

# Media Violence Effects on Brain Development: What Neuroimaging Has Revealed and What Lies Ahead

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[abs.sagepub.com](http://abs.sagepub.com)**Tom A. Hummer<sup>1</sup>****Abstract**

Substantial research has indicated that media violence induces both short- and long-term increases in aggressive thoughts, feelings, and behaviors. Recently, neuroimaging techniques have begun to identify the mechanisms driving these changes. An important avenue that these neuroimaging tools can address is how exposure to media violence in childhood affects brain development, which can have lifelong behavioral consequences. This review highlights neuroimaging research examining how media violence exposure affects the pediatric brain. While such research is limited, evidence suggests that prefrontal mechanisms for controlling emotion and behavior are altered by exposure to violent media. Therefore, long-term increases in aggression and decreases in inhibitory control due to excessive media violence exposure may result from impaired development of prefrontal regions. However, additional neuroimaging research is necessary to establish whether and how exposure to media violence specifically shapes subsequent neural maturation. To optimize the use of neuroimaging in this inquiry, imaging studies should not stand on their own, but instead must be integrated with more traditional research paradigms to establish a more complete picture of effects. Future research must employ more longitudinal approaches to better characterize long-term effects that high exposure to violent screen media may have on brain development, particularly prefrontal and limbic brain regions.

**Keywords**

media violence, MRI, neuroimaging

Characterizing the effects of various forms of violent media on children's thoughts and behaviors has been a focus of psychological research for more than 50 years.

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Tremendous advances have been made through a variety of scientific methods, such as behavioral observation, physiological monitoring, and computerized reaction-time tasks. These methods have enabled researchers to provide substantial evidence that exposure to television, film, and computer/video game violence, which involves purposeful injury of one character by another, can increase aggressive thoughts, feelings, and behaviors (Anderson et al., 2003; Huesmann, Moise-Titus, Podolski, & Eron, 2003; Paik & Comstock, 1994; Wood, Wong, & Chachere, 1991).

As this research has progressed, newer tools have been developed to increase our understanding of how children are influenced by media exposure. Most notably, technological advances now allow us to more directly examine how children's brains are affected by prior or current violent media exposure, using various neuroimaging methods. By integrating neuroimaging techniques into existing research knowledge, a more complete picture of media violence effects on the brain and behavior can be formed.

The most substantial potential consequences of media violence exposure are those that extend beyond the immediate impact of watching a violent show or playing a violent video game. Clarifying long-term effects of violence exposure is one of the primary goals of media violence research, since an enduring impact on behavior patterns or personality traits is much more problematic for the individual and for society. The most critical potential influence of violence exposure is on childhood brain development, as alterations to the developmental trajectory of relevant brain regions will influence individual characteristics and behaviors for many years to come, into and through adulthood. The potential for violence exposure to have a significant impact on brain development is strong, as a confluence of children's increasing media exposure and greater independence combine with the heightened sensitivity of the developing pediatric brain.

If used properly, neuroimaging provides an optimal method for understanding how brain development is influenced by exposure to media violence during childhood and adolescence. Neuroimaging encompasses multiple techniques, including electroencephalography (EEG), magnetic resonance imaging (MRI), and positron emission tomography (PET), among others, which enable us to characterize the structure and function of the brain *in vivo*. Advances in technology and computational power over the past couple of decades have made data collection with these methods more feasible, precise, and usable, leading more scientists to embrace neuroimaging as the next progression in psychological research. The result has been a flood of exciting contributions to the field that have pulled back the curtain on the brain, revealing brain structure and function with increasingly detailed images.

Beyond the excitement derived from the novelty and beauty of imaging the brain, we must evaluate how useful neuroimaging can be as a scientific tool to assess short- and long-term developmental effects of exposure to violent media. In particular, it is necessary to clarify the added value that neuroimaging tools bring to more traditional psychological techniques in understanding effects of violent media. How do neuroimaging techniques help us achieve our goals within media effects research, and how can we ensure that we are maximizing the potential of these tools to inform scientific knowledge?

## What is Neuroimaging?

Brain imaging techniques measure neural characteristics by detecting naturally occurring signals emanating from the brain, or via the interaction of neural properties with exogenous material, such as radioactive isotopes. The most commonly utilized neuroimaging methods, particularly within media violence research, are EEG and MRI. This article focuses primarily on these two methods, which are more widely used due to their relative ease of use and noninvasive characteristics.

In EEG, participants wear headgear that contains a matrix of electrodes that record ongoing electric activity through the scalp. This activity is the result of synchronized oscillations of neuronal activity, emanating primarily from cortical origins. These electric signals can reflect spontaneous activity recorded over an extended period of time (minutes to hours), or activity in response to specific stimuli, such as presented pictures or words. EEG activity recorded with this latter approach is known as event-related potential (ERP), since it is time-locked to stimulus “events.” ERP signals are averaged over many trials during an experiment. In this manner, investigators can determine the brain’s response to specific conditions (such as negatively valenced images), including the strength, latency, and duration of the neural response. Because ERP records activity generated directly by the firing of groups of neurons, the method provides high temporal resolution, on the order of milliseconds. This excellent resolution enables investigators to differentiate immediate sensory responses to a stimulus from subsequent, higher level responses, such as cognitive processes that follow immediate perception. However, electrical signals from neuronal activity disperse as they reach the surface of the scalp, so each electrode measures potential changes that arise over a relatively widespread area of the brain. Thus, spatial resolution is poorer than that of other imaging techniques. In other words, EEG is excellent at determining when activity is taking place, but can only indicate approximately where in the brain neurons are firing.

An MRI scanner is essentially a large tube that contains a very powerful magnet. This magnet moves rapidly in a closed field around a biological target (e.g., the brain), exciting atomic nuclei within the field. The scanner then measures radio frequency signals emitted by these nuclei as they “relax” to their equilibrium state. Different tissue types—including gray matter, white matter, and cerebrospinal fluid—have distinct magnetic susceptibilities and relaxation rates, and generate distinct signals. Using this information, we can reconstruct high-resolution three-dimensional maps of the brain.

To examine brain activity, investigators take advantage of changes in blood flow, blood volume, and oxygen metabolism that accompany neuronal activity. These changes alter the blood-oxygen level-dependent (BOLD) signal, which is collected during functional MRI (fMRI). During fMRI, BOLD signal is quantified during spontaneous activity (“resting state”) or in response to specific presented stimuli. fMRI has better spatial resolution than EEG, typically quantifying the BOLD signal with a resolution of 2 to 3 mm. Because the BOLD signal is based on hemodynamics and lags the actual firing of neurons, fMRI is an indirect measure of brain activity. Moreover, signal detection across the entire brain in fMRI takes 1 to 3 seconds, due to the relaxation time required. Therefore, the temporal resolution of brain activity with

fMRI is on the order of 2 to 3 seconds, poorer than that of EEG, but its spatial resolution is better, detecting much more precisely where activity is occurring.

In addition, MRI can characterize gross structural characteristics of the brain, including gray matter and white matter. Gray matter consists primarily of brain cell bodies, where neural computations and interactions take place. White matter is the fatty tissue, called myelin, which insulates long-range brain connections (axons). Specialized MRI techniques can be employed to gather data on architectural characteristics that help elucidate neurodevelopment, particularly within white matter tracts. Specifically, diffusion tensor imaging (DTI) quantifies diffusion of water molecules within the brain to provide detailed information about microstructural properties. Quantifying this diffusion yields data on the degree of myelination and axonal organization of white matter tracts, as molecule diffusion is more directed when extracellular space is limited by increased myelination. For instance, fractional anisotropy (FA), one commonly used measure of neurodevelopment, represents the degree to which diffusion progresses axially (parallel to fiber tracts) relative to the radial direction (perpendicular to the tract). FA normally increases throughout childhood and adolescence, and thus is a widely used measure of neurodevelopment during these time periods.

In adults, imaging techniques, such as PET or single-photon emission computed tomography (SPECT), can also provide useful information, including neurotransmitter receptor concentrations or brain metabolism. However, these methods are not typically available for pediatric research, as the lightly radioactive contrasts used are avoided in children.

### **Childhood Brain Development**

Neuroimaging tools, particularly MRI, have been vital in mapping out how brain development progresses through childhood and adolescence. The development of cortical volume throughout childhood and adolescence is complex, but there is an overall trend characterized by an average peak in cortical gray matter in early adolescence (Giedd et al., 1999; Reiss, Abrams, Singer, Ross, & Denckla, 1996). This peak timing and subsequent decrease in cortical volume is regionally specific. For instance, volume of the frontal lobe—which is central to such higher order processes as attention, planning, organization, and behavioral control—is highest around age 11 in girls and age 12 in boys (Giedd, 2004; Giedd et al., 1999), though this trajectory may differ slightly with intelligence level (Shaw et al., 2006). This cortical thinning is likely related to the process of pruning, which removes unnecessary neuronal connections, and development of white matter tracts (myelination) that occur as the brain matures (Sowell et al., 2003). Myelination increases, improving the efficiency of neuronal transmission, throughout childhood and adolescence. This development is particularly strong in association fibers, which connect two separate areas of cortex (the surface of the brain), improving function of higher order brain processes (Asato, Terwilliger, Woo, & Luna, 2010; Benes, 1989; Yakovlev & Lecours, 1967). As a reflection of increased myelination, white matter density has a generally linear increase throughout adolescence and beyond (Giedd et al., 1999; Sowell et al., 1999).

The maturation of white matter tracts improves the efficiency of communication between brain regions, with connections between association areas (such as frontal and parietal cortices) strengthening especially during adolescence (Asato et al., 2010). This improved neural communication is associated with improved executive functioning capabilities, including working memory, inhibitory control, and attention. Microstructural properties of white matter, measured via DTI, reflect the degree of myelination and organization of tracts that are associated with neurocognitive performance on a variety of tasks (Mabbott, Noseworthy, Bouffet, Laughlin, & Rockel, 2006; Nagy, Westerberg, & Klingberg, 2004; Olson et al., 2009; Silveri et al., 2006; Tamnes et al., 2010). Moreover, delayed neurodevelopment throughout childhood, as reflected both by the trajectory of cortical thickness and DTI-derived white matter measures, is a key feature of clinical manifestations of executive dysfunction, such as attention deficit hyperactivity disorder (Shaw et al., 2007; Shaw et al., 2011).

Current theory suggests that brain regions primarily responsible for more evolutionarily ancient functions, such as motivation, emotion, and reward sensitivity, mature earlier than those neural regions (most notably prefrontal cortex) that help control these drives. Development of the prefrontal cortex continues into the mid-20s, so psychological processes mediated by prefrontal mechanisms, including attention, inhibitory control, and emotion or behavior regulation, are particularly vulnerable during adolescence.

Environmental factors apart from media violence, such as drugs of abuse (Squeglia, Jacobus, & Tapert, 2009) or stress (Eiland & Romeo, 2013) have extensive long-term effects on brain structure and function when encountered during one's teenage years, particularly early adolescence. There are several reasons why this time period is especially sensitive to long-term effects. First, as noted above, maturation of the prefrontal cortex and associational tracts is particularly robust during this time period, and disruptions of this development have extended consequences on communication between higher level brain regions. Second, the onset of puberty brings about a host of hormonal changes that drive organization of the adolescent brain (Sisk & Zehr, 2005), and hormones play an increasing role in emotion and stress regulation following puberty (Amin, Epperson, Constable, & Canli, 2006; Dedovic, Duchesne, Andrews, Engert, & Pruessner, 2009; Kajantie & Phillips, 2006; Young & Altemus, 2004). These changes typically coincide with increasing independence, which intensifies social pressures and other life stressors. This combination of evolving neurobiological development with psychosocial and environmental changes creates a sensitive period for enduring effects on the brain. While media violence is certainly not the only factor that may alter brain development during adolescence, its prevalence and potential for impact make it an important research topic.

## **Neuroimaging of Media Violence Effects in Children and Adolescents**

Pediatric neuroimaging studies of media violence have built on the existing body of psychological research, in an attempt to determine what is driving the observed cognitive and behavioral effects and to identify effects that may not be detectable

through more traditional techniques. To date, the number of neuroimaging research studies that directly examine neurobiological outcomes of media violence exposure on children and adolescents has been limited, but promising.

The first neuroimaging study to examine the relationship between media violence exposure and brain activity was a correlational study involving aggressive adolescents with disruptive behavior disorder and nonaggressive control youth (aged 13-17 years; Mathews et al., 2005). Past exposure to video game and television violence was quantified via self- and parent-report, and groups were split into low- and high-violence exposure groups based on a median split. During fMRI, participants performed a counting Stroop task, an interference task known to engage the anterior cingulate. This task required participants to press a button corresponding to the number of digits (interference condition) or letters (control condition) in a presented stimulus (e.g., press Button 3 for 111 or XXX). Participants with lower past violent media exposure had a greater anterior cingulate response (interference activity–control activity) than the high-exposure group. This study provided useful preliminary evidence that dysfunction of top-down control regions was related to media violence exposure. However, the study design made it impossible to determine the direction of effects; differences in anterior cingulate function could have been caused by violence exposure, or existing characteristics associated with the different brain activity may have predisposed these youth toward more violent programs or games.

A subsequent fMRI investigation revealed that the presence of a disruptive behavior disorder influenced how past media violence exposure was related to brain activity (Kalnin et al., 2011). These adolescents performed an emotional Stroop task, in which they were presented with aggressive (e.g., hit, harm) or nonaggressive (run, walk) action words, for which they identified, via button-press, the color of the ink with which they were printed. Aggressive words required participants to suppress any emotional response in order to respond as quickly as possible. In control youth, the amygdala, which responds strongly to emotionally arousing stimuli, had a greater response to violent words than in youth with high past media violence exposure. However, youth with a disruptive behavior disorder showed the opposite finding, with higher amygdala activity in the low-violence group, suggesting psychopathology may interact with the effects of media violence on the brain.

To better establish whether exposure to violent content could influence subsequent adolescent brain activity, a controlled fMRI experiment was designed. In this study, adolescents were randomly assigned to play one of two equally exciting, action-packed games for 30 minutes: an exciting, but nonviolent racing game, or a violent first-person shooter game (Hummer et al., 2010; Wang et al., 2009). Immediately after game play, teens were scanned with fMRI while performing counting and emotional Stroop tasks related to emotional and cognitive control, each of which requires regulating automatic responses in order to respond correctly. The group that played violent games had lower interference-related dorsolateral prefrontal cortex activity during the counting Stroop, and higher amygdala activity to aggressive words during the emotional Stroop, relative to the nonviolent game group. In addition, medial prefrontal cortex activity had lower connectivity with the amygdala in the violent game group. These results suggest that inhibitory mechanisms were altered by violent game play, including the ability of prefrontal regions to inhibit the amygdala response to negative stimuli.

During a Go/No-Go task, participants were instructed to press a button to each presented letter (“Go”) except when the letter was an X (“No-Go”). Because No-Go trials were less common, cognitive or behavioral inhibition mediated in part by lateral prefrontal cortex was required to stop the more automatic button-press response. Nonviolent game players had greater right lateral prefrontal activity during No-Go trials compared with the violent game group. Since both games were rated to be similarly exciting, these results have indicated that the violent characteristics of the game may have triggered the different neural responses, indicating that playing a violent video game may attenuate inhibition.

In an fMRI study of healthy male adolescents (Strenziok et al., 2011), response and desensitization to violent videos were examined. Participants watched videos and judged whether the level of aggression was higher or lower compared with the previous video. Response to aggression on video was associated with activity across a wide set of regions, including bilateral inferior frontal cortices, anterior cingulate, fusiform gyrus, and occipital cortex. Investigators then examined for activity changes related to desensitization, diminished response to emotionally arousing stimuli following repeated exposures. A time-by-aggression level interaction was found in the left orbitofrontal cortex and bilateral parietal cortices, where activity decreased over time for more aggressive videos. This result provides evidence that brain activity related to both emotion (orbitofrontal) and attention-related (parietal) aspects of the violent film clips decreased as time went on, indicating neural desensitization.

This group also reported a relationship between brain structure and past self-reported media violence exposure (Strenziok et al., 2010). Gray matter density in the left lateral orbitofrontal cortex was higher with lower levels of reported television and movie violence in adolescence. In addition, recent work in our laboratory indicated that higher violent television exposure is related to lower frontoparietal white matter volume (Hummer, Kronenberger, Wang, Anderson, & Mathews, 2014). While this recent study was conducted in young adult males, the structural characteristics identified suggest that brain development prior to participation, much of which occurred during adolescence, was associated with violence exposure. Similarly, research has found exposure to real-life violence to be related to occipital cortex volume or maturity of visual-limbic tracts in young adults (Choi, Jeong, Polcari, Rohan, & Teicher, 2012; Tomoda, Polcari, Anderson, & Teicher, 2012).

This research fits into a somewhat larger pool of adult neuroimaging research regarding media violence, which has focused on mechanisms regarding desensitization and inhibitory control. For instance, adults with higher past exposure to violent video games have a reduced ERP response to violent images (Bartholow, Bushman, & Sestir, 2006), and the lower ERP responses were correlated with subsequently delivering a more aggressive, intense noise blast to opponents in a competitive game. A recent fMRI study examined brain activity in adults who viewed a violent film clip and compared their responses with those from individuals who watched a nonviolent clip (Guo et al., 2013). The violent clip group had a reduced neural response to images depicting pain in others in the sensorimotor cortex and insula, a brain network involved in evaluating pain in self and others.

Neuroimaging studies of adults have also found a relationship between cognitive control mechanisms and violent media exposure. For instance, Bailey, West, and Anderson (2010) reported that adults with high video game violence exposure had attenuated frontal ERP responses during high-conflict trials which required the greatest cognitive control mechanisms. These studies and others (Engelhardt, Bartholow, & Saults, 2011; Kelly, Grinband, & Hirsch, 2007; Mathiak & Weber, 2006) highlight the relationship between exposure to media violence and brain function, with a consistent association found between decreased activity in prefrontal control mechanisms in participants with greater media violence exposure cumulatively or immediately prior to testing. However, due to the dynamic nature of childhood brain development, it is not so easy to simply assume that neural findings from adults, even young adults, translate easily to children or adolescents.

The degree to which this adult research helps us understand how children's brains are affected by media violence is dependent on the similarities and differences between developing pediatric brains and more stable adult brains. Of course, the fundamental differences between children's and adult brains are precisely the reasons why studying how media violence affects young brains is of particular interest. The complex trajectory of childhood brain development, as outlined earlier, makes this time period more vulnerable to substantial, long-term effects of environmental stimuli, including media violence.

### **Interpreting Imaging Research Through a Neurodevelopment Lens**

Given the significant evidence associating greater media violence exposure with both short- and long-term increases in aggressive thoughts, feelings, and behaviors, there is a strong need to understand the mechanisms underlying emotional and behavioral control and how these mechanisms are influenced by media violence. Thus, research highlighting effects of media violence on prefrontal executive function, and prefrontal interaction with emotion-sensitive regions, may be especially valuable to characterizing media violence effects.

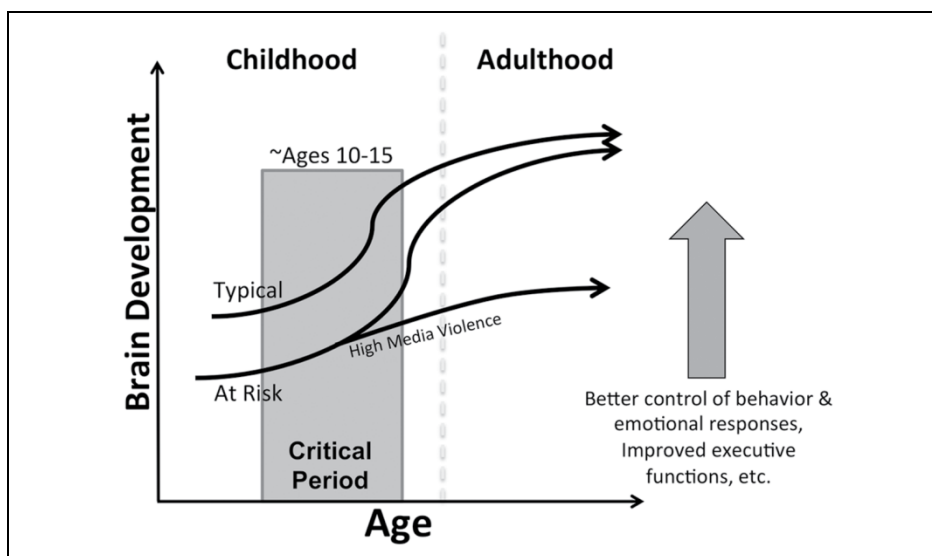
For instance, playing a violent video game was found to reduce subsequent prefrontal activity (compared with a nonviolent game) by Wang et al. (2009) and Hummer et al. (2010) during tasks requiring control of cognitive processes or behavior. These tasks were specifically designed and implemented to engage prefrontal control capabilities. Prefrontal activity during similar tasks has been shown to change across childhood and adolescence (Luna et al., 2001). To understand what this exposure-related reduction in prefrontal activity means in terms of neurodevelopment, additional research must be carried out at different ages, or ideally, at multiple ages within the same participants. Moreover, we must strive to clarify how any prefrontal changes found are related to real-world psychological and behavioral traits of interest.

The interaction of prefrontal regions with emotion-sensitive limbic regions is a key part of emotion regulation (Banks, Eddy, Angstadt, Nathan, & Phan, 2007; Gross, 2002; Hariri, Bookheimer, & Mazziotta, 2000). Characterizing how exposure to media violence may affect maturation of the relationship between these regions during



childhood and adolescence is an important focus of neuroimaging research. Teens who played a violent game for 30 minutes were found to have lower medial prefrontal cortex control over the amygdala during presentation of aggressive words (Wang et al., 2009). The amygdala acts as an alert system for the brain, activating strongest in response to stimuli that demand immediate attention or a behavioral response. Appropriate control of the amygdala by prefrontal regions helps limit overly impulsive, emotional responses to provocation. Since the adolescent prefrontal cortex has not yet reached full maturity, extensive media violence exposure during adolescence may impair prefrontal-limbic communication and have detrimental effects on emotion regulation into adulthood. However, neuroimaging research has yet to examine long-term causal effects of media violence exposure on prefrontal capabilities, partially due to methodological limitations in what we can ascertain with an experimental design.

This framework is helpful for interpreting research regarding long-term effects of media violence exposure (Gentile, Coyne, & Walsh, 2011; Huesmann et al., 2003). Longitudinal research has indicated that, even when controlling for childhood aggression levels, adults with greater exposure to television violence as children exhibited more aggressive behaviors as adults (Huesmann et al., 2003). This long-term outcome may be due to altering the neurodevelopmental trajectory of the prefrontal cortex (Figure 1), resulting in diminished inhibitory control of negative behaviors and an increased likelihood of aggressive behavior.



**Figure 1.** A hypothesized model for neurodevelopmental effects of media violence.

*Note.* One potential model for media violence effects on brain development is depicted. Individuals demonstrating poor or delayed development may be more susceptible to potential effects of high levels of media violence, particularly during a sensitive period in early adolescence. Brain development may be quantified by a variety of neuroimaging methods, including diffusion tensor imaging indicators of microstructural properties of white matter tracts.

## Optimizing Neuroimaging in Media Effects Research

As with any research method, neuroimaging has its limitations. Participants are lying alone in an enclosed space and must remain still, so it is difficult to simulate real-world exposure to violent media, limiting external validity. Laboratory or epidemiologic data may better reflect or quantify real-world outcomes, but cannot elucidate underlying biological mechanisms. The research value of neuroimaging is dependent on our ability to integrate the neurobiological and neurodevelopmental information it can glean with research using other methodologies to investigate cognitive, emotional, and behavioral processes.

It is also important to triangulate neuroimaging data with results from other methodologies in order to generate meaningful findings on real clinical outcomes. Investigators must take care not to overestimate the novelty or significance of findings simply because, for instance, fMRI images are presented. One early brain imaging primer laid out this notion in a straight-forward, yet necessary, principle: “. . . investigations that simply show there are changes in brain activation that correspond to some aspect of social cognition, emotion, or behavior contribute little—after all, what scientific theory would predict otherwise!” (Cacioppo et al., 2003, p. 652). In other words, finding brain activity changes in response to media violence is not, on its own, novel evidence that media violence exposure is having a meaningful effect. After all, substantial behavioral research already provides evidence that increased levels of aggression can follow exposure to media violence—so of course the brain is involved. The key is in using neuroimaging to contribute to understanding the nature and mechanism of the effect.

In other words, altered brain activity following violent video game exposure does not provide definitive proof that the games are “good” or “bad” for players, or even that the games increase aggression. These studies do, however, provide evidence that inhibitory control deficits may drive increases in aggression found with other research paradigms. Interpreting neuroimaging results in studying media effects is best performed with a full understanding of the limitations of the approach and of the background psychological literature.

Similarly, investigators should not shy away from imaging paradigms based on a lack of complexity alone—relatively simple paradigms can provide results with more clarity, even if external validity is lower. During cognitive control fMRI paradigms, such as the Go/No-Go, the in-scanner tasks are not overly difficult and the participants are in a relaxed state, so the true capacity of prefrontal cortex is likely not reached. Yet we hope to extrapolate findings to how the region would act during heightened states of arousal and/or peer-influenced situations, when overt aggressive behavior is more likely and prefrontal control more necessary. This principal is similar to a physician’s stethoscope, which is often used on a still, relaxed patient in the doctor’s office to detect potential concerns, even though the risk of heart problems is greatest when a person is much more active. Establishing ecological validity in fMRI paradigms can be even more problematic than psychological laboratory experiments, given the constraints of testing immobile participants in an MRI scanner. Nevertheless, clearly identifying changes in inhibitory control mechanisms provides an excellent complement to existing psychological research.

We must take care to not overextend the conclusions we draw from such findings. To maximize the generalizability of results, one option is to examine the relationship between behavior measured outside the scanner with brain activity data. In this manner, the strengths of multiple methods can be more easily combined. If repeated attempts to find a relationship between brain activity changes and physiological, emotional, or behavioral changes outside the scanner are unsuccessful, it is possible that the importance of neural changes is minimal. That said, it would certainly be difficult to ascertain that an identified neural change has absolutely no effect on real-world thoughts or behaviors.

## **Future Directions**

Ultimately, a main purpose of such research is to identify and limit any potential detrimental effects that exposure to media violence may have on the developing brain. Neuroimaging research on the topic should therefore focus on precisely characterizing how violent media affects the brain, establishing what characteristics of viewing or game play are most influential, and determining who is most at risk for negative effects. Answering these questions will provide direction on where to focus prevention, interventions, and policy recommendations in order to limit negative long-term effects on the brain.

One consistent difficulty in studying long-term effects of media violence research is distinguishing whether exposure to large amounts of media violence actually *contributes to* increases in aggression (Anderson et al., 2003; Paik & Comstock, 1994) or poorer executive function (Kronenberger et al., 2005), or whether individuals with worse attention and weaker self-control are drawn to violent media. Unfortunately, it is ethically impossible to develop a longitudinal experimental investigation of the effects of exposure to media violence. We cannot assign randomized groups to solely watch educational programming or violent programming for several years during childhood and see what happens. Instead, evidence must be combined from complementary sources: observational studies that identify the outcomes with which past media violence exposure is correlated; longitudinal designs that follow media habits and measure behaviors over many years; experimental investigations that can more directly pinpoint violence exposure as a cause of short-term effects; and training or intervention studies that can determine whether long-term effects can be reduced. To date, neuroimaging studies have started to address several of these avenues in children and adults, particularly long-term correlational and short-term experimental research (Hummer et al., 2010; Mathews et al., 2005; Strenziok et al., 2011). Going forward, such work should continue to examine prefrontal-limbic interactions in particular, in order to investigate control of aggressive thoughts and behaviors.

Extended neuroimaging studies, with repeated measures within the same individuals, would be immensely helpful in completing the story in whether and how media violence exposure influences brain development. Longitudinal neuroimaging studies, which measure neural characteristics at several points during childhood, have been essential to outlining the trajectory of childhood and adolescent brain development (Giedd, 2004; Giedd et al., 1999; Gogtay et al., 2004). Similar research, adding continuous measurements of television, film, and video game habits, can help

ascertain whether ongoing neurodevelopmental changes are influenced by current violence exposure. For example, if structural characteristics indicating delayed development (e.g., lower FA measured by DTI) predict later levels of violent video game play, then media violence exposure may be viewed as the result, rather than the cause of developmental issues. On the other hand, if violence exposure predicts neural changes after controlling for age-related developments, then the evidence would support the hypothesis that such exposure affects brain development. These questions are significant given that the trajectory of cortical thickness and white matter maturation is linked to attention problems (Konrad & Eickhoff, 2010; Shaw et al., 2007) or other neurocognitive functions (Mabbott et al., 2006; Olson et al., 2009; Silveri, Tzilos, & Yurgelun-Todd, 2008), and both experimental and correlational research link media violence to deficits in attention and other facets of self-control (Bailey et al., 2010; Bushman & Huesmann, 2006; Kronenberger et al., 2005).

One can also propose a model in which children who demonstrate somewhat delayed development and/or have a higher vulnerability to the impact of environmental factors are driven either further “off-course” by extensive exposure to media violence (Piotrowski & Valkenburg, **IN PRESS[PE: Please include year of publication and provide complete reference details for Piotrowski & Valkenburg, IN PRESS at the proof stage.]**). A similar model is used in characterizing the effect that adolescent substance abuse may have on long-term brain development (Figure 1). Longitudinal neuroimaging investigations could clarify whether such a model is appropriate for media violence.

Along these lines, it is important to identify any potential risk factors that alter the degree to which media violence may influence a person’s brain. Media violence is just like any other experience, such as an exercise regimen, that enacts biological changes, with the strength and manner of effects based on a combination of an individual’s baseline characteristics, susceptibility to change, and features of the experience. In this case, baseline factors of interest include not only existing neurobiological characteristics which can be assessed through imaging techniques but also genetic, family environment, and personality variables.

Moreover, the effects of various contextual features of television or video game exposure, including whether games are played in individual or social/multiplayer settings, are also important factors to explore in future neuroimaging investigations. Considering the many nuances of video games, distinguishing the impact of each specific aspect of game play on subsequent brain function is increasingly difficult, and investigators should always take care not to lose the scientific forest for the trees. In addition, while the focus of this review is to identify potential effects of violent media exposure on brain development, the influence of positive or prosocial video games or other media interactions should not be ignored. Certainly, violence is not the only game characteristic that may shape the brain. Indeed, neuroimaging evidence has indicated that cognitive training games may strengthen maturation of prefrontal regions (McNab et al., 2009; Mozolic, Hayasaka, & Laurienti, 2010).

## Summary

Neuroimaging tools are vital to characterizing brain development during childhood and adolescence. Neurodevelopment is affected by a variety of external influences, including the potential impact of various forms of media violence. Neuroimaging techniques provide an essential tool to investigate how high levels of media violence exposure may modify brain development. To optimize the utility of neuroimaging tools, investigators must design and interpret imaging studies integrated with other media violence research methods, including survey data, behavioral measurements, and physiological recordings. To date, neuroimaging research suggests that increased exposure to violent media content is associated with lower prefrontal control of emotions or behaviors and with delayed development of frontal or frontoparietal regions. As neuroimaging techniques evolve and measurement resolution of brain form and function continue to improve, researchers should integrate these methods with diverse research tools to focus on understanding long-term effects of exposure to violent media on the development of young brains, focusing on prefrontal and limbic regions and their interactions.

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