

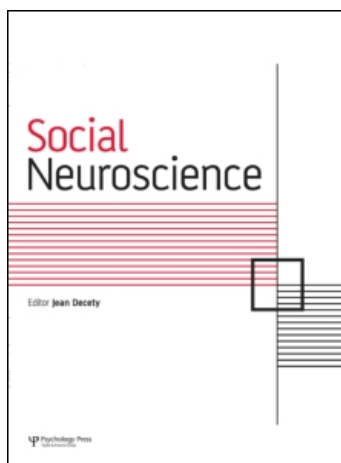
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The neural processing of voluntary completed, real and virtual violent and nonviolent computer game scenarios displaying predefined actions in gamers and nongamers

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The neural processing of voluntary completed, real and virtual violent and nonviolent computer game scenarios displaying predefined actions in gamers and nongamers

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Studies investigating the effects of violent computer and video game playing have resulted in heterogeneous outcomes. It has been assumed that there is a decreased ability to differentiate between virtuality and reality in people that play these games intensively. fMRI data of a group of young males with (gamers) and without (controls) a history of long-term violent computer game playing experience were obtained during the presentation of computer game and realistic video sequences. In gamers the processing of real violence in contrast to nonviolence produced activation clusters in right inferior frontal, left lingual and superior temporal brain regions. Virtual violence activated a network comprising bilateral inferior frontal, occipital, postcentral, right middle temporal, and left fusiform regions. Control participants showed extended left frontal, insula and superior frontal activations during the processing of real, and posterior activations during the processing of virtual violent scenarios. The data suggest that the ability to differentiate automatically between real and virtual violence has not been diminished by a long-term history of violent video game play, nor have gamers' neural responses to real violence in particular been subject to desensitization processes. However, analyses of individual data indicated that group-related analyses reflect only a small part of actual individual different neural network involvement, suggesting that the consideration of individual learning history is sufficient for the present discussion.

Keywords: fMRI; Violent computer games; Aggression; Violence; Individuality; Virtuality; Reality.

INTRODUCTION

Video and computer games, as electronic media played in arcades, on home consoles, and on computer screens (Gentile & Anderson, 2006) have become a very popular spare-time activity for children, adolescents, and adults (Bryce & Rutter, 2003; Entertainment Software Association,

2005). These games provide a medium that allows the players to actively engage in narrative contexts, challenges them on a skill-based as well as on a cognitive level and simply provides excitement and thrills (Jansz, 2005; Klimmt, Rizzo, Vorderer, Koch, & Fischer, 2009). Furthermore, recent advances in computer and video game development have created games with a high level of

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real-life relations, interactivity and involvement (Gentile & Anderson, 2006, Klimmt, Vorderer, & Ritterfeld, 2007). Soon after the appearance of the first video games containing violent context ("violent games" incorporate "aggression that has extreme harm as its goal", according to Anderson & Bushman, 2002), the potential effects of violent video game play on real-life behavior were discussed (see Gentile & Anderson, 2006). Subsequently, the majority of studies investigating the effects of video games focused on the harmful effects, especially of violent video games, on cognitive, emotional, physiological, and behavioral aspects related to aggression or violence (for reviews see Bensley & Van Eenwyk, 2001; Sherry, 2001). These studies especially considered reported cases of targeted violence, in which delinquent actions resembled actions of violent video games (Anderson, 2004; Anderson & Bushman, 2001; Anderson & Dill, 2000; Dill & Dill, 1998; Krahé & Möller, 2004; Vastag, 2004). Although findings from studies regarding the effects of violent video game play are heterogeneous, and there are no results from longitudinal studies as there are for the effects of TV violence (Bensley & Van Eenwyk, 2001), violent video games tend to be one of the most popular scapegoats of the twenty-first century. At the same time, gamers are imputed to be subject to transfer processes between the virtual and the real world, which means a takeover effect of similar or same cognitions or actions into different phenomenal worlds (such as the real and the virtual worlds). This ranges from suggested emotional transfer according to the excitation transfer model (Zillmann, 1983, cited in Geen & Donnerstein, 1998) to Pavlovian conditioning (McCabe et al., 2009) and/or to actual aggressive action transfers (Gentile & Gentile, 2007), suggesting equal actions in the real and in the virtual world. These theoretical approaches, however, provide monocausal explanations for an obviously multicausal problem. Against the background of schema theory approaches, alternative explanations were suggested by research groups investigating gamers' experiences with different phenomenal worlds, such as the real and the virtual world (Fritz, 2005). It was argued that gamers manage to apply thoughts and action-guidelines to the correct sources and they were assumed to still have an intact framing competence, which means that they could still apply thoughts and action scripts to the respective worlds—the virtual and real ones.

In the present study, the aim was to focus on the processes actually present while one is confronted with violent computer game scenarios, and to address potential neural correlates of the distinction between perceiving virtual and real displays of computer-game-related violence in individuals with a long-term history of playing violent computer games. Functional magnetic resonance imaging (fMRI) was used to examine brain activation patterns (distributions of blood-oxygen-level-dependent (BOLD) activation clusters as a correlate of neural brain activation) during the processing of virtual and realistic violent scenarios. Typical violent and nonviolent scenarios were captured from a first-person ego-shooter, and a parallelized video version with real human actors showing comparable locations and actions was produced and presented to gamers and a group of control participants. A button press response was included to ask participants to voluntarily initiate the completion of the displayed scenarios. This ensured that both gamers and controls executed the situation-related action in the same way, but with a voluntary component comparable to real gaming. As both gamers and controls previously confirmed their consent to participate in the present study, which includes *inter alia* the voluntary confirmation of violent action scenarios, this approach seems to provide high ecological validity.

It was hypothesized that in the case of support of existing studies suggesting takeover effects, the processing of virtual and real violence-related aspects should produce a considerable overlap of brain activation patterns especially in gamers. Otherwise, in the case of a falsification of these theories and a verification of theoretical schema theory-based approaches, as described above, it might be concluded that in gamers framing competence or, say, the ability to automatically apply thoughts and action scripts to the appropriate virtual and real context is still present, even after years of intense violent computer game play. To examine this, we conducted both complex and simple group and additional individual analyses on fMRI data.

MATERIALS AND METHODS

The group of participants consisted of 22 German male adults between 21 and 33 years (mean age 25.9, $SD = 2.9$ years), who were recruited from a student population from the University of Bremen. They were assigned to one of two groups, gamers ($n = 11$) or controls ($n = 11$), based on

their self-reported experience with (violent) video games. Such experience was assessed using an in-house questionnaire of media use.

This questionnaire inquired of all participants their age of first having played a video game, their age of first having played a violent video game, and the regularity of their individual game play. Furthermore, all participants were asked about the annual and monthly frequency and duration of general as well as of violent video game play, and the last time they had played intensively. We also inquired about names of the games they preferably played, the contexts in which they were most likely to play, if they preferred to play by themselves or with friends, and the impact that their game play had on their emotional life (e.g. arousing, calming). Furthermore, the questionnaire inquired about gaming-related thoughts and strategies (for example, "Do you sometimes think about game strategies in a nongaming context"?). Group assignment to the gamer group first required that the participant regarded himself as a "computer gamer with violent video game experience". Furthermore, to be assigned to the gamer group, a participant had to meet all following criteria: The percentage to which the reported game play consisted of violent video games had to be at least 50%, the reported annual frequency of violent video game play had to be at least once a month, and the reported frequency of violent video game play during the four weeks prior to the testing session had to be at least once a week. Two gamers currently did not engage as much in violent video game play as they had prior to the beginning of their studies, yet, due to the content of the games they reported to have played regularly for over seven years, they were both assigned to the gamer group.

Compared to controls, the gamers had a significantly higher frequency of video game, $t(20) = 4.1$, $p < .01$, and violent video game, $t(20) = 3.3$, $p < .01$, use over the previous four weeks. The analysis of a t -test for independent samples revealed that the gamers had played significantly more violent video games than the controls over the previous 12 months, gamers: $M = 131$ h/year, controls: $M = 6$ h/year, $t(20) = 2.45$, $p < .01$, as well as over the four weeks prior to the testing session, gamers: $M = 14$ h/month, controls: $M = 0.4$ h/month, $t(20) = 3.98$, $p < .01$. Significantly more gamers than controls reported that they thought about strategies regarding game-play in a nongaming context, $\chi^2(2) = 6.39$, $p < .01$. Except for variables concerning (violent) computer game play, there were no systematic differences (e.g.

regarding age or education) between the two groups of participants, which might have confounded the functional imaging results. All participants were right-handed according to the Edinburgh Handedness Inventory (Oldfield, 1971), and did not report any history of psychiatric or neurological illness, abnormal vision, regular drug use, or current medication. The participants were familiarized with the stimulus presentation environment and underwent a demonstration trial before entering the scanning room. They were informed about the study procedure and gave written consent to participate in the experiment. The experimental set-up was designed according to the Code of Ethics of the World Medical Association (Declaration of Helsinki, published in *British Medical Journal*, July 18, 1964), and the study was approved by the local ethics committee at the University of Bremen.

The stimuli for the fMRI experiment consisted of video clips, which displayed scenarios comprising two modalities, real and virtual context, with three categories each: low-level-baseline, nonviolent, and violent content. The virtual stimuli were captured from a prominent first-person-shooter computer game, which falls in the category of highly developed ego-shooters with a narrative component. Scenes depicted situations in different surroundings such as hallways or between walls. The real stimuli consisted of video scenes displaying real situations parallelized to the actions in the virtual scenes in order to resemble the same contexts in real and virtual stimuli. Two actors with martial arts training played the two characters from the computer game (each defined as either friend or enemy) and were dressed like them. Because one of the game characters had a face mask and the other's face was visible, game character attribution was counterbalanced across participants within each group to control for character-specific effects. The videos displaying real scenarios were filmed at locations that resembled the context of the virtual scenes by a cameraman who also served as an involved character, as he filmed from the first-person perspective during the displayed actions. The cameraman held a practice gun in his right hand just like the game character in the ego-shooter. Therefore, participants in the experiment watched virtual and real scenes from a first-person perspective and could see "their" right hand carrying a gun.

In Figure 1 the different trial elements are illustrated. Each trial began with the first-person character running around a corner for 4 s. The

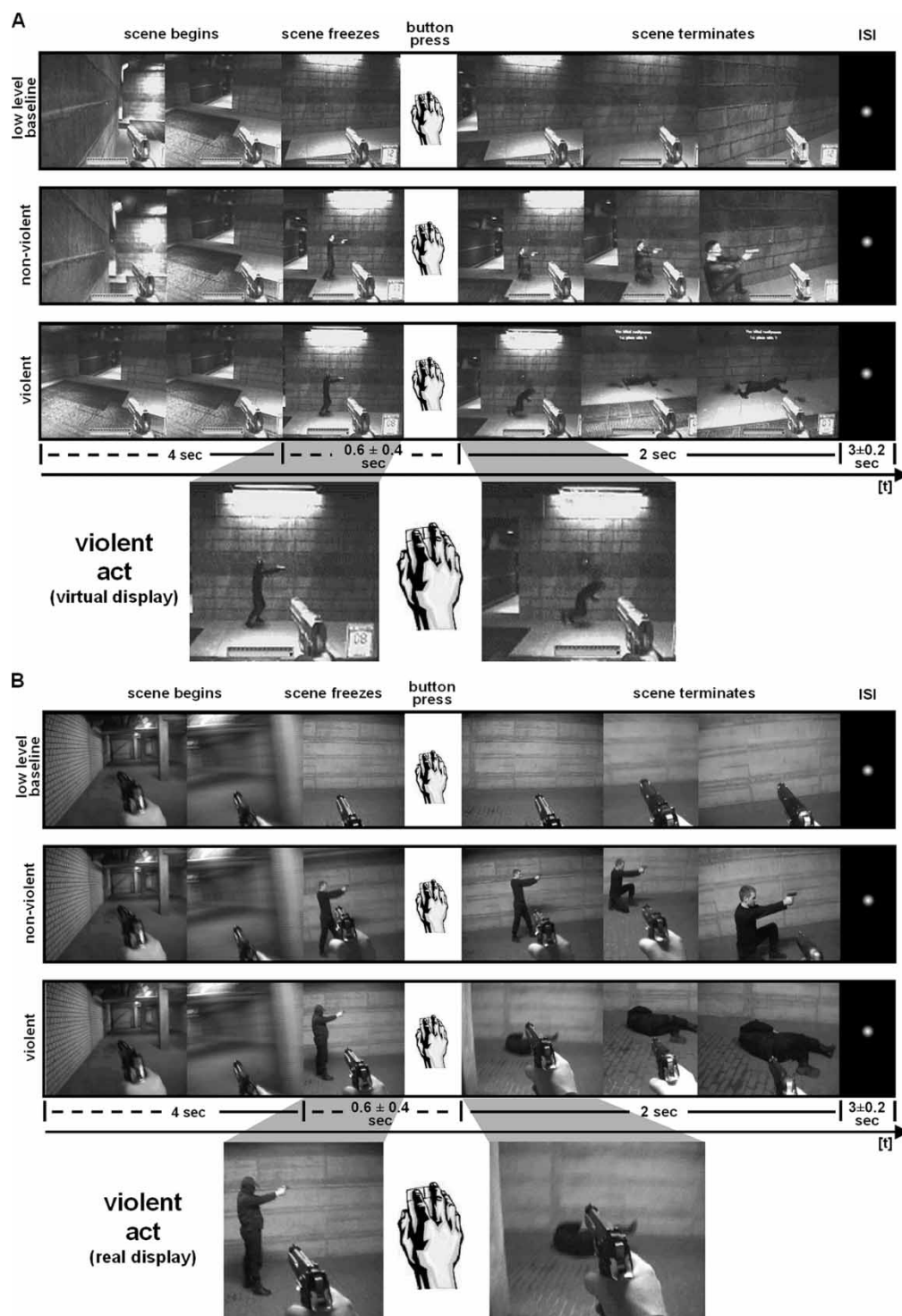


Figure 1. Trial description for sequentially presented task elements for the virtual (A) and the real (B) modality. Each trial started with the first-person character running around a corner for 4 s. The character was then confronted with one of three possible situations according to the stimulus categories: (1) A wall or place with no person visible (low-level-baseline), (2) an armed friend (nonviolent), (3) and an armed enemy (violent). The scene then froze and participants in the experiment were told to press a button with their right index finger to allow the scene to continue. Depending to the stimulus category, the scene appropriately terminated with the character: (1) approaching the displayed wall or place (low-level-baseline), (2) approaching the friend and resting next to him (nonviolent), (3) or shooting the enemy (violent). The total length of each trial lasting from the beginning of a scene to the beginning of the fixation dot was approximately 7 s.

character was then confronted with one of three possible situations according to the stimulus categories: (1) a wall or place with no person visible (low-level-baseline), (2) an armed friend (nonviolent), (3) an armed enemy (violent). The scene then froze and participants in the experiment were told to press a button with their right index finger to allow the scene to continue. This button press served as a computer-game-like executive action, and was controlled by a fibre-optic MR-compatible button response equipment. Depending on the stimulus category, the scene appropriately terminated with the character: (1) approaching the displayed wall or place (low-level-baseline), (2) approaching the friend and resting next to him (nonviolent), (3) shooting the enemy and approaching the dead body (violent).

All scenes started alike but ended in a different way, according to what the character was confronted with after turning the corner. The sequence did not terminate until the button press occurred. The total length of each trial lasting from the beginning of a scene to the beginning of the fixation dot was approximately 7 s (see Figure 1 for an illustration of the trial elements). Stimuli were presented in a pseudorandomized nonstationary probabilistic sequence (Friston, 2000). There were ten different scenarios that were each presented four times along the experimental run, which comprised a total of 240 experimental stimuli (ten different scenarios by three categories and two modalities presented four times, visual angle below 4.0°). The stimuli were presented in two blocks, each presenting stimuli of only one modality (120 virtual scenes or 120 real scenes; see Figure 2 for an illustration of the trial sequences). The functional and structural MRI data were obtained using a 3-T Siemens Magnetom Allegra[®] system (Siemens, Erlangen, Germany) equipped with a standard quadrature head coil. Changes in BOLD T2*-weighted MR signal were measured using a gradient echo-planar imaging (EPI) sequence (44 3-mm thick axial (AC-PC) slices in interleaved acquisition order with whole brain coverage; FOV = 192×192 mm, 64×64 matrix, TR = 2500 ms, TE = 30 ms, flip angle = 90°). About 500 volumes were obtained during one complete run. Structural MRI data were collected after the functional scanning runs (MPRAGE-magnetization prepared rage; 160 slices, slice thickness of 1 mm, FOV = 256×256 ; matrix: 256×256 , TI = 900 ms, TR = 2300 ms, TE = 4.38 ms; resulting in 1 mm^3 of voxel with the same orientation).

Image analysis was performed using the Statistical Parametric Mapping software package (SPM2, Wellcome Department of Cognitive Neurology, London, UK) on a Matlab 6.5 platform (The MathWorks, Natick, MA). For each session and participant, images were slice-time corrected, motion estimated, realigned, normalized to the Montreal Neurological Institute Template (MNI) (Collins, 1994), and smoothed using an isotropic Gaussian kernel (full width half maximum = 8 mm) prior to further analysis. Global effects were removed from the functional MRI data and a high-pass filter (200 s) was applied to remove low-frequency signal drifts. Trial elements of the complete trial of approximately 7 s were modeled separately by the standard canonical hemodynamic response function (SPM2). The trial elements modeled in the design matrix comprised the beginning of each trial until the video stops, the time period until a button response occurred, and the last part of the video sequence, during which the stimulus category-specific action became evident. Regressors for the last trial element served as the basis for contrasting violent vs. nonviolent conditions. The preprocessed data sets were further analyzed using a second-level random effects model (Holmes & Friston, 1998). To focus on activation patterns produced by the violent aspect of the respective scenarios, second-level analyses were performed by calculating a *t*-statistic for predetermined category effects at each voxel for each participant and experimental run, producing a statistical image for the contrasts violent vs. nonviolent situations in each modality (real and virtual). Individual contrasts were further used to identify the main task effects by means of a one sample *t*-test. Oriented on former functional imaging studies on complex mental aspects, and to provide comparability to other studies, for modality related violent vs. nonviolent category contrasts a threshold of $p < .001$ (corrected by an *ad hoc* determined lowered significance threshold, $k \geq 10$ voxel cluster size) was applied to identify significant activation clusters. MNI-coordinates of activation were converted from the SPM output into Talairach space with a transformation algorithm (mni2tal.m, available at www.mrc-cbu.cam.ac.uk/Imaging/mnispac.html). The Talairach Daemon software (www.talairach.org/daemon.html) was used as a reference template based on the Talairach atlas (Talairach & Tournoux, 1988) to determine anatomical regions of interest (Lancaster, 1997).

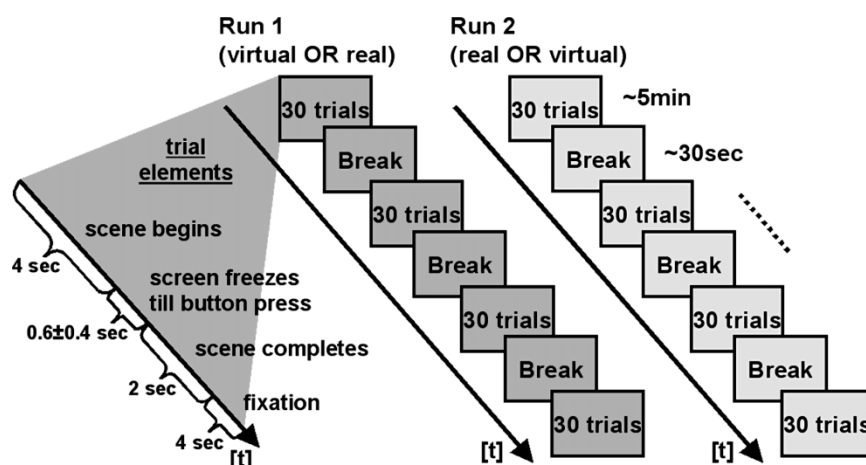


Figure 2. Stimuli of different scenario types were presented in a pseudorandomized nonstationary probabilistic sequence. There were ten different scenarios that were repeatedly presented four times along the experimental run, which comprised a total of 240 experimental stimuli (ten different scenarios by three categories and two modalities presented four times). The stimuli were presented in two blocks, each presenting stimuli of only one modality (120 realistic scenes or 120 virtual scenes). The presentation order of runs was balanced across study participants. As one of the game characters wore a face mask, the attribution of who is the “friend” or the “enemy” was counterbalanced across participants to control for face-specific effects. Trial elements are illustrated at the left side.

Common activation patterns for gamers and control participants and for the different modalities (real and virtual) were investigated by conjunction analyses (Nichols, Brett, Andersson, Wager, & Poline, 2005), including the contrast violent vs. nonviolent tasks. To confirm presentation-modality-related group differences, interaction analyses were calculated for gamers vs. controls and controls vs. gamers including the repeated measurement factor real vs. virtual modality based on contrast images violent vs. nonviolent scenarios. All complex analyses were based on a statistical threshold of $p < .001$ ($k \geq 10$ voxel cluster size) comparable to the one-sample t -test analyses reported above.

FMRI data of the present study were also analyzed at an individual level. For each participant first-level analyses were performed for violent vs. nonviolent scenarios separately for real and virtual modality. Comparable to group analyses, a threshold of $p < .001$ ($k \geq 10$ voxel cluster size) was applied in all individuals to identify significant activation clusters. The revealed activation patterns were inspected for anatomical regions to be involved in the modality-related processing of violent vs. nonviolent scenarios, and the accordance of group analyses with single individual data was parameterized as the percentage of principal anatomical overlap between single individual and group data.

To examine individual data in more detail, a parameter that relatively quantifies the overlap of

activations across anatomical regions between modalities was determined. As a premise, when more than one activation focus was located in one anatomical region (e.g., right cerebellum or left middle frontal gyrus), this region was counted as one activated region. This procedure is largely substantiated as a good methodological approach by studies on complex mental processing showing that there are considerable differences across individuals in the localization of task-related activations both within one and across different anatomical region(s) (e.g., Burbaud et al., 2000; Wang, Kakigi, & Hoshiyama, 2001). First, the number of activated anatomical regions was determined for each individual and modality. Thereafter, e.g., for the real modality, the number of regions that were also activated in the virtual modality was divided by the overall number of activated regions in the real modality, and vice versa, to get individual percentage values of relative principal overlap of regional brain activity between modalities. Group-related differences were calculated by respective t -statistics.

RESULTS

Group analyses on fMRI data: Violent vs. nonviolent condition contrast

For all group- and modality-related violent vs. nonviolent condition second level t -contrasts,

Talairach coordinates and statistical parameters are listed in Table 1. Activation patterns are illustrated in Figure 3. For interaction analyses, Talairach coordinates and statistical parameters are listed in Table 2.

In the real modality gamers showed right inferior frontal, left lingual, and left superior temporal activation patterns. During the presentation of virtual scenes, they showed activation patterns in regions comprising left and right inferior frontal gyrus, left postcentral gyrus, left and right middle occipital gyrus, left inferior occipital gyrus and cuneus, right middle temporal gyrus, and left fusiform gyrus.

In the real modality control participants showed left superior, middle and inferior frontal, bilateral medial frontal, left superior temporal

activation patterns, and insula activation for the violent vs. nonviolent condition contrast. When presented with virtual scenes they showed activation foci in left paracentral and left inferior parietal lobules, left and right precuneus, left inferior occipital gyrus, left and right cuneus, and left cerebellum.

Both gamers and control participants showed activation patterns in left superior temporal gyrus for the virtual, and in left inferior occipital gyrus and cuneus for the real modality. Gamers showed right inferior frontal activation for both the virtual and the real modality.

Conjunction analyses ($p < .001$, $k \geq 10$ voxels) including group- and/or modality-related violent vs. nonviolent condition contrasts did not reveal any significant results. Group interaction analyses

TABLE 1

Talairach coordinates, anatomical regions (identified with 9 mm tolerance), and t -scores for the contrast violent versus nonviolent scenarios in gamers and nongamers (controls), and for the virtual and real modalities

Anatomical region	H	Violent vs. nonviolent scenario							
		Real modality				Virtual modality			
		Gamers		Controls		Gamers		Controls	
		T	x, y, z	T	x, y, z	T	x, y, z	T	x, y, z
Superior frontal gyrus	L			5.5	-32 52 23				
	L			4.8	-6 26 54				
Medial frontal gyrus	B			4.8	0 44 25				
Middle frontal gyrus	L			6.0	-28 59 19				
Inferior frontal gyrus	L			5.9	-40 19 -1	6.8	-53 17 27		
	L			5.2	-51 10 14	5.5	-48 11 23		
	L					4.9	-57 11 33		
	R	6.0	30 23 -13			5.3	57 17 21		
	R	5.2	53 19 -4						
Insula	L			6.2	-53 -38 20				
Paracentral lobule	L							4.8	-2 -36 50
Postcentral gyrus	L					4.8	-50 -22 56		
Inferior parietal lobule	L							6.2	-57 -53 38
Precuneus	L							5.3	-4 -79 46
	R							5.1	26 -77 44
Middle occipital gyrus	L					5.4	-38 -83 1		
	L					4.8	-26 -95 8		
	R					5.7	48 -68 -10		
Inferior occipital gyrus/cuneus	L					6.0	-26 -91 1	5.6	-28 -84 -9
Cuneus	L							5.0	-8 -96 27
	L							4.9	-2 -94 16
	R							8.6	12 -75 17
Lingual gyrus	L	7.1	-4 -91 -4						
Superior temporal gyrus	L	6.4	-55 10 0	6.9	-42 -8 -11				
	L	6.2	-34 15 -19						
Middle temporal gyrus	R					7.1	55	-60	1
	R					4.7	57 -53 -9		
Fusiform gyrus	L					4.7	-46 -57 -11		
Cerebellum	L							5.8	-30 -69 -17

Notes: All contrasts $p < .001$, $k \geq 10$ voxel threshold.

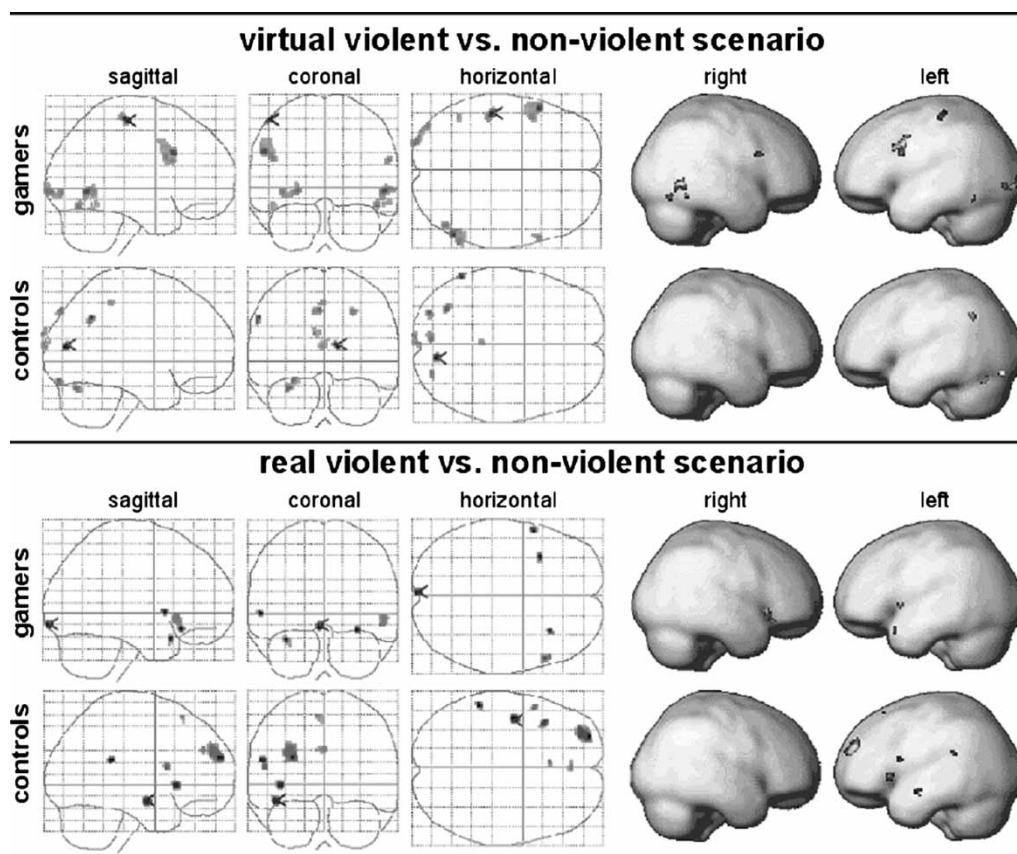


Figure 3. Glass-brain views (left) and rendered statistics (right) for violent versus nonviolent scenario contrasts ($p < .001$, $k \geq 10$ voxel threshold). Upper panel shows activation patterns for the virtual and lower panel for the real modality. MNI to Talairach transformed coordinates are given in Table 1.

confirmed t -test analyses as reported above (see Table 2), but also provide evidence for presentation-modality-related group differences in cingulate gyrus, parahippocampal gyrus, and thalamus (please see below for further details).

Individual analyses on fMRI data: Violent vs. nonviolent condition contrast

Group analyses, as documented above, suggest only few focused activation foci reflecting the violent aspect of the mental stimulus processing. Analyses of individual activation patterns, however, revealed a more complex picture. Results for all single individual and modality-related violent vs. nonviolent condition first-level t -contrasts are described in Table 3 (virtual modality) and Table 4 (real modality). Single individual BOLD activation patterns are illustrated in Figure 4.

As first-level contrasts were not parametrically compared to second-level group contrasts, the respective interpretations of differences should be performed in a qualitative manner. Individual contrasts revealed activation patterns, which extends group analysis for all violent vs. nonviolent condition contrasts.

Considering all activation foci in anatomical brain regions (e.g., middle frontal gyrus or precuneus, separately for left and right hemisphere) for the virtual modality, gamers showed three regions to be involved in violence processing at group level, whereas across single individual analyses 54 regions were identified to be involved. This documents that at group level 5.6% of anatomical regions were identified to be involved in comparison to single individual analyses. For the real modality, group analyses showed eight (17.8%) regions to be involved compared to single individual analyses, which revealed 45 different anatomical regions as being involved. Control participants showed seven (14.9%) regions at group level compared to 47

TABLE 2

Talairach coordinates, anatomical regions (identified with 9 mm tolerance), and *t*-scores for the interaction analyses gamers vs. nongamers (controls) including the repeated measurement factor modality (real vs. virtual) based on contrast images violent vs. nonviolent scenarios

Anatomical region	<i>H</i>	<i>Real vs. virtual</i>			
		<i>Gamers > controls</i>		<i>Controls > gamers</i>	
		<i>T</i>	<i>x, y, z</i>	<i>T</i>	<i>x, y, z</i>
Medial frontal gyrus	L			4.2	−6 10 44
Paracentral lobule	L			4.3	−6 −21 43
Paracentral/medial frontal				5.0	−59 7 14
Inferior frontal gyrus	L			4.2	12 −17 47
Insula	L			4.2	−40 0 −3
Insula/claustrum	R			5.4	34 6 7
Postcentral gyrus	L	4.3	−40 −28 64	4.9	−12 −39 66
	L			4.7	−18 −34 62
	L			4.0	−38 −31 48
Inferior parietal lobule	L	4.7	−50 −53 38	4.6	−59 −28 29
	L			3.6	−51 −34 27
	L			5.3	−42 −36 22
Precuneus	B	4.1	0 −60 51		
Cingulate gyrus	R			4.3	10 −14 28
Posterior cingulate g.	L			5.4	−8 −36 20
Middle occipital gyrus/posterior cingulate g.	L			4.7	−26 −68 7
Lingual gyrus	L				
Superior temporal gyrus	L			4.2	−36 −25 7
Middle temporal gyrus	R			4.4	55 −41 4
Fusiform gyrus/parahippocampal gyrus	R			3.8	42 −32 −14
Thalamus	R			4.1	12 −11 4

Notes: All analyses $p < .001$, $k \geq 10$ voxel threshold.

different regions across single individuals for the virtual modality, and also seven (16.3%) regions at group level compared to 43 regions at single individual level for the real modality to be involved in the perceptual violence processing.

Except for left insula (for control participants in the virtual modality), all regions being potentially involved in task-related violence processing as identified in group analyses were located in neocortical rather than in subcortical regions and/or at least not in regions dedicated to emotion-processing. At single individual level, few individuals showed activation foci in, e.g., parahippocampal gyrus, thalamus, anterior cingulate gyrus, fusiform gyrus, and brainstem unsystematically distributed over both groups and modalities (see Tables 3 and 4 for further details).

Further analyses on individual fMRI data revealed more detailed results. The number of activated anatomical regions was determined for each individual and modality (see Tables 3 and 4 for a detailed listing of activated regions). Thereafter, e.g., for the real modality, the number of regions that were also activated in the virtual modality was divided by the overall number of

activated regions in the real modality, and vice versa. For gamers, in the virtual modality 11.3% ($SD = 8.9$) of the anatomical regions involved were also activated in the real modality. The other way round, in the real modality, 25.1% ($SD = 29.4$) of the activated regions were also involved in the virtual modality. For controls, in the virtual modality 20.7% ($SD = 13.1$) of the principal anatomical regions involved were also activated in the real modality. And the other way round, in the real modality, 17.1% ($SD = 17.9$) of the activated regions were also involved in the virtual modality. *F*-tests confirmed homoscedasticity between all group- and modality-related variances, which should enhance validity for subsequent group- and modality-related parametric *t*-tests. *T*-tests for dependent samples (within-group comparison between modalities) did not reveal any differences between modalities in the two groups. Two-tailed *t*-tests for independent samples revealed no group difference in the real modality, whereas in the virtual modality control participants showed a larger percentage of regions (20.7%; $SD = 13.1\%$) to be activated as also activated in the real modality than the

Number of activation foci in principal left/right anatomical brain regions for each single study participant for the contrast violent vs. nonviolent scenarios in the virtual stimulus modality

[illegible]

TABLE 3 (Continued)

	Violent vs. nonviolent scenario									
	Gamers					Controls				
Inferior temporal gyrus	0/1	0/2	0/1			1/0	2/2	1/0	2/0	1/0
Parahippocampal gyrus (PHG)							2/0		1/1	
Thalamus							2/2		2/1	0/1
Anterior cingulate gyrus			0/1	1/1	1/0			2/0	2/0	1/1
Posterior cingulate gyrus								2/0		
Basal ganglia			0/1	0/4			1/0		1/0	0/1
Cerebellum		0/1	2/0	0/1	2/1	0/2	5/3	5/6	0/3	4/1

Notes: G = gamer, C = control participant; $p < .001$, $k \geq 10$ voxel threshold.

gamers (11.3%; $SD = 8.9\%$), indicated by a statistical trend ($t = -2.0$; $p = .06$).

DISCUSSION

fMRI was used to explore brain activation patterns during the presentation of virtual and real violent compared to nonviolent scenarios via video clips in study participants with (gamers) and without (controls) a long-term history of violent video game playing.

In gamers the processing of real displays of violence in contrast to nonviolence produced brain activation patterns in right inferior frontal, left lingual and superior temporal brain regions, whereas virtual violence activated a network comprising bilateral inferior frontal, occipital, postcentral, right middle temporal, and left fusiform regions. Control participants showed activations in left frontal regions, in the insula and in superior frontal regions for the processing of real, and posterior activations during the processing of virtual violent scenarios. Group interaction analyses suggest an additional involvement of cingulate and parahippocampal gyri and thalamus in controls, whereas gamers seem to present additional presentation-modality-related differences in parietal regions when compared to controls. The latter analyses, however, might be influenced by a potentially reduced statistical restrictivity, which was generally discussed for complex fMRI analyses (see also Nichols & Hayasaka, 2003; Nichols et al., 2005). Analyses of individual data confirm this view, as some but not the majority of individuals showed activations in cingulate, parahippocampal, and thalamic brain regions. Individual data are discussed more in detail below.

The introductory hypotheses assumed that more violence-related computer gaming diminishes the ability to distinguish between reality and virtuality, and therefore gamers should show a larger overlap of activations for the processing of virtual and real displays of computer game scenarios with violent content than controls. The present data, however, do not support such an effect. Data analyses rather indicate a larger overlap for controls, which suggests that virtuality and the reality are better distinguished by gamers. The revealed brain activation patterns and possible conclusions will be discussed in detail.

Number of activation foci in principal left/right anatomical brain regions for each single study participant for the contrast violent vs. nonviolent scenarios in the real stimulus modality

	Violent vs. nonviolent scenario																					
	Gamers											Controls										
Study participant	G01	G02	G03	G04	G05	G06	G07	G08	G09	G10	G11	C01	C02	C03	C04	C05	C06	C07	C08	C09	C10	C11
Anatomical region																						
Superior frontal gyrus				3/0			1/0		0/2				0/3	2/0						1/0	0/1	2/0
Medial/sup. frontal gyrus																					1/0	
Medial frontal gyrus	1/0			2/1			2/0		0/2				0/1		1/0		1/0		0/1			
Precentral gyrus								0/2	0/1						1/0			1/0			0/1	
Middle frontal gyrus				1/1			2/0				0/1	0/2	2/4	0/1			2/0	1/3	1/1	3/3	4/2	
Inferior frontal gyrus			1/0	1/0			1/0		1/3		2/0	0/2	1/0	1/0		0/1		1/0	1/1	0/2	0/1	
Orbital gyrus									3/1													
Insula		1/0			1/0			1/0							1/0						0/1	
Paracentral lobe	1/1					3/1			1/0			0/1	1/1				1/0		2/0			
Postcentral gyrus			1/0			1/0		1/0					0/3			1/0						
Supramarginal gyrus							1/0								1/0							
Angular gyrus								0/1														
Inferior parietal lobe				0/2									0/1	0/2	2/0			1/0		1/0		
Precuneus		2/1		1/0				0/1					0/1							2/0		
Cuneus			1/0				1/0		1/0				0/1			1/0				0/1		
Middle occipital gyrus			1/1			1/0			0/2											2/4		
Inferior occipital gyrus				1/0																		
Lingual gyrus		0/1		0/1				1/0											1/0		2/0	
Fusiform gyrus				0/1			1/0	0/1		1/0												
Superior temporal gyrus		0/1		3/1	1/0	1/0			0/2	0/1	0/1			0/1		1/2			3/3		0/1	
Middle temporal gyrus		2/1	1/0	3/0		1/0					0/2			1/1	0/1	0/1			2/3	1/0	1/1	
Inferior temporal gyrus							1/0		0/1		0/1				0/1							
PHG/thalamus					0/1			0/1	1/1	1/0		0/1	1/3								1/0	

TABLE 4 (Continued)

	Violent vs. nonviolent scenario						
	Gamers			Controls			
Anterior cingulate gyrus			3/1				0/2
Posterior cingulate gyrus	3/1	3/0				1/1	
Basal ganglia	2/0		2/1				1/0
Brainstem/midbrain			0/1			1/0	
Cerebellum	1/0	2/5	3/3	8/2	1/0	0/1	0/2

Notes: G = gamer, C = control participant; $p < .001$, $k \geq 10$ voxel threshold.

Common brain activation patterns in gamers and controls during the perception of violent actions

There were regions commonly activated in gamers and in controls during the perception of real and virtual violence. During the perception of real violence both groups showed left lateralized activation patterns in the superior temporal gyrus. This region has been shown to be involved when individuals observed human actions (Carr, Iacoboni, Dubeau, Mazziotta, & Lenzi, 2003; Perrett et al., 1989; Perrett, Harries, Mistlin, & Hietanen, 1990), but also in relation to language perception (Binder, 2000; Karnath, 2001). Thus, real displays of violent-related content might generally induce activations in brain regions involved in the evaluation of social interaction and communication.

The present analyses additionally revealed extended activation patterns in left inferior occipital gyrus, including parts of the cuneus region during the perception of virtual violence, in both gamers and control participants. Although these brain areas are commonly held to be involved in primary visual processing and basic object recognition, the present results support an alternative approach that discusses these presumptive unimodal areas in the cerebral cortex as multisensory in nature (Ghazanfar & Schroeder, 2006), supporting the integrative nature of the cerebral cortex when dealing with complex multimodal information that requires fast and efficient processing. Thus, complex and/or suggestive (since there was no action-related sound) multisensory demands of the presented scenarios might have engaged these regions as part of a stimulus-driven complex mental process.

A further explanation for striate and extrastriate activations might be an attention-dependent visual analysis during the perception of the emotionally relevant stimuli, caused by potential recurrent modulation of activation in the primary visual cortex, as has analogously been shown in studies focusing on attention-related processes on V1 (see Boehler, Schoenfeld, Heinze, & Hopf, 2008). Confirmatively, emotionally laden stimuli have been shown to draw more attention, which resulted in higher arousal levels and visual attention (Geday, Gjedde, Boldsen, & Kupers, 2003; Herrmann et al., 2007; Lang et al., 1998; Pessoa, Kastner, & Ungerleider, 2002; Pietrini, Guazzelli, Basso, Jaffe, & Grafman, 2000). Virtual violent scenarios might have represented a higher eva-

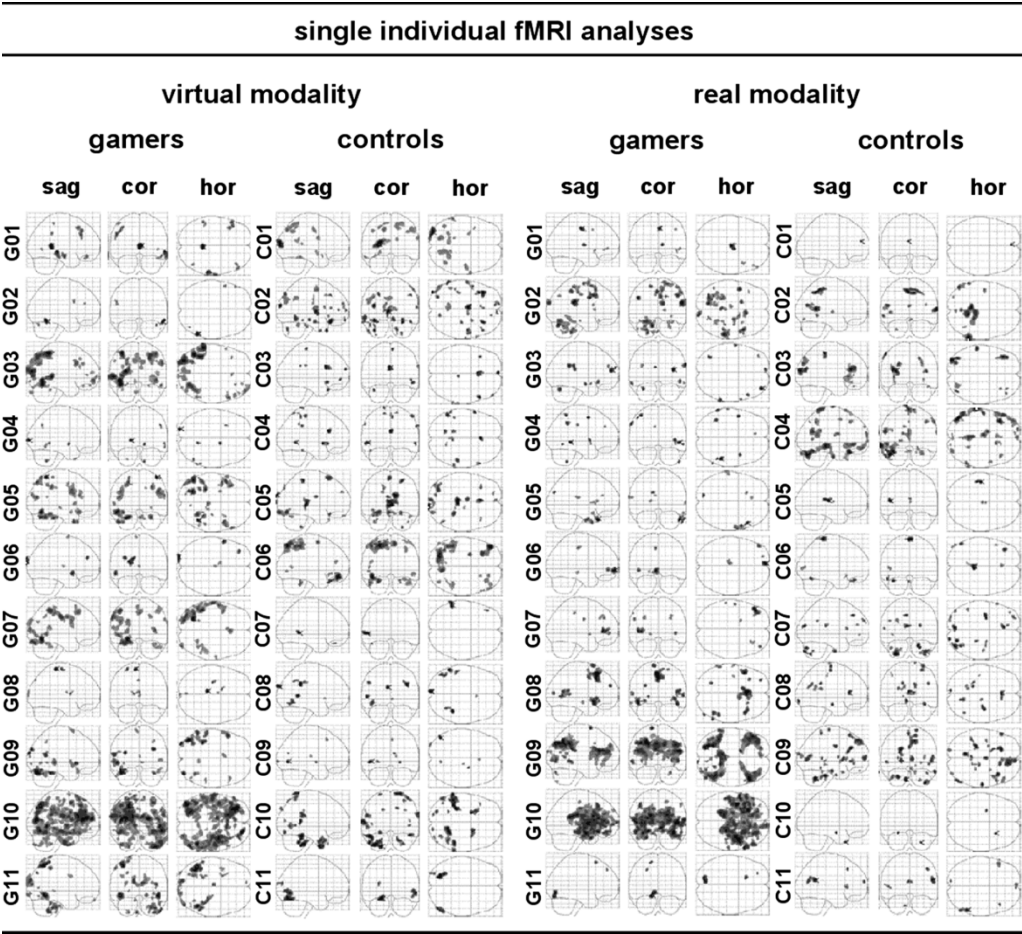


Figure 4. Glass-brain views of single individual fMRI analyses displaying the results of violent vs. nonviolent scenario contrasts ($p < .001$, $k \geq 10$ voxel threshold).

lulative demand than real scenarios due to their virtual features. Furthermore, they are possibly not processed highly automatically as the brain might not provide prototypic and learned information as a basis for potentially fast and appropriate situational analysis and/or interpretation as for the processing of real scenarios. Although for gamers, virtual violent scenes belong to a familiar and well-trained life context, the present data suggest that they might still be processed differently in comparison to real scenes, at least regarding their visual analysis. This led directly to the conclusion that already on the level of primary and basic visual analysis, violent aspects of virtual and realistic scenarios were processed differently, and that the resulting brain activation patterns are not feasible to substantiate theories about potential transfer or takeover processes between violent computer game and realistic context processing as hypothesized, e.g., by Funk, Baldacci, Pasold, and Baumgardner (2004).

Different brain activation patterns in gamers and controls during perceptual processing of computer-game-related real and virtual violence displays

Apart from the regions commonly activated in gamers and controls discussed above, the majority of activations identified in each group could be shown to be distinct for the perception of real and virtual violence displays, respectively.

During the perception of real violence in contrast to the nonviolent baseline condition, gamers showed exclusively right inferior frontal and lingual gyrus activation patterns. For this contrast, controls predominantly showed exclusive recruitment of widespread left frontal brain regions and insula. And during the processing of virtual violent in contrast to nonviolent scenarios, gamers showed exclusive activation patterns in bilateral inferior frontal, left postcentral, middle occipital, right middle temporal, and left fusiform

regions. Controls showed exclusive activation patterns for the virtual violent condition in paracentral lobule, inferior parietal regions and precuneus, right cuneus, and left cerebellum.

The perceptual processing of real violence from a first-person perspective produced widespread left frontal activation patterns in controls, engaging superior, middle, medial and left inferior frontal cortex and insula, which can be interpreted as potentially reflecting the empathic processing of motivated and/or instrumental goal-directed violent action. This interpretation is corroborated by statements of Harmon-Jones (2004), who reviewed a large body of literature and concluded that left frontal brain activation can be related to positive behavioral appetitive approach tendencies, but also to rather deleterious behavioral tendencies motivated by anger, greed, lust, and mania. Interestingly, in a recent study by Ravaja, Turpeinen, Saari, Puttonen, and Keltikangas-Järvinen (2008), analogous psychophysiological responses (facial EMG) were obtained irrespective of whether an event was positive or negative when the player was actively involved in the action. Thus, in controls, real scenarios might involve brain regions related to positive and/or appetitive approach processing because they are usually confronted by television media showing violent approach behavior in a more or less successful and/or in a more or less justified way. Gamers, however, are usually confronted with gaming situations, in which several options are provided: behaving passively, withdrawing or attacking, in both successful and unsuccessful contexts. On one hand, this trains the gamers to act in a controlled and adaptive way, but on the other hand, this seems to hold exclusively for gaming situations without any takeover potential into realistic contexts as the prominently different activation patterns for realistic and virtual conditions suggest. However, comparable right inferior frontal activation for real and virtual modality in gamers might indicate an exclusive transfer for only these behavioral control and inhibition mechanisms. This, however, means that chronically playing violent computer games would improve especially positive social competencies, and that negative aspects of behavior are selectively practiced to be better controlled (see also Mathiak & Weber, 2006). This conclusion seems to contradict observations that showed an enhancement of aggressive behavioral tendencies after violent computer game playing (Anderson, 2004; e.g., Anderson & Bushman, 2001; Bartholow, 2006;

Bartholow & Anderson, 2002; Carnagey & Anderson, 2005; Uhlmann & Swanson, 2004; for review see Griffiths, 1999; Irwin & Gross, 1995; Sherry, 2001). On the other hand, all these studies pointed only to short-term effects, and there is a lack of longitudinal examinations substantiating either conclusion (Bensley & Van Eenwyk, 2001).

Controls might tend to process the perception of real violent action in a more executive way, whereas gamers tend to evaluate the situation more differentially and seemed to automatically inhibit possible violent actions as they selectively trained in computer games. However, an alternative explanation of the lack of left frontal brain activation patterns in gamers might also be that gamers compared to controls might have reduced their abilities to emotionally process violent situations, which would support the often hypothesized desensitization processes (Baldaro et al., 2004; Bartholow, 2006; Carnagey & Anderson, 2007; Carnagey, Anderson, & Bartholow, 2007; Funk et al., 2004; Murray et al., 2006) on a neural level associated with the frequent exposure to violent media.

The first of the above interpretations might be supported by exclusive brain activation patterns in gamers potentially reflecting a more detailed visual and/or object-related situational analysis (lingual gyrus and more widespread superior temporal activation patterns) combined with right inferior frontal activation foci potentially reflecting executive control, inhibitory behavior and withdrawal tendencies (Aron, Fletcher, Bullmore, Sahakian, & Robbins, 2003; Garavan, Hester, Murphy, Fassbender, & Kelly, 2006; Garavan, Ross, & Stein, 1999; Harmon-Jones, 2004; Liddle, Kiehl, & Smith, 2001; Rubia et al., 2001; for an overview see Simmonds, Pekar, & Mostofsky, 2007; Wager et al., 2005). The alternative second explanation, which points to possible neglected emotional context-related processing in gamers, might be corroborated by the lack of context-related insula activation exclusively in gamers. Insula involvement was frequently discussed to be related to emotional processing of disgust (Carr et al., 2003; Wicker et al., 2003), and has also been suggested to represent empathy during the perception of the pain of others (Singer, 2007; Singer et al., 2004). Furthermore, insula activation has been suggested to hold a communicative role, relaying action representation information into emotional information (Carr et al., 2003). Insula activation in the control group might reflect a potential conflict, emerging when one

is confronted with violence toward a human character in real displays. Again, a lack of insula activation in the gamer group might subsequently be interpreted as a neural correlate of desensitization to both realistic and virtual violence. In controls, violence in virtual context might provide a rather unfamiliar and new form of stimulation, and might, therefore, be processed in a prominently perceptual form as indicated by predominantly posterior brain activation patterns. However, analyses of individual data provided a more differential picture, as discussed below.

As mentioned above, gamer and control groups showed predominantly different activation patterns across perceptual processing of real and virtual violence-related scenarios. Gamers showed common activations for real and virtual scenarios in right inferior frontal regions, which have been discussed as a neural correlate of possible takeover effect of inhibitory and/or control behavioral competencies. Indeed, the markedly different activation patterns across groups and condition modalities do not substantiate an assumption of violence-related takeover effects from virtual to real world contexts as had been hypothesized (Funk et al., 2004). The data rather suggest that the brain is capable of clearly differentiating between virtual and real context, whereas there seem to be differences between gamers and controls in how they do that. Summarizing, gamers and controls showed predominantly different activation patterns for the processing of violent in contrast to nonviolent scenarios, which, however, cannot sufficiently be interpreted as a negative or positive consequence of violent computer game play and/or other violent media consumption.

Individual learning history and brain activation patterns: The need for longitudinal studies

Complex mental processing has been shown to be related to complex brain activation patterns in neuroimaging studies and to complex bio-signal parameter compositions in studies using EEG or MEG, varying remarkably across different individuals (e.g., Achtziger, Fehr, Oettingen, Gollwitzer, & Rockstroh, 2009; Burbaud et al., 2000; Fehr, Achtziger, Hinrichs, & Herrmann, 2003). Comparably, the present data also revealed considerable differences between study participants. Group statistics reflected only a section of net-

works responsible for the processing of violent in contrast to nonviolent stimulus content. For example, gamers did not show insula activation at a group statistical level, which has been interpreted in terms of potential emotional desensitization in relation to realistic violence. However, on a single-individual level, 3 out of 11 gamers showed activations in left insula. Thus, individual learning history, cognitive and/or emotional style, personality traits, brain developmental state (brain development extends into the third decade of life), sociodemographic and environmental factors, and other aspects might play a sufficient role in how an individual mentally processes a violent context (see also Baron & Richardson, 1994; Griffiths, 1999). However, it might also be possible that the individual's responses to the experimental situation and manipulation manifest themselves in spread-out activation foci. While the study was planned to provide the highest amount of experimental standardization, individual differences should not be concerned with external confounding factors. Thus, individual differences can potentially be related as to how participants actually processed the situation. On the other hand, analyses indicate that notwithstanding general individual differences, complex between-group differences could also be identified.

Modality-related individual analyses within groups corroborated group-related analyses in principal as there were large differences between individual activation patterns in virtual compared to real violent scenarios separately in both gamers and controls. Therefore, a potential takeover effect of violence processing between virtuality and reality is not supported by the present single individual data. In more detail, a statistical trend indicated that controls even showed a larger overlap of anatomical regions to be activated in virtual as compared to real modality. This trend was not observed for the gamers who were particularly found to be at risk for potential takeover effects and a potential confusion of virtual and real mind frameworks (e.g., Funk et al., 2004).

For the processing of violent in contrast to nonviolent scenarios, most activation foci were, even at individual level, located in neocortical regions. Subcortical regions, which might be brought together with arousal-related violence processing, were shown to be hardly involved, unsystematically distributed across participants and modalities in, e.g., the brainstem, anterior

cingulate gyrus, parahippocampal gyrus, and thalamus. Interaction analyses confirmed the group-related involvement of most of these brain regions in relation to modality-related violence processing, whereas results revealed by complex analyses on fMRI data should be interpreted cautiously. Possibly the applied stimulation triggered a 'cold' neocortical represented form of emotional processing rather than a subcortical and potentially arousal-related form. Thus, even at individual level, a general desensitization to violent displays might be present, if at all, equally in both gamers and controls. The abovementioned aspects should be examined more precisely in prospective studies to more validly determine predictors for violent behaviors. Additionally, different media chronically addressing inadequate associations between context and violence (books, comics, radio dramas, TV, cinema, video and computer games, and many more), e.g., in an unrealistic success-related and/or perverted enjoyable form, should in parallel be taken into account when selective behavioral transfer effects of a certain media are addressed. However, a different explanation is possible: It is assumed that physiological arousal during video game play peaks after approximately 10 min, and then dissipates and is substituted by states such as boredom and tiredness (Sherry, 2001). In a meta-analysis (Sherry, 2001), it was reported that the length of video game play time and aggressive behavioral outcomes had a negative relationship; the longer the participants played, the lower was their arousal level. The participants in this study were being presented with different conditions of virtual and real contexts for approximately 50 min in total. Therefore, the majority of scans obtained results from a time when arousal levels and novelty effects might have already dissipated to some extent.

Limitations of the present study

The presently used experimental design does not cover the whole complexity of a real gaming situation, whereas long-term memory-related concepts of a real gaming situation should be activated by the visual presentation of well-known cues for gamers. Additionally, the implemented motor response should have simulated an executive involvement analogously to a real gaming situation. Furthermore, the validity of the present data might be substantiated by a preliminary

report of Fehr, Strüder, Lück, Herrmann, & Roth (2007), who introduced a similar video inventory (BRAIN—Bremen Aggression Inventory) displaying scenarios from an ego perspective, which were related to hitting, kicking, jostling, and other comparable actions in realistic reactive aggressive contexts. These actions were assumed to be more related to the physical experiences and learning histories of normal people not using guns every day. Brain activation patterns were reported to show both neocortical and subcortical activation foci at group level, especially in male study participants, indicating ecological validity of the methodological approach.

It should be mentioned that the conclusions drawn here hold true only for healthy individuals. The effect and risks of violent video and computer gaming might be completely different in mentally ill individuals. Another aspect that has not been covered by the present study is the addiction potential of (violent) video and computer games and gaming. However, the aim of the present study was to put the focus on average healthy male gamers and potential differences between them and a comparable cohort of healthy male controls in relation to the processing of violent visual material of different phenomenal origin, virtual and real. The selection of a healthy male student population yet implied one potentially limiting factor that should be taken into account: Although the gamers clearly described themselves as such and met the criteria chosen to distinguish a gamer from a control, two gamers reported a decrease in violent video game play over the previous year due to the increasing intensity of their studies. Also, all of the controls also had some experiences with video game play and had been exposed to a violent video game (this was included in the study requirements in order to prevent participants from potentially harmful effects that the stimulus material might have on a participant naïve to violent video games, not to mention that it is practically impossible in an average male university student population to find young men without any prior history of (violent) video game play. These two observations indicate that unlike in a patient study, where the group assignment is clearly based on a standardized diagnosis-based classification system, in the current study the groups of healthy gamers and healthy controls might contain partially overlapping features.

Individual analyses of the data showed impressively that group statistics are indicating only

a small part of the whole brain processing related to violent aspects of computer game scenarios. Thus, results should be interpreted with caution and, furthermore, potential modulations by individual factors, such as learning history, personality, and socialization, should be considered carefully when drawing further conclusions relevant for practice from the present data.

A further aspect that might have modulated brain activations substantially could be that the two groups might experience the experimental setting and environment in fundamental different ways, which might additionally have modulated the violence-related processing of the stimuli. More detailed information about such factors should be obtained and considered in analogous future studies.

An additional caveat

The present results should not be used as a basis for the justification of inappropriate violent computer gaming in young people. This holds especially for adolescence, during which the brain dramatically reorganizes large dendritic networks in grey matter (e.g., Changeux & Danchin, 1976; Giedd et al., 1999; Huttenlocher, 1990; Lenroot & Giedd, 2006; Luna et al., 2001); also, myelinization progresses profoundly throughout the end of the third life decade (e.g., Giedd, et al., 1999; Paus et al., 1999; Yakovlev & Lecours, 1967), and a complex integration of cognitive and emotional life contextual features has been discussed (e.g., Jamner et al., 2003; Spear, 2000). This has been shown not only for the critical and conflict-laden developmental time span of adolescence, but also for postadolescent development, especially regarding frontal and striatal brain regions, which have been suggested to be involved in learning processes (Sowell, Thompson, Holmes, Jernigan, & Toga, 1999).

Adequate training and education of social behavior in natural contexts seems to provide an indispensable basis to prevent deleterious behavioral tendencies, negative emotional personality, and social withdrawal. The last two aspects have been identified to represent the accompanying key characteristics of especially male individuals showing physical aggressive behavior (Strüber et al., 2008). Thus, excessive (aggression-related) behavior and/or chronic omission of adequate behaviors, especially during the periods of ado-

lescence and early adulthood, might lead to the establishment of lifelong persistent and irreversible brain physiological elaboration of complex perception-action cycles (e.g., Fuster, 2006), as comparably discussed for the neural establishment of addiction memory networks (Fehr, Wiedenmann, & Herrmann, 2006, 2007).

The current study provides a novel approach to differentially investigate gamers' brain activation while perceiving virtual and real violence. The findings support a careful handling of the construct of violent computer game play and its potential and often assumed consequences, such as difficulties in differentiating between virtuality and reality and a transfer of aggressive action tendencies from the virtual into the real world. In contrast, the obtained fMRI data suggest a psychophysiological correlate of gamers' ability to differentiate automatically between real and virtual context.

Future studies should more accurately obtain data from individual learning histories and how the study participants think and feel in the actual experimental setting. Furthermore, individual differences in brain activation patterns should better be considered in experimental designs and analyses addressing complex cognitive and/or emotional processing to discover and describe the obviously present complexity of the underlying neural substrates more adequately. Prospective studies making clear predictions on the basis of well-known risk factors of violent behavior (e.g., male gender, low self-control and high impulsivity, and a propensity of negative emotionality; for review see Strüber, Lück, & Roth, 2008) should be realized with longitudinal experimental set-ups including different juvenile subgroups with different violent media consumption behaviors. Such studies might provide more substantial evidence for the influence of violent computer game play on persistent real life aggression and violent behaviors. Studies such as the present one might provide the basis for reasonable hypotheses.

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