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Violence in video game produces a lower activation of limbic and temporal areas in response to social inclusion images

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Abstract

Exposure to violence in video games has been associated with a desensitization toward violent content, a decrease of empathy, and prosocial behavior. Moreover, violent video games seem to be related to a reduction of neural activation in the circuits linked to social emotional processing. The purpose of the present study was to compare the neural response to social inclusion images after violent and nonviolent video game playing. Electroencephalographic data of the 32 participants were recorded during a visual task with three presentations (T0, T1, T2) of 60 stimuli (30 social inclusion vs. 30 neutral images). After the T0 presentation, the participants played with a video game (orientation or violent). After the T1 presentation, the participants played with the other video game (orientation or violent). The two types of video games were randomly displayed. Event-related potential (ERP) components and low-resolution electromagnetic tomography (sLORETA) were analyzed. The main findings showed a longer latency of the P2 component on occipito-temporal montage and a lower activation of the limbic and temporal areas in response to the social inclusion images post violent video game compared with the post orientation video game. The findings suggest a reduction of emotional engagement in social processing after playing violent video game.

Keywords Violent video game · Social inclusion · Event-related potential · sLoreta

Introduction

Potential effects of violent video games have been broadly discussed, in particular regarding their association with the real-life behavior (Anderson & Bushman, 2001; Anderson, Shibuya, Ihori, Swing, Bushman, Sakamoto et al., 2010; Bushman & Anderson, 2002; Bennerstedt, Ivarsson & Linderoth, 2012; Carnagey, Anderson & Bushman, 2007; Sestir & Bartholow, 2010; Tear & Nielsen, 2013). Violent video games often have been considered as enhancer of aggressive reactions (Weber, Ritterfeld & Mathiak, 2006a; Olson, Kutner, Warner, Almerigi, Baer, Nicholi et al., 2007a). Several theories have been developed to clarify how the exposure to violence in video games could create short- and long-term effects on aggressive behaviors (Anderson & Bushman, 2001; Anderson et al., 2010; Carnagey & Anderson, 2003; Dill & Dill, 1998; Griffiths, 1999; Weber, Ritterfeld & Kostygina, 2006b). Previous studies have suggested that human aggressiveness could be only slightly influenced by the effects of violent video games use and that the violence in video games could only shape the expression of the aggressive behaviors (Ferguson, 2013; Ferguson & Garza, 2011; Ferguson, San Miguel & Hartley, 2009; Kutner & Olson, 2008; Olson, Plotzker & Ezzyat, 2007b).

On the other hand, prior studies have indicated a direct and causal relationship between the use of violent video games and aggressiveness, where the use of violent video games may produce short-term consequences on the aggressive or impulsive behavior (Anderson & Bushman, 2001). It seems that long-term exposure to violence in video games could be considered a cognitive cuing effect that leads to an increase of aggressiveness by learning, preparation, and reinforcement of aggressive

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behavior (Anderson & Dill, 2000). Moreover, a desensitization toward violent content and a decrease of empathy and prosocial behavior has been hypothesized (Huesmann, Moise-Titus, Podolski & Eron, 2003; Sparks & Sparks, 2002). Meta-analytic reviews reported a significant association between playing violent video games, an increase in aggressive cognition, and a decrease in empathy and prosocial behavior, resulting from chronic violent video games exposure (Anderson et al., 2010; Brockmyer, 2015; Greitemeyer & Mügge, 2014). Coherently, many neurobiological studies have reported that the long-term exposure to external stimuli can be considered as a cognitive cuing that could lead to the emergence of specific changes in neuroplasticity and to impaired behaviors or psychological diseases (Serafini, Hayley, Pompili, Dwivedi, Brahmachari, Girardi, et al., 2014). Specifically, a reduction of activation in neuronal circuits linked to emotional regulation after paying violent video games use has been previously found. Using functional magnetic resonance imaging (fMRI), Weber et al. (2006a) reported that, during violent video game performing, there was a reduced neural activity in emotional brain areas (amygdala and anterior cingulate cortex) and in the rostral anterior cingulate cortex, whereas there was an increased activity in the dorsal anterior cingulate cortex. The authors suggested that it could represent a suppression of affective information processing during aggressive video game play. Moreover, previous studies reported that the parietal P300 component of the event-related potential is reduced after violent video games use (Bartholow, Bushman & Sestir, 2006; Engelhardt, Bartholow, Kerr & Bushman, 2011). As described by Montag et al. (2012), the excessive use of violent video games may influence the neural processing of unpleasant emotions, likely involving top-down effects on emotional control. These authors reported a lower activation of the left-lateral prefrontal cortex in first-person-shooter-video game players compared with a nonplayers group, suggesting that regular gamers had developed some habituation to violent stimuli and a reduction of the experience of empathy (Montag, Weber, Trautner, Newport, Markett, Walter et al., 2012). Moreover, using fMRI during a violent video game performance, a previous study indicated that the virtual violence was related to an activation of dorsal parts of anterior cortex cingulate (ACC) and deactivation of rostral ACC and amygdala, suggesting patterns of suppressed activation of the affective structures induced by virtual violence (Mathiak & Weber, 2006). As reported by Mathiak et al. (2011), the right temporal pole was less activated in response to failures during a first-person-shooter video game in those subjects who reported higher negative affect in an assessment after playing (Mathiak, Klasen, Weber, Ackermann, Shergill & Mathiak, 2011). Temporal pole activation was frequently observed in emotional tasks, in particular with socially important narratives (Olson et al., 2007), and it seems involved in the prediction and evaluation of our own affective responses in social situations (Mathiak et al., 2011).

However, in a SPECT study, Chou et al. (2013) reported that cerebral blood flow (CBF) was significantly decreased in the prefrontal cortex and increased in the temporal cortex equally after playing both violent and nonviolent video games (Chou, Yang, Hsu, Wang, Lin, Huang et al., 2013). Furthermore, recent studies reported that there were no evidences for a neural desensitization in the processing of emotionally salient stimuli in long-term users of violent video games (Szycik, Mohammadi, Hake, Kneer, Samii, Münte et al., 2017a; Szycik, Mohammadi, Münte, & Te Wildt, 2017b; Gao, Pan, Li, Weng, Yao, & Chen, 2017).

The majority of neurobiological studies investigated the brain functioning while performing violent video games (Chou, et al. 2013; Gentile, Swing, Anderson, Rinker & Thomas, 2016; Mathiak & Weber, 2006; Mathiak, et al. 2011; Regenbogen, Herrmann & Fehr, 2010), and very few studies tested neural activity after the exposure to violent video games (Hummer, Wang, Kronenberger, Mosier, Kalnin, Dunn et al., 2010; Liu, Lan, Teng, Guo & Yao, 2017; Szycik et al., 2017a; Wang, Mathews, Kalnin, Mosier, Dunn, Saykin et al., 2009), where the effects of exposure to violent video gaming were investigated only on cognitive inhibition response (Hummer, et al. 2010) or on emotional processing (Liu et al. 2017; Szycik et al. 2017a). However, the exposure to violence in video games could have important social implications, which have been to date poorly investigated. The neural pattern activation in response to the virtual violence may represent a plausible learning mechanism that may explain how playing violent video games could elicit aggressive reactions in social real life (Mathiak & Weber, 2006).

Currently, little attention has been paid to how the social stimuli are processed after the exposure to violent video games. The purpose of the present study was to compare the neural activation in response to social pictures after performing violent and nonviolent video games in a within-research design. The study hypothesized a lower fronto-limbic and temporal activation in response to social pictures after playing a violent video game compared with after playing an orientation video game in the same participants.

Methods

Participants

The research project was approved by the Ethical Committee of [edited for blinded review]. The study was performed at the Clinical Neuroscience Laboratory of the same Department. Thirty-two volunteer participants (14 males and 18 females; age 24.2 ± 3.3) were enrolled among the student community of the Medicine and Psychology Faculty of [edited for blinded review]. All subjects self-reported that in the past 6 months before the recruitment, they were not substance users or addicted and that they did not habitually play video games. Moreover, they stated that they had not received any psychiatric diagnosis during their life. All participants signed the informed consent for participation.

Stimuli

The visual stimuli consisted of 30 digital still images with social interactions among peers showing more than two people of the same age having fun, laughing with their peers, or sharing activities and objectives with them. Thirty digital still images of the neutral objects commonly used were inserted in the procedure as control stimuli. Each one of the 60 black and white images with a size of 800 x 450 pixel has been edited by Gnu Image Manipulation Program (GIMP) version 2.8 (Free Software Foundation, Inc. 2007). The stimuli were presented at centre of the screen on light grey background.

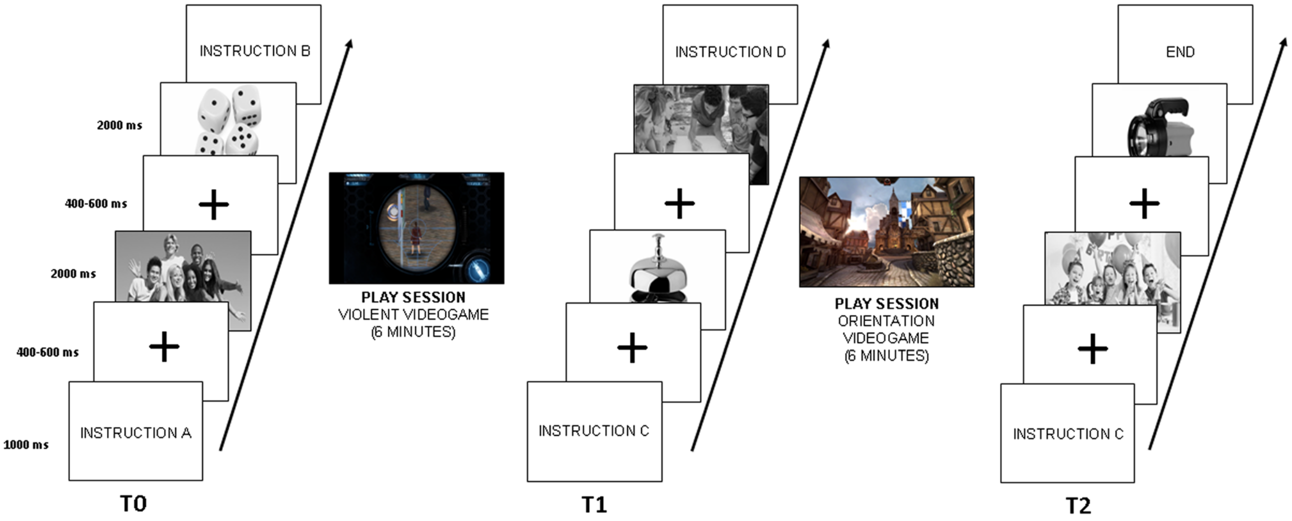
Video games

Both the video games were in a first-person perspective in three-dimensional environment. The violent video game was *iSniper 3D Arctic Warfare* (Triniti Interactive Limited©), a first-person shooter game, allowing to explore the surrounding environment to shoot at the enemies. The game uses dual zones of the screen: the left for the control of the orientation and the right for the pointing and shooting at the target. The *iSniper 3D Arctic Warfare* has a rating of 12+, indicating a violent but not restricted content.

The orientation game was *Epic Citadel* (Epic Games, Inc.© 2013) that allows players to explore the landscape. The game uses dual zones of the screen: the right to control the camera angle and the left to control the motion of the camera.

Experimental procedure

As shown in Figure 1, each participant performed three visual stimuli presentations (T0, T1, T2) and two video game play sessions (orientation and violent). The three presentations (T0, T1, T2) were composed by 60 visual stimuli (30 images of social inclusion vs. 30 neutral images). The neutral images were inserted to avoid the habituation effect to the visual task. After the T0 presentation, each participant played, by using a tablet, for 6 minutes with a video game (orientation or violent). Then, T1 presentation was performed. After the T1 presentation, by using the same tablet, each participant played for 6 minutes with the other video game (orientation or violent). Finally, the T2 presentation was executed. The presentation



Note: INSTRUCTION A: "Now the images will be presented on the screen. Please, pay attention to images. Press the spacebar when you are ready."; INSTRUCTION B: "Now a play session will start. You can click the icon on the screen of the tablet to start the "I-SNIPER 3D ARCTIC WARFARE" game. During the game, click on the left side of the screen to orientate yourself and on the right side to shoot with the viewfinder in the middle of the screen. If you lose, press "Restart". Please, continue to play until this screen will become black and the instructions will change."; INSTRUCTION C: "Please pay attention to images that will appear on the screen. Press the spacebar when you are ready."; INSTRUCTION D: "Now a play session will start. You can click the icon on the tablet screen to start the "EPIC CITADEL" game. During the game, click on the left side of the screen for move yourself and on the right side to explore the environment. Please, continue to play until this screen will become black and the instructions will change".

Fig. 1 Experimental procedure. *Note.* INSTRUCTION A: “Now the images will be presented on the screen. Please, pay attention to images. Press the spacebar when you are ready.”; INSTRUCTION B: “Now a play session will start. You can click the icon on the screen of the tablet to start the “I-SNIPER 3D ARCTIC WARFARE” game. During the game, click on the left side of the screen to orientate yourself and on the right side to shoot with the viewfinder in the middle of the screen. If you lose, press “Restart”. Please, continue to play until this screen will become black and the instructions will change”; INSTRUCTION C: “Please pay attention to images that will appear on the screen. Press the spacebar when you are ready”; INSTRUCTION D: “Now a play session will start. You can click the icon on the tablet screen to start the “EPIC CITADEL” game. During the game, click on the left side of the screen for move yourself and on the right side to explore the environment. Please, continue to play until this screen will become black and the instructions will change” order of the two types of video games was randomly assigned ("T0; orientation video game; T1; violent video game; T2" vs. "T0; violent video game; T1; orientation video game; T2").

Participants were positioned at 80 cm from a monitor (27 cm, 75-Hz, 1,024 x 768) in a dimly lit room for the acquisition of their EEG activity during the visual task. The visual task was presented through E-Prime software (v.2.0.8.90; Psychology Software Tools, Inc.; Pittsburgh, PA), and the T0 presentation started with the following instructions: "Now the images will be presented on the screen. Please, pay attention to images. Press the spacebar when you are ready." After the T0 presentation, the following instructions appeared on the computer screen: "Now a play session will start. You can click the icon on the screen of the tablet to start the "I-SNIPER 3D ARCTIC WARFARE" game. During the game, click on the left side of the screen to orientate yourself and on the right side to shoot with the viewfinder in the middle of the screen. If you lose, press "Restart". Please, continue to play until this screen will become black and the instructions will change."

After the play session, the following instructions were presented on the computer screen: "Please pay attention to images that will appear on the screen. Press the spacebar when you are ready" in order to introduce the T1 presentation. After the T1 presentation, the following instructions were presented on the computer screen: "Now a play session will start. You can click the icon on the tablet screen to start the "EPIC CITADEL" game. During the game, click on the left side of the screen for move yourself and on the right side to explore the environment. Please, continue to play until this screen becomes black and the instructions will change." After the play sessions, the following instructions were presented: "Please pay attention to images that will appear on the screen. Press the spacebar when you are ready" to introduce the T2 presentation. At the end of the T2 presentation, the experimental procedure was terminated.

Each visual presentation (T0, T1, and T2) started with a fixation cross displayed for 1,000 ms, followed by the stimulus (social inclusion or neutral) presented for 2,000 ms, with an interstimulus interval varying between 400 and 600 ms. A total of 30 trials for condition was presented in a random order.

Electroencephalographic recording and event-related potentials analysis

Electroencephalographic (EEG) data were recorded continuously at 250 Hz using NetStation 4.4.2 with 250-channels HydroCel Geodesic Sensor Net referenced to the vertex (Cz). Impedances were kept below 50 KΩ.

The data were digitally filtered (30 Hz low-pass) offline. The segmentation epoch was −100 ms before to 1,000 ms after stimulus onset. NetStation artefact detection settings were set to <200 μV for bad channels, 140 μV for eye blinks, and <100 μV for eye movements. Segments that contained an eye blink, an eye movement, or more than 15 bad channels were excluded, and bad channels replacement was performed (Picton, Bentin, Berg, Donchin, Hillyard, Johnson et al., 2000; Tanner, Morgan-Short & Luck, 2015). The baseline was corrected at –100 ms before stimulus onset. Following visual inspection of the grand-averaged waveforms, the data analysis on the event-related potentials (ERP) components was executed on P1 (65-170 ms), N1 (170-230 ms), P2 (230-300 ms), LC1 (300-400), LC2 (400-500), LC3 (500-700 ms), and LC4 (700-1,000 ms).

The analysis on the mean amplitude and latency of P1 and N1 components on occipital (left: 116; right: 160) and occipito-temporal montages (left: 76-85-96-97-98-106-108; right: 140-151-152-160-161-171-172) and of P2 on occipito-temporal (see above) and frontal (left: 23-36-40-41-47-49; right: 4-6-213-214-222-224) montages, and on the mean amplitude of the late components (LC1, LC2, LC3, LC4) on the occipito-temporal and frontal montages (see above) were conducted.

Source analysis (s-LORETA)

To identify the locations of the neural generators of ERP components, the default standardized low-resolution electromagnetic tomography (sLORETA) (Pasqual-Marqui, 2002; Canuet, Ishii, Pascual-Marqui, Iwase, Kurimoto, Aoki et al., 2011) inverse model of the GeoSource software (version_2.0; EGI, Eugene, OR), with the Sun-Stok4- Shell Spere head model and Tikhonv 1x10 -2 regularization was used. sLORETA is based on the assumption of the standardization of the current density which implies that not only the variance of the noise in the EEG measurements is taken into account but also the biological variance in the actual signal is considered (Pascual-Marqui, 2002; Imperatori, Farina, Quintiliani, Onofri, Gattinara, Lepore et al., 2014; Milz, Faber, Lehmann, Kochi & Pascual-Marqui, 2014; Pascual-Marqui, 2007; Pascual-Marqui, Biscay, Bosch-Bayard, Lehmann, Kochi, Kinoshita et al., 2014; Pascual-Marqui, Lehmann, Koukkou, Kochi, Anderer, Saletu et al., 2011). This biological variance is taken as independent as uniformly distributed across the brain resulting in a linear imaging localization technique having exact, zero-localization error (Jatoi, Kamel, Malik & Faye, 2014).

The MRI normalization of data and the extraction of MRIs data of each subject was performed. Source locations were derived from the probabilistic map of the MNI305 average (Montreal Neurological Institute 305 subjects). Based on the probabilistic map, gray matter volume was parcellated into 7-mm voxels; each voxel served as a source location with three orthogonal orientation vectors. This resulted in a total of 2,447 source triplets whose anatomical labels were estimated using a Talairach daemon (Massaro, Altavilla, Aceto, Pellicano, Lucarelli, Luciani et al., in press; Lai, Luciani, Di Giorgio, Fiorini, Yaya, Pellicano et al., 2018; Cecchini, Aceto, Altavilla, Palumbo & Lai, 2013; Cecchini, Iannoni, Pandolfo, Aceto & Lai, 2015; Lai, Altavilla, Ronconi & Aceto, 2016; Lancaster, Woldorff, Parsons, Liotti, Freitas, Rainey et al., 2000; Luciani, Cecchini, Altavilla, Palumbo, Aceto, Ruggeri et al., 2014).

Referring to the main literature on the neurobiological responses to violence in video games (Gao, et al. 2017; Szycik et al., 2017a,2017b; Montag, et al., 2012; Mathiak & Weber, 2006; Mathiak, et al. 2011), five regions of interest (ROIs), corresponding to specific combinations of Brodmann areas (BAs), have been defined. Specifically, the cingulate cortex ROI (CC) included BAs 23, 24, 25, 29, 30, 31, 32, and 33; the prefrontal cortex ROI (PF) included BAs 9, 10, 11, 46, and 47; the temporal cortex ROI (T) included BAs 20, 21, 22, 38, 39, 41, 42, and 43; and the limbic ROI (L) included BAs amygdala, hippocampus, 13, 27, 28, 34, 35, and 36. The mean intensity (nA) of each BAs in response to social inclusion images was extracted for each ERP component.

Statistical analyses

Repeated measures ANOVAs video games (orientation vs. violent; within-subjects) per hemisphere (left vs. right; within-subjects) on occipital, occipito-temporal, and frontal ERP montages for social inclusion condition in each interval were performed. The difference between neutral condition and social inclusion condition has been tested.

For the sLORETA data, within-subjects repeated measures ANOVAs: 2 conditions (*After orientation game session* vs. *After violent game session*) x n BAs (belonging to each ROI) x 2 hemispheres (left and right) on the mean intensity have been performed. The analysis was repeated for each component. Basic single comparisons (Fisher's *F*) on each BA intensity were performed. Bonferroni corrections were applied for each ROI. The significance threshold for 0.05 *p*-value was set from 0.003 (for Cingulate, Temporal, and Limbic ROIs, where were identified 8 BAs x 2 hemispheres = 16 comparisons: 0.05/16 = 0.003) to 0.005 (for Prefrontal ROI, where were identified 5 BAs x 2 hemispheres = 10 comparisons: 0.05/10 = 0.005).

Results

After applying EEG data cleaning, the data of 15 participants (7 males and 8 females; age 25.0 ± 2.3) were included in the analysis. The mean of the trials included after the artifacts rejection was: inclusion trials in T0 (mean [M] = 20.27, standard deviation [SD] = 5.96), neutral trials in T0 (M = 16.93, SD = 5.76), inclusion trials post violent video game (M = 19, SD = 6.51), neutral trials post violent video game (M = 17.87, SD = 6.60), inclusion trials post orientation video game (M = 17.87, SD = 6.25), and neutral trials post orientation video game (M = 16.04, SD = 6.59).

To test the difference between the social inclusion and neutral stimuli, a preliminary ANOVAs hemisphere (left vs. right) *per* video games (orientation vs. violent) *per* stimuli (social inclusion vs. neutral stimuli) on the ERP amplitude and latency were performed. A main effect of the Stimuli was found on the latency in occipital (P1: F(1,13) = 7,1; *p* = 0.019) and in occipito-temporal

Table 1 ANOVA hemisphere (left vs. right) per video games (orientation (O) vs. violent (V)) on mean amplitude and latency of P100, N170 and late components (LC1, LC2, LC3, LC4, LC5) in response to the social inclusion images

Component	Montage	*Post hoc*
P1	**Occipital** Hemisphere: F(1,14)=7,06 p=.019 **Occipito-Temporal** Hemisphere F(1,14)=29.73 p=.00009	right > leftright > left
N1	**Occipito-Temporal** Hemisphere F(1,14)=29,49 p=.00009 *Hemisphere F(1,14)=7,57 p=.016*	right > leftleft > right
P2	**Occipito-Temporal** Hemisphere F(1,14)=29,66 p=.00009 *Video game F(1,14)=18,08 p=.0008* *Hemisphere per Video game F(1,14)=16,02 p=.001*	right > left V>O O left<V left; O left<V right; O right<V left; O right<V right; V left<V right
LC1	**Occipito-Temporal** Hemisphere F(1,14)=28 p=.0001	right > left
LC2	**Occipito-Temporal** Hemisphere F(1,14)=33,81 p=<.0001	right > left
LC3	**Occipito-Temporal** Hemisphere F(1,14)=33,59 p=<.0001	right > left
LC4	**Occipito-Temporal** Hemisphere F(1,14)=15,54 p=.001	right > left

montages (P1: F(1,13) = 7,7; $p = 0.016$; N1: F(1,13) = 12,0; $p = 0.004$), and on the amplitude in occipito-temporal montage (P2: F(1,13) = 5,0; $p = 0.044$; LC1: F(1,13) = 6,1; $p = 0.028$), where the social inclusion stimulus showed a shorter latency and a greater amplitude compared with the neutral stimulus.

Moreover, a preliminary ANOVA hemisphere (left vs. right) *per* video games (orientation vs. violent) *per* Presentation Order of the video games (orientation-violent vs. violent-orientation) did not show significant effects of the Presentation Order.

As reported in Table 1, ANOVA hemisphere (left vs. right) *per* video games (orientation vs. violent) on the ERP amplitude in response to the social inclusion images showed a main effect of hemisphere for the P1 component of occipital montage and for all the components of occipito-temporal montage, where the right hemisphere showed a greater amplitude compared with the left one (except for N1 where the effect was inverted).

Moreover, the main effect of Video games and the interaction effect of hemisphere *per* video games for the P2 latency on occipito-temporal montage in response to the social inclusion images were significant, where the violent video game showed a longer latency compared with the orientation video game overall on the right hemisphere (Figure 2).

As reported in Table 2, source analysis (sLORETA) indicated that the social inclusion images post violent video game showed a lower activation of the limbic, cingulate, and temporal ROIs compared with the social inclusion images post orientation video game (Figure 3). Only for the BA46 (prefrontal ROI), the social inclusion images post violent video game showed a higher intensity compared to the social inclusion images post orientation video game.

Discussion

The main finding of the present study was that playing a violent video game seemed to lead to a longer latency of the P2 component on occipito-temporal montage and to a lower activation of the cingulate cortex, limbic, and temporal areas in response to social inclusion images. The neural pathways consisting in the activation of limbic and temporal cortex seems to correlate with the emotional involvement during emotional task as showed in previous neurobiological and

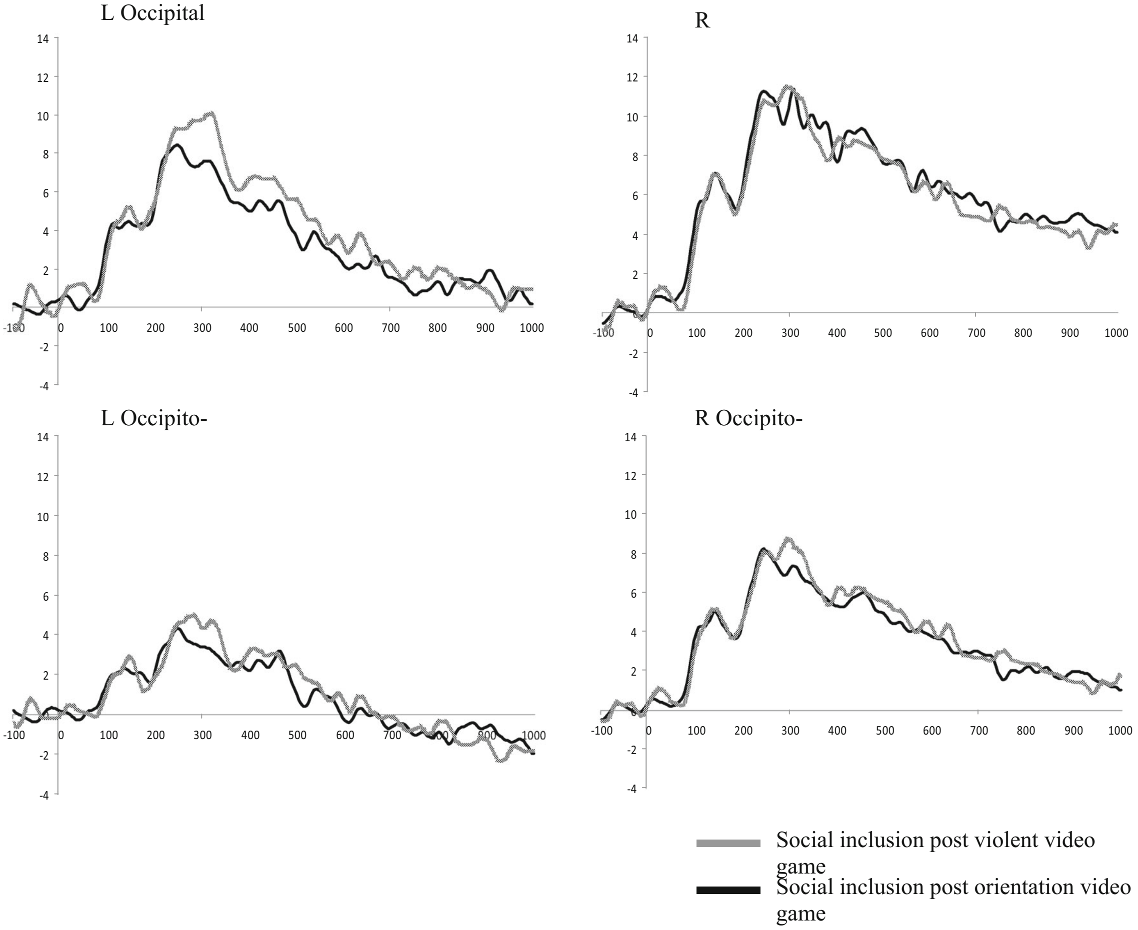


Fig. 2 The grand average of the event-related potential (ERP) in response to the social inclusion images after playing with violent or orientation video game in left (L) and right (R) hemisphere of occipital and occipito-temporal montage

Table 2 Basic single comparisons (Bonferroni correction was applied with accepted *p*-value from 0.003 to 0.005) on each Broadmann Areas (BA) mean intensity for each region of interest (ROI) for all the intervals (P1, N1, P2, LC1, LC2, LC3, LC4) in both hemisphere left (l) and right (r) in response to social inclusion images post orientation video game compared to post violent one

ROIs	P 1(65-170 ms)	N1(170-230 ms)	P2(230-300 ms)	LC1 (200-300 ms)	LC2 (300-400 ms)	LC3 (400-500 ms)	LC4 (500-1000 ms)
L	**l&rAmy**$^{p<.0001;p<.0001}$	**l&rAmy**$^{p=.0006;p<.0001}$	l&r**Amy**$^{p=.11;\mathbf{p<.0001}}$	**l&rAmy**$^{p<.0001;p<.0001}$	**l&rAmy**$^{p<.0001;p<.0001}$	**l&rAmy** $^{p<.0001;p<.0001}$	**l&rAmy**$^{p<.0001;p<.0001}$
	l&rBA13$^{p=.21;p=.11}$	l&rBA13$^{p=.02;p=.04}$	l&rBA13$^{p=.16;p=.23}$	l&rBA13$^{p=.005;p=.01}$	l&rBA13$^{p=.01;p=.02}$	l&rBA13$^{p=.06;p=.08}$	l&rBA13$^{p=.004;p=.02}$
	l&rBA27$^{p<.0001;p<.0001}$	**l&rBA27**$^{p<.0001;p<.0001}$	**l&rBA27**$^{p<.0001;p<.0001}$	**l&rBA27**$^{p<.0001;p<.0001}$	**l&rBA27**$^{p<.0001;p<.0001}$	**l&rBA27**$^{p<.0001;p<.0001}$	**l&rBA27**$^{p<.0001;p<.0001}$
	l&rBA28$^{p<.0001;p<.0001}$	**l&rBA28**$^{p<.0001;p<.0001}$	l&rBA28$^{p=.01;\mathbf{p<.0001}}$	**l&rBA28**$^{p<.0001;p<.0001}$	**l&rBA28**$^{p<.0001;p<.0001}$	**l&rBA28**$^{p<.0001;p<.0001}$	**l&rBA28**$^{p<.0001;p<.0001}$
	l&rBA34$^{p<.0001;p<.0001}$	**l&rBA34**$^{p<.0001;p<.0001}$	l&rBA34$^{p=.01;\mathbf{p<.0001}}$	**l&rBA34**$^{p<.0001;p<.0001}$	**l&rBA34**$^{p<.0001;p<.0001}$	**l&rBA34**$^{p<.0001;p<.0001}$	**l&rBA34**$^{p<.0001;p<.0001}$
	l&rBA35$^{p<.0001;p<.0001}$	**l&rBA35**$^{p<.0001;p<.0001}$	**l&rBA35**$^{p=.0001;p<.0001}$	**l&rBA35**$^{p<.0001;p<.0001}$	**l&rBA35**$^{p<.0001;p<.0001}$	**l&rBA35**$^{p<.0001;p<.0001}$	**l&rBA35**$^{p<.0001;p<.0001}$
	l&rBA36$^{p<.0001;p<.0001}$	**l&rBA36**$^{p<.0001;p<.0001}$	**l&rBA36**$^{p<.0001;p<.0001}$	**l&rBA36**$^{p<.0001;p<.0001}$	**l&rBA36**$^{p<.0001;p<.0001}$	**l&rBA36**$^{p<.0001;p<.0001}$	**l&rBA36**$^{p<.0001;p<.0001}$
	l&rHippo$^{p<.0001;p=.0002}$	**l&rHippo**$^{p=.0002;p<.0001}$	**l&rHippo**$^{p=.002;p<.0001}$	**l&rHippo**$^{p<.0001;p<.0001}$	**l&rHippo**$^{p<.0001;p<.0001}$	**l&rHippo**$^{p<.0001;p<.0001}$	**l&rHippo**$^{p<.0001;p<.0001}$
CC	**l&rBA23**$^{p<.0001;p<.0001}$	**l&rBA23**$^{p<.0001;p<.0001}$	**l&rBA23**$^{p<.0001;p=.0004}$	**l&rBA23**$^{p<.0001;p<.0001}$	**l&rBA23**$^{p<.0001;p<.0001}$	**l&rBA23**$^{p<.0001;p<.0001}$	**l&rBA23**$^{p<.0001;p<.0001}$
	l&rBA24$^{p=.59;p=.68}$↑	l&r**BA24**$^{\mathbf{p=.0006};p=.03}$	l&rBA24$^{p=.84\uparrow;p=.54}$↑	l&r**BA24**$^{\mathbf{p=.001};p=.005}$	l&rBA24$^{p=.009;p=.004}$	l&rBA24$^{p=.03;p=.29}$	l&rBA24$^{p=.03;p=.19}$
	l&rBA25$^{p<.0001;p<.0001}$	**l&rBA25**$^{p<.0001;p<.0001}$	**l&rBA25**$^{p<.0001;p<.0001}$	**l&rBA25**$^{p<.0001;p<.0001}$	**l&rBA25**$^{p<.0001;p<.0001}$	**l&rBA25**$^{p<.0001;p<.0001}$	**l&rBA25**$^{p<.0001;p<.0001}$
	l&rBA29$^{p<.0001;p<.0001}$	**l&rBA29**$^{p<.0001;p<.0001}$	**l&rBA29**$^{p=.0005;\ p<.0001}$	**l&rBA29**$^{p<.0001;p<.0001}$	**l&rBA29**$^{p<.0001;p<.0001}$	**l&rBA29**$^{p<.0001;p<.0001}$	**l&rBA29**$^{p<.0001;p<.0001}$
	l&rBA30$^{p<.0001;p<.000}$	**l&rBA30**$^{p<.0001;p<.000}$	**l&rBA30**$^{p<.0001;p<.000}$	**l&rBA30**$^{p<.0001;p<.000}$	**l&rBA30**$^{p<.0001;p<.000}$	**l&rBA30**$^{p<.0001;p<.000}$	**l&rBA30**$^{p<.0001;p<.000}$
	^{1}l&r**BA31**$^{\mathbf{p=.002};p=.02}$	^{1} l&rBA31$^{p=.02;p=.03}$	^{1} l&rBA31$^{p=.02;p=.19}$	^{1} **l&rBA31**$^{p<.0001;p<.000}$	^{1} **l&rBA31**$^{p<.0001;p<.000}$	^{1} **l&rBA31**$^{p=.0001;p<.000}$	^{1} **l&rBA31**$^{p=.0001;p<.000}$
	l&rBA32$^{p=.81;p=.54}$↑	**l&rBA32**$^{p<.0001;p=.002}$	l&rBA32$^{p=.88\uparrow;p=.86}$↑	^{1} l&rBA32$^{p=.007;p=.006}$	^{1} l&**rBA32**$^{p=.02;\mathbf{p=.0005}}$	^{1} l&rBA32$^{p=.02;p=.13}$	^{1} l&rBA32$^{p=.31;p=.71}$
	l&rBA33$^{p=.07;p=.12}$	**l&rBA33**$^{p<.0001;p<.0001}$	l&rBA33$^{p=.14;p=.18}$	**l&rBA33**$^{p<.0001;p<.0001}$	**l&rBA33**$^{p=.0002;p<.0001}$	**l&rBA33**$^{p=.0001;p=.0001}$	**l&rBA33**$^{p<.0001;p=.001}$
T	l&rBA20$^{p=.02;p=.30}$	l&**rBA20**$^{p=.08;\mathbf{p=.0003}}$	l&rBA20$^{p=.10;p=.006}$	l&r**BA20**$^{\mathbf{p=.001};p=.04}$	l&r**BA20**$^{\mathbf{p=.0009};p=.16}$	l&rBA20$^{p=.06;p=.69}$	l&r**BA20**$^{\mathbf{p=.0007};p=.11}$
	l&rBA21$^{p=.94;p=.63}$	l&rBA21$^{p=.20;p=.28}$	l&rBA21$^{p=.05;p=.71}$	l&rBA21$^{p=.03;p=.05}$	l&rBA21$^{p=.44;p=.47}$	l&rBA21$^{p=.55;p=.96}$↑	l&rBA21$^{p=.37;p=.65}$
	l&rBA22$^{p=.96;p=.53}$	l&rBA22$^{p=.41;p=.33}$	l&rBA22$^{p=.81;p=.64}$	l&rBA22$^{p=.55;p=.37}$	l&rBA22$^{p=.81;p=.37}$	l&rBA22$^{p=.74;p=.70}$	l&rBA22$^{p=.51;p=.36}$
	l&rBA38$^{p=.03;p=.32}$	l&rBA38$^{p=.07;p=.004}$	l&rBA38$^{p=.81;p=.03}$	l&rBA38$^{p=.09;p=.03}$	l&rBA38$^{p=.009;p=.02}$	l&rBA38$^{p=.24;p=.27}$	l&rBA38$^{p=.07;p=.04}$
	l&rBA39$^{p=.77;p=.10}$↑	l&rBA39$^{p=.87;p=.23}$↑	l&rBA39$^{p=.79;p=.009}$	l&rBA39$^{p=.74;p=.48}$	l&rBA39$^{p=.77;p=.68}$↑	l&rBA39$^{p=.87;p=.04}$↑	l&rBA39$^{p=.88;p=.13}$↑
	l&rBA41$^{p=.42;p=.22}$	l&rBA41$^{p=.23;p=.02}$	l&rBA41$^{p=.62;p=.30}$	l&rBA41$^{p=.17;p=.10}$	l&rBA41$^{p=.32;p=.09}$	l&rBA41$^{p=.50;p=.19}$	l&rBA41$^{p=.15;p=.09}$
	l&rBA42$^{p=.62;p=.04}$	l&**rBA42**$^{p=.43;\mathbf{p=.0005}}$	l&rBA42$^{p=.57;p=.04}$	l&**rBA42**$^{p=.30;\mathbf{p=.006}}$	l&**rBA42**$^{p=.55;\mathbf{p=.001}}$	l&rBA42$^{p=.70;p=.009}$	l&rBA42$^{p=.24;p=.009}$
	l&rBA43$^{p=.71;p=.04}$	l&**rBA43**$^{p=.52;\mathbf{p=.003}}$	l&rBA43$^{p=.61;p=.008}$	l&rBA43$^{p=.34;p=.01}$	l&**rBA43**$^{p=.54;\mathbf{p=.001}}$	l&rBA43$^{p=.75;p=.004}$	l&rBA43$^{p=.28;p=.009}$
PF	l&rBA09$^{p=.99\uparrow;p=.63}$↑	l&rBA09$^{p=.05;p=.06}$	l&rBA09$^{p=.79\uparrow;p=.81}$	l&rBA09$^{p=.18;p=.34}$	l&rBA09$^{p=.18;p=.26}$	l&rBA09$^{p=.57;p=.83}$	l&rBA09$^{p=.60;p=.96}$
	l&rBA10$^{p=.38\uparrow;p=.57}$↑	l&rBA10$^{p=.07;p=.89}$	l&rBA10$^{p=.16\uparrow;p=.95}$	l&rBA10$^{p=.04;p=.39}$	l&rBA10$^{p=.05;p=.43}$	l&rBA10$^{p=.86\uparrow;p=.80}$↑	l&rBA10$^{p=.58;p=.83}$↑
	l&rBA11$^{p=.009;p=.008}$	l&rBA11$^{p=.03;p=.008}$	l&**rBA11**$^{p=.15;\mathbf{p<.0001}}$	**l&rBA11**$^{p=.0005;p<.0001}$	**l&rBA11**$^{p=.0008;p=.0008}$	l&rBA11$^{p=.02;p=.007}$	l&**rBA11**$^{p=.004;\mathbf{p=.0004}}$
	l&r**BA46**$^{\mathbf{p=.002}\uparrow;p=.36}$↑	l&rBA46$^{p=.16;p=.13}$	l&r**BA46**$^{\mathbf{p=.0009}\uparrow;p=.99}$↑	l&rBA46$^{p=.30;p=.32}$	l&rBA46$^{p=.35;p=.004}$	l&rBA46$^{p=.12\uparrow;p=.60}$	l&rBA46$^{p=.24\uparrow;p=.54}$↑
	l&rBA47$^{p=.34;p=.17}$	l&rBA47$^{p=.01;p=.11}$	l&rBA47$^{p=.85;p=.03}$	l&rBA47$^{p=.28;p=.01}$	l&rBA47$^{p=.01;p=.002}$	l&rBA47$^{p=.48;p=.65}$	l&rBA47$^{p=.26;p=.20}$

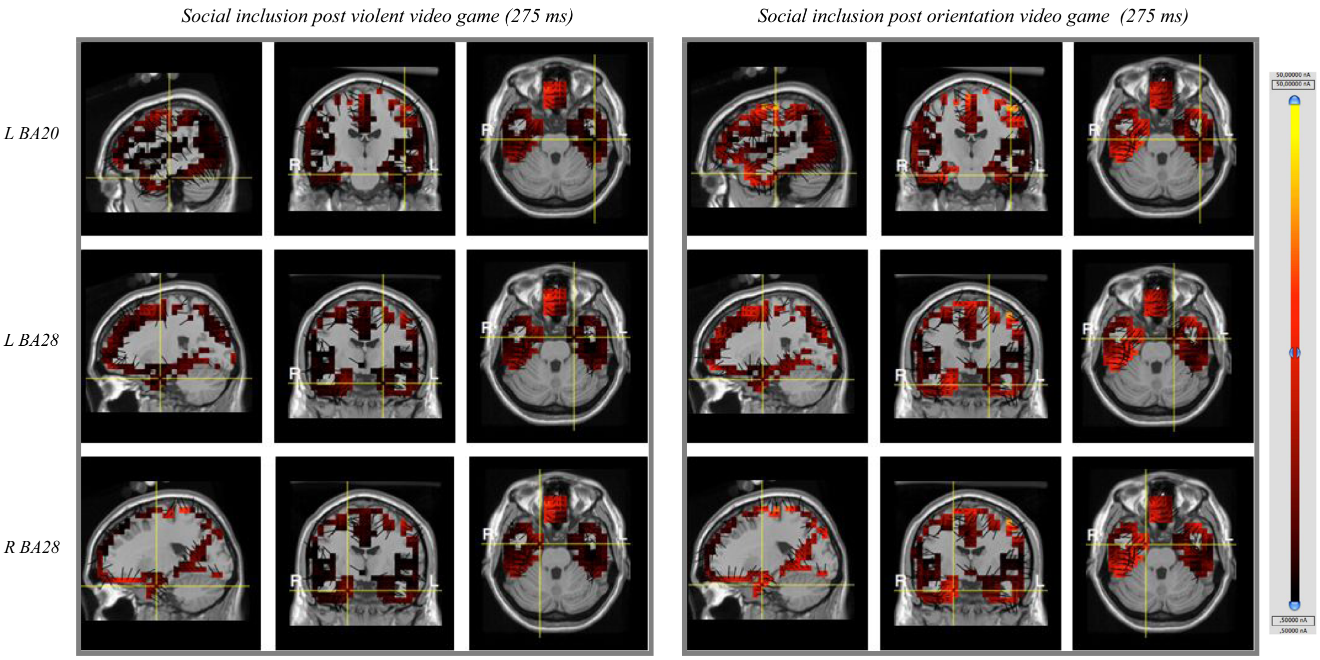
The BAs intensity post orientation video game was higher compared to the post violent video game one for all the comparisons, except for those indicated with ↑

Amy = Amygdala; Hippo = Hippocampus. ROIs: L = Limbic areas; CC = Cingulate cortex; T = Temporal areas; PF = Prefrontal cortex behavioural studies (Bates, Kiehl, Lauren, & Liddle, 2002; Lai, Altavilla, Mazza, Scappaticci, Tambelli, Aceto et al., 2017; Tonioni, Mazza, Autullo, Cappelluti, Catalano, Marano et al., 2014; Yau, Potenza, Mayes, & Crowleyet, 2015). According to the previous studies, the lower limbic and temporal activation after playing violent video game suggests a reduction in emotional engagement in social processing (Brockmyer, 2015) and may bring insights in the association between the performance of violent video games and the subsequent aggressive behaviour. As reported by Anderson and Bushman (2001), the effects of violent video game on aggressive behaviour could implicate a desensitization to violence, resulting in a reduction of physiological reactivity (Bartholow et al. 2006; Engelhardt et al. 2011), as well as in a decrease of empathy processing (Anderson & Bushman, 2011; Anderson et al., 2010). Studies focused on the neural activation during the performance of a violent video game reported a suppression of fMRI responses in amygdala, temporal lobe, and anterior cingulate gyrus (Gentile et al., 2016; Weber et al., 2006a), suggesting a blunted emotional reactivity. Kelly et al. (2007) reported a decreased responsiveness in the amygdala and in the lateral orbitofrontal cortex immediately after exposure to violence in media. As suggested by Siegal and Varley (2002), the amygdala is a core structure for the comprehension of others' thoughts and emotions.

Conversely, studies on long-term effects of the exposure to violent video games reported different results (Szycik et al., 2017a, 2017b; Gao et al., 2017), where habitual use of violent video game in chronic players did not produce any effect on brain activity in response to emotional stimuli compared to nonchronic players. These studies sustain that the violent contents in video games do not have long-term influence on brain activity, emotional processing, or aggressive behaviours but only possible short-term effects immediately after or during the exposure to violent video games (Szycik et al., 2017a, 2017b). Szycik et al. (2017b) did not provide evidence for neural desensitization in the processing stimuli designed to elicit empathic reactions after playing violent video games. However, in the same study, the authors reported significant differences in personality traits (clinical and behavioural) between violent video game habitual users and the control group. It could be interesting explore possible reasons of this discrepancy between the presence of these clinical and behavioural differences and the absence of different neurobiological correlates (Serafini et al., 2014).

The design of the present study, showing differences in the neural activation directly within the same participants after violent and nonviolent video game playing, confirmed that the violent contents in the video game have immediate effects on brain activation in response to social inclusion images. However, how long these effects could be enduring and stable during the time remains unclear and needs further investigation through a new longitudinal study.

According to the hypothesis, in the present study, the frontal Brodmann area (BA) 11 was significantly less activated after the violent video game compared with the post orientation one; however, unexpectedly, the activation of frontal BA46 was significantly higher after playing the violent video game. These dissimilar results in the activation of frontal areas could be to the different functional role of those areas (Alvarez


Social inclusion post violent video game (275 ms)

Social inclusion post orientation video game (275 ms)

Fig. 3 Brain activation (left (L) temporal (BA20) and left and right (R) parahippocampal areas (BA28)) in response to social inclusion images post violent video game compared with the social inclusion images post orientation video game

& Emory, 2006). The BA11 region deals with the value of an anticipated reward, and it is strictly connected to the limbic system (Coenen, Schumacher, Kaller, Schlaepfer, Reinacher, Egger et al., 2018). This brain area is implicated in the reward anticipation and in the expectation to emotional stimuli (Coenen et al., 2018). The BA46, instead, belongs to the cortical and striatal-thalamic circuit mediating involved in attentional control processes in the context of emotional distracter stimuli, which serves as competitors with cognitive resources (Kerestes, Ladouceur, Meda, Nathan, Blumberg, Maloney et al., 2012; Anticevic et al. 2010). The violent stimuli of the video game could have enhanced the selective attentional control processes to make the performance as accurate as possible and, consequently, to isolate and exclude from the attention the emotional information of the context, considered as competitors with the cognitive control. Previous studies reported a similar involvement of the lateral prefrontal cortex in processing violent video games (Hummer et al., 2010; Montag, et al., 2012). Montag and collaborators (2012) presented a set of stimuli with emotional content after the violent video game performance and found higher brain activity in lateral prefrontal cortex, confirming the function of this area in the integration of emotion and control of cognition (Gray, Braver & Raichle, 2002).

Therefore, a possible explanation of the inverse association between violent content in video game and the activation of these two frontal brain areas (BA11 and BA46) is that the violence in video game could decrease the response to social stimuli and could increase the selective attention towards specific stimuli.

To the best of our knowledge, the present study is the first to evaluate the short-term effects of the violence in video game on neural activity during the processing of social stimuli. Previous studies investigated how the violent video game exposure could affect the prosocial behaviours, by using behavioural or psychological tasks (Greitemeyer & Mügge, 2014; Staude-Müller, Bliesener & Luthman, 2008), providing evidences that video game exposure has an impact on social behaviour and related cognitive and affective variables. Findings from the present study strengthen these behavioural results, showing that the violent video games have a short-term impact on neural activity, leading to a lower emotional areas reactivity during the processing of inclusive social situations. The reduction of the emotional reactivity may improve the ability to react accurately in a violent situation and virtually kill enemies, enhancing the chances of survival (Mathiak & Weber, 2006). A possible interpretation of the findings of the present study is that the others' representation perceived during fighting activities (kill enemies) is in contrast with the representation of the others experienced during social involvement. The discrepancy between these findings and those discussed above of recent studies that did not report a neurobiological desensitization (Szycik, et al. 2017b; Gao et al., 2017) could be explained by the different stimuli used among the studies. In fact, in those previous studies the neurobiological activation were evaluated in response to stimuli designed to elicit empathic reactions to pain. It could be possible that the violence in videogame could favour a decrease in social involvement but not have effects on others' pain perception.

From a clinical point of view, it seems that particularly violent video games could facilitate a lower desire for sharing positive social experiences, enhancing the risk of a greater isolation, which could have more pervasive repercussions on the psychological and social well-being of the individuals. A deeper comprehension of the association between violence in video games and a disengagement in sharing positive social experiences could give important clinical information in those patients who are massive users of video games. Moreover, the risk of a greater social retirement, facilitated by the violent video game, seems to be relevant for psychological and educational purposes, particularly for those individuals who already appear more socially withdrawn. The findings could have relevant clinical implications, especially considering that the social support may confer resiliency to numerous psychological diseases (Kleiman & Liu, 2013; Dumont & Provost, 1999), and it is directly associated with a global good quality of life (Siedlecki, Salthouse, Oishi, & Jeswani, 2014).

This study presents some limitations. First, given its cross-sectional nature, the procedure of the present study does not allow to evaluate long-term effects of the violence in videogame on neural response. It could be very interesting to further investigate how long these effects could be enduring and stable during the time through a future longitudinal and neurobiological study. Second, the sample size was small; however, the main independent variable (violent video game vs. orientation video game) was analysed within-subjects. Moreover, many previous neurobiological studies reported similar sample size (Szycik et al., 2017a; Weber et al., 2006a).

Conclusions

The present study supports the hypothesis that the use of violent video game leads to a lower activation of the neural activity in limbic and temporal areas, in response to a successive social inclusion processing. The risk of a social retirement facilitated by the violent video game seems to be relevant, especially considering that the social support is a protective factor for the onset of several psychological diseases. Further studies are needed to investigate how these effects could persist during the time and if this lower activation in limbic and temporal areas could be associated with differences in behavioural response to social situations.

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