concerted research effort to determine the extent of causal relationship.

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Criteria for environmental factor implicated in ASD causation

An environmental exposure that is implicated as a causal factor in ASD would likely: (1) Show an increased likelihood of exposure in infants that generally follows the increase in prevalence of ASD over time. (2) Have a correlation with atypical brain development and be consistent with theories of interference with typical social brain development. (3) Interfere with social learning opportunities. (4) Be modified in early intervention. (5) Have an association with autism and impaired language development. (6) Be understudied (overlooked) in large-scale ASD sibling studies and environmental studies. The authors will show that AV screen exposure in infancy fulfills these criteria.

Background

Autism spectrum disorder (ASD) begins early in life and is characterized by deficits in social interaction, communication and restricted and repetitive patterns of behavior [1].

* Corresponding author. Tel.: +1 215 816 5687; fax: +1 209 383 7450.

E-mail address: hefflerk@ssas-c.com (K.F. Heffler).

Environmental factors implicated in ASD causation

Recent analysis of ASD causation has implicated a significant component to environmental factors and gene-environment interactions [2]. Previous twin studies had estimated very high genetic risk in autism [3,4]. More recent studies, however, indicate that autism cause is a combination of genetic and environmental factors, with the environmental factors accounting for at least 50% of ASD risk [5,6]. Review of current literature reveals interest in environmental factors and their potential causal impact on ASD by interfering with neural synchronization [7], and epigenetic regulation [8]. Stamou et al. suggest that while environmental factors are important in the pathogenesis of ASD, the specific factors remain elusive [9].

Experience induced brain plasticity in animal models

Studies demonstrating brain plasticity in animal models indicate that environmental stimuli can cause significant changes in

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neurologic structure [10,11]. Research performed in monkeys reveals that changing the pattern of tactile stimulation alters the cortical representation of these somatosensory areas [12,13]. Similarly, animals with a deficit in one sensory modality from birth mitigate their deficit by developing increased perception in other, more utilized senses, a process referred to as crossmodal neuroplasticity [14]. Bilateral blindness is compensated for by somatosensory [15] and auditory [16,17] enhanced abilities, with evidence of these non-visual senses driving neurons in visual areas of the brain, and increasing their cortical territory [18–20]. Neural plasticity is also seen in monocularly deprived kittens [21–23], with a critical period in development in which the altered sensory input has the greatest effect on neural pathways [24]. The sensory induced neural changes can be further altered, or reversed, by again changing the environmental sensory input during a critical period [25]. These examples illustrate experience-driven plasticity, whereby the animal's neurologic pathways are changed based on the animal's specific sensory exposure, which, in turn, shapes the animal's behavior.

Plasticity of infant brain responsive to environmental stimuli

Based on the animal models, one would expect that human infants would also show significant neuroplasticity. The infant brain undergoes tremendous growth in volume of 1% per day in the early postnatal period [26]. Johnson suggests that the relatively delayed development of the human brain compared to other mammals allows for a much greater effect of postnatal experience on development [27]. Studies on early intensive intervention for ASD have demonstrated marked improvement in some children such that the developmental abnormality is no longer detected [28,29]. Other studies have shown significant plasticity of the infant brain when given experience with non-human face processing [30], active acoustic training [31], and exposure to foreign language [32], allowing increased abilities in these areas. These studies demonstrate a high degree of plasticity of the young mind, in which the infant's behavior is altered in response to the exposure, allowing adaptation to the specific environmental stimuli.

ASD atypical findings emerge after brief period of typical development

Jones and Klin [33] studied eye fixation in 2–6 month-old infants, and found that eye fixation is normal at the earliest time, but declines from 2 to 6 months in those who develop ASD. Ozonoff et al. found that infants who are later diagnosed with ASD have comparable responses to those with typical development in the frequency of gaze to faces, social smiles and vocalizations at 6 months of age, but significantly declining trajectories of these indices over time [34]. Diffusion tensor imaging, used as an assessment of the organization of white matter fiber tracts, indicates that infants who go on to a diagnosis of ASD have a significant difference in the trajectory of white matter tracts during the developmental ages of 6–24 months, compared to those with typical development [35]. These researchers suggest that irregular development of white matter pathways precede autistic symptoms in the first year. In addition, there is evidence that in the infant who develops ASD, the brain is not enlarged early on, but becomes larger than typical by 12 months of age [36–38]. There appears to be hyper-connectivity of the ASD brain found in electroencephalography (EEG) studies of 14-month-old infants viewing videos [39], as well as in functional magnetic resonance imaging (fMRI) studies in children [40].

Increasing prevalence of autism corresponds with timing of increasing AV availability and exposure

Rising rates of autism

Many countries have seen an increase in autism prevalence over the last 25 years [41]. In order to understand any environmental impact on a particular group of infants in time, it is important to take into consideration the age of the group studied. Several autism studies indicate a stable prevalence of ASD of 4 to 5 per 10,000 in birth cohorts from the 1950's through the early 1980's [42–46]. In Minnesota, Gurney et al. found ASD prevalence among children aged 6–11 years increased from 3 per 10,000 in 1991–1992 to 52 per 10,000 in 2001–2002 [47], reflecting a significant increase in autism among children born in the 1990's. Studies from the UK [48] documented a rising rate of autism in birth cohorts from the late 1980's to mid 1990's, which then stabilized. An Israeli study [49] similarly found a stabilization of rates after rising incidence in birth cohorts through the 1990's into mid 2000's. When considering an environmental ASD causal factor to which infants are exposed, we would expect to see greater effect as the exposure is increasing, as well as stabilization of autism rates once saturation of that factor is reached in a community.

Recent CDC reporting indicates ASD prevalence of 14.7 per 1,000 (one in 68) among 8-year-olds in the US in 2010 [50], a rate almost 30 times the prevalence found in the birth cohorts through the early 1980's. Some have suggested that the increase in ASD may be attributed to diagnostic substitution, broadening diagnostic criteria, better screening, and awareness [51–54]. Further analysis reveals that these factors only account for part of the rise [55–57], suggesting a true increase in autism prevalence.

Increased screen based AV exposure in infants parallels rise in ASD

Environmental factors show an increase in availability and exposure of AV materials starting in the 1980's, with much higher consumption in the 1990's and 2000's, corresponding to the rise in ASD. Although AV content available on screens has become a frequent component of everyday life, it is important to recall that home video viewing at one's whim was not generally available until the introduction of Betamax in 1975 and VCR in 1977 [58], opening the door for increasing home video consumption in the 1980's and 1990's, and for the first time allowing repetitive viewing of videos. VCR's were present in only 1.1% of US households in 1980, but increased to 85.1% of US households by 2000, while US households with cable rose from 15.2 million in 1980 to 73.8 million in 2004 [59]. Growth in home video sales (in 2007 dollars) during this period was a worldwide phenomenon, accounting for \$2.2 billion in revenues in 1980, increasing to \$13.1 billion by the year 2000 and to \$22.6 billion by 2005 [60]. Prior to 1977 there were no children's cable channels in the US. By the year 2000, 15 different network and cable channels had programming dedicated to children [61]. There has been an explosion in viewing opportunities for infants over the past 25 years, which parallels the rise in autism.

There is significant evidence to support that many infants are exposed to AV screen materials during infancy. Despite the American Academy of Pediatrics policy statement issued in 1999 to avoid television viewing in the first two years of life [62], Kaiser Family Foundation found in 2003 that 68% of children under two used screen media, with the average time watched just over 2 h, 43% watched daily and 26% had a TV in their bedroom. Additionally, 36% of households reported having TV on almost all the time, while 2/3 had the TV on at least half the time, even if "no one is watching" [63]. In addition to TV and video, infants

may be exposed to other AV screen stimuli that their parents or siblings are viewing such as video games, computer, tablet or smart phone. In 2013, a study found that 38% of children under 2 have used a mobile device [64].

Model of autism causation

Infants are attracted to viewing AV materials, which offer the naive infant no social relevancy. Through a process of neuroplasticity, the AV screen exposure causes specialization of brain pathways that process audio and visual stimuli in a non-social manner. These specialized sensory pathways interfere with attention to social stimuli, and disrupt the development of social brain specialization. The lack of attention to caretaker and the social scene contributes to global developmental delay. The model explains many of the atypical neurologic findings in ASD. Positive effects of early intervention are consistent with the model.

Saliency of AV materials

Many of the child-directed programming is animated and vibrant with colors and sounds designed to attract the developing mind. Young infants are attracted to the saliency of television and video. Frank et al. found that visual fixation preference in typical 3-month-old infants is determined by luminance and motion that override preference for fixating on faces [65]. Attention in the vulnerable infant is drawn away from healthy social interactions toward TV, computer screens, and electronic toys.

Infants do not recognize AV screen stimuli as socially relevant

Because of the lack of real life social interaction, and limited multisensory input, the audiovisual world (AVW) is quite different compared to the actual world (AW). Older typical children and adults can understand the AVW in humanistic terms as they have developed the typical brain pathways that process the world in terms of social relatedness and speech. As typical adults we can map the AVW onto the AW and relate the 2 dimensional moving images, fixed position of sound and limited screen size to our 3 dimensional real-world. However, screens offer no reciprocal social reward such as a returned smile or eye gaze for looking at the eyes of the projected individual, and no opportunities for joint attention, turn taking, or the complexities of social engagement. A naive infant viewing a screen sees a face that does not respond to the baby's smiles, coos, or directed gaze toward the actor. Electronic toys with lights and sounds may have an effect similar to screen materials, consisting of non-social acute sensory stimulation. We posit that the newborn does not have the social processing ability in place to recognize social relevancy in these types of exposures. It is not until 9-months of age, according to Frank et al., that the typical infant prefers attending to faces on video over the saliency provided by light and motion.

Aberrant neural processing of social stimuli and specialization of AV brain processing pathways

Atypical face processing in ASD

Researchers have identified aberrant neural social processing pathways in individuals with autism compared to those with typical development. Young infants are known to orient toward faces, an important factor in social development [66,67]. However, children with autism have a deficit in the ability to recognize faces [68–70]. When evaluated with fMRI, face processing invokes atypical brain activity in individuals with ASD. The fusiform gyrus, an area of the brain associated with face processing

in typical individuals [71–73] shows less activity with face processing in those with ASD, while other brain regions show increased activity [74]. Schultz et al. found that during face processing, individuals with ASD show activity of the inferior temporal gyri, and concluded that those with ASD process faces in a manner similar to the way in which typically developing individuals process objects [75].

Aberrant speech, auditory and visual neural processing in ASD

Speech, auditory and visual stimuli are processed differently in those with ASD. As shown by atypical event-related potential (ERP) signals to speech, Kuhl et al. found that individuals with more severe autism prefer mechanically sounding auditory signals over the infant-directed speech preferred by those with typical development [76]. Another study found that compared to typically developing children, those with autism have impaired attention to speech, but greater response of ERP to non-speech pitch changes [77], consistent with the ability of enhanced pitch processing in ASD found by Bonnel et al. [78]. Using fMRI to evaluate response to novel auditory stimuli, Gomot et al. found that compared to typically developing individuals, children with high functioning autism showed shorter reaction time, activation of a widespread network of brain regions as well as activation of brain regions that positively correlated with Autism Spectrum Quotient [79]. Similarly, individuals with ASD have enhanced abilities in visual discrimination [80–82], and motion detection [83]. Clery et al. studied fMRI in response to unexpected visual stimuli in adults and found that those with ASD have greater connectivity of visual sensory occipital cortex, but less connectivity to other regions compared to typical adults [84]. In ASD there is evidence of enhanced visual and auditory brain responsiveness and connectivity, along with atypical and poorly developed social brain responsiveness consistent with non-social auditory and visual stimulation.

Preference for AV synchrony over biological motion in ASD

In ASD, atypical neural processing is also seen in the perception of biological motion. Biological motion preference appears very early in development, and has been demonstrated in newly hatched chicks [85], as well as in 2 day-old human infants [86]. In striking contrast, 2-year-old toddlers with ASD, when shown a split screen with a video of light sources representing upright biologic motion on one side and upside down images shown in reverse order on the other side, do not orient to the biological motion [87]. Instead, these toddlers with ASD show a preference for audiovisual synchrony (sound change and image change occurring at the same time), and this accounted for over 90 percent of viewing preference in ASD. This is in contrast to typically developing and non-ASD developmentally delayed controls, who orient to biological motion and show no preference for audiovisual synchrony over biological motion, according to Klin et al. In order to attend to a stimulus of audiovisual synchrony, one has to be able to process this information and, in the case of the ASD group, specialize in AV processing. Kwakye et al. found that children with ASD have a longer period of time for processing AV stimuli in a multisensory manner [88]. We suggest that exposure to AV screen materials in infancy is a likely source of stimulation to promote specialization of the auditory and visual neurologic pathways that compete with and impair typical social brain development.

Lost opportunities to develop social brain in ASD

The infant who is developing ASD attends to AV synchrony over biological motion [87], mouth over eyes [89] (likely because of synchrony), mechanical speech over infant-directed speech [76], and has no preference for faces over objects [75]. The non-social neural pathways confound face and speech processing. The infant, who

does not orient to biological motion, would be less likely to develop appropriate neural response to socially important stimuli. In contrast to typically developing children, those who develop ASD show slower face processing [90], lack of differentiation of gaze direction toward vs away [91], decreased attention to social scenes [92,93], and no quickened response to an object cued by eye gaze [94], signifying a defect in joint attention. We suggest that the non-social AV brain specialization alters the response to social experience, consistent with the finding that children with ASD are effective processors of nonhuman AV stimuli, but they exhibit lower processing scores than typical when faces and voices are involved [95].

The socially disengaged infant would lose further shared attention opportunities to learn about his or her environment and develop language skills. The preference for artificial speech would diminish attention to caregiver and interest in interactive speech, creating an obstacle to learning language [32]. Wan et al. found that infant attentiveness to the parent at 12-months predicted 3-year ASD outcome [96]. A baby disinterested in the social scene would be less likely to participate in behavior such as imitation and turn taking. Infant directed learning, as shown by pointing to an object of interest, results in greater learning from teaching related to that object [97]. Without interest in a social partner, the infant will not engage with others, further limiting learning opportunities and contributing to global developmental delay.

Altered development in ASD determined by neuroplasticity

Consistent with examples of brain plasticity based on sensory stimulation presented earlier in this paper [12–22], we suggest that a pathway to the development of ASD is extensive sensory stimulation provided by AV screen viewing. This heightened sensory exposure, we propose, alters the neural circuitry during the first 2 years of life, a critical time of development [98,99]. The occipital (visual) cortex is the brain region most actively developing connectivity in the early postnatal months, while the higher-order, more frontal regions of the brain are slower to develop [100]. As the infant brain becomes wired to respond more to the demands of audio and visual stimulation, the behavior of the infant is changed to devote more attention to these primary sensory stimuli, and less attention to other environmental exposures, such as faces, social scenes and processes that would develop higher levels of thinking.

Sensory connectivity interferes with higher-order cognitive development

Alteration of primary sensory connectivity early in development would likely affect subsequent neural development, and could explain the atypical connectivity seen in ASD. The anterior cingulate cortex (ACC), an area of the brain associated with behavioral response monitoring [101], displays atypical activation in individuals with ASD compared to controls during higher-order attention tasks [84,102–104]. There is evidence of greater functional connectivity of the ACC to sensory regions, but less connectivity to frontal cortical areas in adults with ASD compared to controls [84], and ACC activation during response monitoring has been shown to correlate to rigidity and repetitive behavior ratings in adults with ASD [103].

Compared to controls, individuals with ASD rely more on visuo-spatial processing and less on working memory and executive areas during an embedded figures task assessed by fMRI [105,106]. During a task of relevant stimuli selection, Belmonte and Yurgelun-Todd found increased occipital cortex activation on fMRI in those with ASD compared to a control group. These researchers propose that a flood of input from over-aroused

primary sensory processing, starting early in infancy, overloads higher-order cognitive processes [107]. Based on principles of plasticity, we further this premise by suggesting that this hyper-responsive sensory state is an adaptation to the extensive sensory demands of the AV world.

Hyper-connectivity, enlarged brain and unusual sensory responses in ASD

In this model, the infant brain is altered in its response and developmental trajectory when it is presented with extensive audiovisual exposure with lights, colors and sounds. The infant orients to the saliency of luminosity and motion over social attention [65], but does not yet have the experience necessary to order the response to the stimuli in any socially meaningful way. The hyper-connectivity of the ASD brain shown in both EEG [39] and fMRI [40] studies may represent this response to the onslaught of sights and sounds which direct developmental pathways that specialize in non-social processing of audio and visual information. Enlarged head circumference that develops in infants with ASD compared to those with typical development [36–38], we suggest, is a result of this hyper-connectivity. Greater neural responsiveness to auditory and visual stimuli in youth with ASD [108] might explain the unusual sensory responses that are seen in many individuals with ASD [109].

Positive effects of early intervention consistent with model

Positive effects of early intervention on ASD outcome suggest that an environmental cause of autism would be somehow negated by this treatment. Early intervention therapies have been effective in decreasing the signs and symptoms of autism, especially if started early and intensively applied [110,111]. Lovaas, a pioneer in applied behavior analysis (ABA) treatment for autism, utilized intensive intervention an average of 40 h per week, which he considered to be almost the toddler's entire waking hours [112]. Another technique, Early Start Denver Model, utilizes a parent-implemented approach with emphasis on social interaction that includes a strategy of turning off TV, other screens and electronic toys when they compete with social attention [113]. These successful early interventions have a significant dual impact by eliminating or decreasing the audiovisual screen exposure and promoting face-to-face social interaction with shared attention. As shown in the animal model, reversal of sensory induced aberrant neural connectivity can be achieved by altering sensory exposure during a critical time of development [25]. Dawson et al. were able to show not only gains in language and adaptive behavior after early intervention for ASD, but also documented normalized EEG activity when viewing faces, indicative of improved social neural pathways [114]. In terms of the autism causation theory presented, we propose that early intervention decreases stimulation of brain areas that respond to audiovisual input, while increasing social brain stimulation.

AV screen exposure is associated with ASD and language delay

Studies have shown that AV screen exposure in infancy is associated with ASD. Waldman et al., using data on precipitation levels, American time-use and autism rates, found that the amount of television a young child watches is positively related with precipitation in their community and that county autism rates are positively associated with precipitation [115,116], suggesting television viewing as a trigger in autism. To further test this hypothesis, they looked at cable television subscription rates and autism, and found that autism rates of a birth cohort were positively correlated with the percentage of households who

subscribed to cable television when the cohort was under 3 years of age, and called for further study on the relationship between TV viewing and autism [115]. We could find only one study on the AV/autism link subsequent to this call for action. Chonchaiya et al. reported an association of autism with earlier television viewing and more time spent watching television than children without autism. They found that those with autism on average started viewing by 6 months of age versus those without autism who on average started viewing at 12 months of age [117]. In addition, it has been noted that some children with autism may be unable to communicate in a social sense, yet can recite every word of multiple children's videos [118].

Language delay is frequently seen in those with ASD [119]. Research has also shown an association between infant viewing of DVDs/videos and impaired language development [120]. Chonchaiya and Pruksananonda found that children who started watching TV younger than 12 months of age and watched more than 2 h/day were six times more likely to develop language delay [121]. Christakis et al. studied children two-months to 4-years of age and found that each hour of audible television was associated with significant reduction of both adult and child vocalizations [122]. One could suggest that language delay in this scenario may result from decreased exposure to interactive spoken language. Kuhl et al. demonstrated that infant language learning occurs with interpersonal socially motivated interaction, but not with audiovisual recordings [32].

Screen based AV exposure overlooked as potential causal factor in ASD

To our knowledge, major autism sibling studies have yet to gather information on infant audiovisual screen viewing, despite reported association with ASD. In addition to genetic causes, autism researchers have focused on factors including environmental toxins, which poorly correlate to autism rise [123], and more recently on peri- and prenatal risk factors in the Early Autism Risk Longitudinal Investigation (EARLI study) [124]. It appears parents are also unaware of studies linking screen time with autism. Top categories of parents' beliefs in ASD causal factors include genetics, brain structure, will of God, toxins in vaccines and environmental pollution [125]. Sadly, AV exposure in infancy as a likely causative agent has been overlooked.

Discussion

With the introduction of color, larger screens, improved audio, child programming and repetitive viewing opportunity, screen exposure has intensified. Previously many researchers had thought that the rise in autism might have been due to differences in diagnostic criteria over time or possibly over-reporting. Many believed genetic factors were mostly responsible and that autism was determined prior to birth. Recently, we have seen a wealth of new information suggesting that autism is a postnatal neuro-developmental disorder with actual rising prevalence, which, in addition to genetic factors, has a significant environmental component of causation. We now know that structural brain changes in the first year of life correlate to later diagnosis of autism.

We present a developmental model of autism, consistent with studies of brain plasticity, in which exposure to screen-based audiovisual input in infancy stimulates specialization of non-social audiovisual processing in the brain. The specialized AV processing pathways compete with preference for social processing and biological motion, negatively affecting development of social brain and higher cognitive pathways. Genetic factors, social environment, extent of AV exposure, and early intervention likely determine the ultimate neurologic and clinical outcome,

explaining the varied spectrum of ASD. The model is consistent with many studies of early development, sensory and social processing, as well as higher cognitive tasks in ASD.

Relationship to other models

The lack of orienting to biologic motion in ASD can be understood through the "interactive specialization" theory proposed by Johnson, which explains brain development and specialization through infant-environment interactions, which influence inter- and intraregional cortical connections, such that specialization of a brain system during postnatal development emerges as a result of activity-dependent interaction and competition of cortical regions [27]. We suggest that exposure to AV material in infancy allows specialization of brain processing of these types of stimuli and a preference for similar sensory input. This atypical sensory neural connectivity further competes with typical social brain activity and cognitive pathways.

Researchers have proposed models to describe many of the changes found in ASD. The enhanced perceptual model of autism implicates overfunctioning of primary sensory brain regions as being involved with autism [126], while the underconnectivity theory of autism suggests that ASD is due to a primary abnormality in connectivity between the frontal and posterior cortical regions [127]. Our model, while agreeing with many of the descriptive features of these models, differs significantly in that it is grounded in neuroplasticity and proposes an environmental sensory exposure that impacts the neural connectivity seen in ASD.

Other researchers have suggested that the social impairments in ASD are not the fundamental defect, but result from a primary abnormality in social motivation, which causes a failure to attend to and recognize social factors [128]. Relating our model to the social motivation theory, we suggest that the difficulty in social motivation in many children with ASD is secondary to AV exposure induced specialization of non-social neural processing pathways, which interfere with social engagement. TV and video have previously been suggested as contributing to ASD by distracting attention from caregiver-child eye contact and social interaction [129,130]. The present model incorporates this idea and further implicates AV screen exposure in ASD causation by stimulating aberrant sensory pathways and neural hyper-connectivity that interfere with attention to social stimuli, and disrupt social brain development. In our model, early intervention is effective as it decreases opportunities to reinforce the brain pathways orienting to audiovisual screen stimuli while simultaneously strengthening the social brain pathways.

Limitations of the model

The most obvious limitation of this model is that there is evidence to show an association [115,117], but not a causal relationship between AV screen exposure and ASD. In addition, the model was developed based on published research and our interpretation of these studies. Further, we have suggested that recent evidence of typical development in the first few months of life, prior to atypical neurologic and functional findings in ASD [33–35], suggests that an external factor is affecting the aberrant trajectory. An alternative theory is that development is pre-determined in utero and that the changes in the response to social factors that begin to manifest in the first year of life in ASD are primarily the result of genetic factors. While the authors acknowledge that other factors likely play a role, we suggest that studies on brain plasticity [10–25], responsiveness of the infant brain to experimentally controlled environmental stimuli [30–32], as well as twin studies [5,6], indicate that environmental factors contribute significantly to ASD. Finally, we have postulated that the increased sensory

connectivity and superior abilities related to auditory and visual function suggest increased exposure to these types of stimuli, and corresponding brain plasticity to allow better neural response to the AV exposure. However, there may be other causes not obvious to the authors.

Investigational studies

We know that TV screen time in infancy is associated with autism, but we don't know to what extent this exposure may contribute to the development of autism. Could this association be due to individuals who already have ASD gravitating toward screen stimuli? These two studies do not support that postulate. The first study [115] positively correlated rising autism rates of birth cohorts with increasing cable subscriptions rates at the time when the cohort was younger than 3 years of age. This strongly suggests exposure related outcome, as infants who were later diagnosed with ASD, would not likely have influenced the cable subscribing pattern of their county. The second study correlated increased autism diagnosis with more hours spent viewing TV/videos and earlier viewing in 6 month-old infants [117], before children have the capacity to declare their desire to watch or turn on a screen. While these studies show an association, further studies are needed to better understand the relationship between screen exposure in infancy and ASD and to understand to what extent a causal relationship may exist.

Recommended research going forward

What studies are needed to determine if exposure to AV materials contributes to the development of ASD and how much exposure is detrimental? Siblings of children with ASD have a significantly higher risk of developing ASD [131,132]. The authors suggest that ASD sibling studies include parental documentation of infant audiovisual viewing data that could be analyzed prospectively with respect to ASD outcome. The authors would also like to see a prospective multi-centered ASD infant sibling study undertaken in which willing families of study participants attempt to eliminate or significantly decrease audiovisual exposure in the infant study group from birth for a two-year period. Parents of the study group and control group would document the extent of infant media exposure. Researchers would follow the study and control ASD sibling groups for ASD outcome determined by clinical evaluation and research assessments.

Additionally, we would like to see a therapeutic study on young children with recent ASD diagnosis. This study would evaluate the impact of eliminating AV screen exposure in addition to early intervention, compared to early intervention alone, on therapeutic outcome. Since the hypotheses we propose suggests a competition between social and non-social experiences, we are hopeful that the research community may also look at some of these factors and their impact on infant brain development.

Implications of model for parents and society

AV screen exposure in infancy as a potential contributing factor to autism has significant implications. Parents naturally like to protect their children. However, viewing patterns have significantly changed and screens are ubiquitous in many societies. Parents may not know about the association between ASD and TV exposure. Research has not yet been done to answer many questions regarding the impact of social and non-social experiences on a young child's brain with regard to ASD, beyond knowing that increased AV exposure and exposure at a younger age are associated with autism and language delay. We are hopeful that awareness of this model will encourage research that will answer these

questions, and, in turn, empower parents to make decisions based on scientific findings. Currently, as reflected by the puzzle piece as a symbol of autism, ASD is steeped in mystery and parents feel confused and helpless when faced with questions about autism.

If, as predicted by this model, AV exposure is shown to have a causal effect on ASD, and social experiences are shown to have a protective effect, parents will have the tools to make healthy decisions relating to their child's exposure. Despite the American Academy of Pediatrics recommendation to avoid screen viewing for the first two years of life [62], it does not seem to be adequately conveyed during pediatric visits. In 2006, only 15% of parents of children age 6 and younger reported ever having discussed their child's media use with their pediatrician [133]. It is prudent to educate the public about the association of AV exposure in infancy and autism, as well as the recommendations of the American Academy of Pediatrics to avoid screen exposure before the age of 2, while further studies are undertaken.

Conclusion

The authors propose a model of ASD causation in susceptible infants, in which non-social AV viewing in infancy drives sensory brain hyper-connectivity. This heightened neural response to the sensory exposure alters the infant's behavior, and impacts further social and cognitive growth through an aberrant trajectory of neurodevelopment. Many aspects of ASD are explained by this model, including neural hyper-connectivity, areas of special ability, interference with typical social brain development, time-course of emerging symptoms, varied spectrum of involvement, increase in prevalence, as well as positive effects of early intervention. The authors suggest that AV screen viewing in infancy is a dose-related environmental exposure, and likely contributing factor to the rise in autism over the last 25 years. We urge increased public awareness of the association between screen viewing in infancy and ASD, and call for a concerted effort by the research community to study this exposure and determine extent of causation.

Conflicts of interest

The authors have no conflicts of interest to declare.

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