

# Chronic Exposure to Violent Video Games is Not Associated with Alterations of Emotional Memory

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*Summary: Although acute effects of violent video game (VVG) exposure on affect and behaviour have been studied extensively, less is known about VVG effects on cognition. The present study examined whether chronic exposure to VVGs was associated with alterations in emotional long-term memory. Participants completed an old-new recognition task with 300 pictures of scenes ranging in emotion (negative, neutral and positive). We analysed accuracy and reaction time data using diffusion modelling to test a desensitization hypothesis. According to this hypothesis, VVG players would show reduced memory or a less liberal response bias for negative stimuli, compared with nonplayers. Contrary to the desensitization hypothesis, VVG exposure was not associated with differences in memory or response bias. This result suggests that, unlike other cognitive domains, long-term memory may be robust to deleterious influences of chronic VVG exposure. Copyright © 2011 John Wiley & Sons, Ltd.*

## INTRODUCTION

Video games have become the fastest growing sector of the entertainment industry in North America, earning almost \$20 billion in the United States in 2009 alone (NDP Group, 2010). Unlike television, violent video games (VVGs) are interactive. Players receive rewards for virtual violent acts and can come to identify with the character they control (Carnagey, Anderson, & Bushman, 2007). In light of the overwhelming popularity of VVGs, the public has become increasingly concerned that these games may have lasting negative effects on players, many of whom are adolescents and young adults. The current study examined the possibility that chronic exposure to video game violence may reduce the memorability of negative stimuli. The ability to remember negative experiences serves important adaptive functions (e.g. Christianson, 1992) and affects not only how we remember the past, but also how we think about and behave in the present and future. If I vividly remember the negative repercussions of a bar fight, I will probably try to get out of an argument with strangers that could lead to a similar escalation. As this example illustrates, VVG-related modulation of emotional memory would not only be of scientific interest, but would also have significant public-health implications. Although emotional memory has not been studied in VVG players, there is already significant evidence for VVG effects on behaviour, affect and cognition (for a recent review, see Anderson et al., 2010).

### Habituation versus desensitization

One important question regarding the effects of VVGs is whether they are best characterized as desensitization or as habituation to violence. Wolpe (1982) defines desensitization as a sustained reduction in psychological or emotional responsiveness to a stimulus class after repeated exposure. In contrast, habituation operates in the short term and does not

persist in the presence of novel stimuli (Bradley, Lang, & Cuthbert, 1993). The VVG literature sometimes uses these terms interchangeably, but it may be argued that habituation is less harmful than desensitization because it implies that behavioural, affective and cognitive responses eventually return to normal levels, even after frequent use of VVGs. To date, no studies have employed longitudinal methods to examine the time course of VVG effects (but see, e.g. Huesmann, Moise-Titus, Podolski, & Eron, 2003, for longitudinal evidence that childhood exposure to violent television predicts aggressive behaviour in adolescents). Instead, researchers have used experimental or quasi-experimental (individual-differences) approaches and a single measurement occasion. Experimental studies in which responses to VVG exposure are measured immediately following a brief laboratory-based exposure cannot disentangle habituation and desensitization effects (however, see Sestir & Bartholow, 2010). Individual-differences research with participants who vary with respect to self-reported past VVG exposure is better suited to examine possible desensitization effects, although at the cost of giving up experimental control over the type and duration of the VVG experience. Before describing the rationale for the current study, which relied on an individual-differences approach, we review extant research using both experimental and individual-differences methods.

### Short-term effects: Experimental VVG exposure

On the behavioural level, laboratory VVG exposure has been shown to increase aggressive affect, aggressive thoughts and irritability (e.g. Anderson & Bushman, 2001), and to decrease helping behaviour (e.g. Bushman & Anderson, 2009; see also Anderson et al., 2010; Carnagey et al., 2007; Dill & Dill, 1998). Interestingly, these increases in aggressive cognitions, affect and behaviour may be only short-lived, lasting less than 15 minutes in one recent study (Sestir & Bushman, 2010). Several experimental studies of affective responses to VVG exposure have yielded evidence of reduced responsiveness to negative emotional stimuli. For example, Carnagey et al. (2007) reported that 20 minutes of

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VVG playing lowered participants' physiological reactivity (heart rate and galvanic skin response) to footage of real-world violence. Similarly, in another study (Staudé-Müller, Bliesener, & Luthman, 2008), 20 minutes of playing a VVG led to a decrease in physiological reactivity (heart rate, respiration) to aversive photographs, relative to a control condition in which participants had played low-violence video games. Interestingly, physiological responses to aversive stimuli depended on participants' level of video game experience, with more experienced players showing weaker physiological responses. Staudé-Müller et al. (2008) suggested that the latter finding may reflect an 'emotional hardening' (p. 48)—i.e. desensitization—induced by repeated exposure to violence in video games. Of note, in the same study, a subset of negative-arousing photographs that depicted aggressive behaviours (e.g. threatening situations) elicited a *stronger* physiological response in the VVG condition, compared to the non-violent control condition. This finding hinted at the possibility that VVG exposure can also heighten sensitivity to violence, at least in the short term.

Additional support for the idea that VVG exposure leads to alterations in affective and cognitive domains was recently provided by Wang et al. (2009). Participants played either a violent or a nonviolent video game for 30 minutes and then underwent functional magnetic resonance imaging (fMRI) while they performed an executive-control task (Counting Stroop or Emotional Stroop). Relative to participants in the nonviolent control condition, participants who had played the violent video game showed stronger responses in the right amygdala, a brain region associated with arousal and emotional reactivity. They also showed reduced activity in prefrontal regions (e.g. ventrolateral prefrontal cortex) associated with emotion regulation and executive control.

In sum, the experimental literature suggests that even brief (e.g. 20 minute) VVG exposure can produce affective and cognitive changes. However, recent research found that effects from acute VVG exposure may last only a few minutes, consistent with short-term habituation. Furthermore, the evidence is mixed with regard to the direction of VVG effects, with most findings pointing towards desensitization, but others raising the possibility of sensitization to violence.

### Long-term effects: Habitual VVG exposure

Evidence for long-term effects of chronic VVG exposure has come from quasi-experimental and individual-differences research. Three published studies have compared individuals with different levels of self-reported VVG exposure on tests of executive function, primarily the Stroop task.

Kronenberger et al. (2005) assessed media violence exposure (television and video game) and behavioural measures of executive function (e.g. Stroop interference effect) in adolescents with a history of aggressive-disruptive behaviour and age-matched controls. Media violence exposure was a negative predictor of executive function in both groups, but the relationship was stronger in the group with aggressive-disruptive behaviour disorder. This finding suggests possible links between VVG exposure and executive deficits, as well as between VVG exposure and aggression.

Additional support for this interpretation came from an fMRI study by the same research group (Mathews, Kronenberger, Wang, Lurito, Lowe, & Dunn, 2005). Both trait aggression and media violence exposure were associated with reduced frontal recruitment (anterior cingulate, lateral frontal cortex) during Stroop interference trials, relative to control trials. Finally, a recent ERP study of the Stroop interference effect (Bailey, West, & Anderson, 2010) also yielded evidence of frontal executive-control deficits among frequent video game players, compared to controls with low video game exposure. Specifically, reduced amplitude of a medial frontal negativity (400–500 ms post-stimulus) and a frontal slow wave in frequent gamers were interpreted as evidence that video game exposure selectively reduces preparatory processes characterized as 'proactive cognitive control' (Braver, Gray, & Burgess, 2007).

Of particular relevance to the current research, a study by Bartholow, Bushman, & Sestir (2006) examined processing of emotional and neutral stimuli in habitual VVG players and nonplayers, using ERPs. Of interest was the P300, an early positive-going ERP component whose amplitude and latency are thought to be markers of stimulus-induced attention and arousal (Linden, 2005). Compared to non-violent video game players, VVG players showed reduced P300 amplitude and increased P300 latency in response to violent images, but not to non-violent aversive images. This suggests that chronic exposure to VVGs may lead to desensitization expressed at relatively early stages of information processing, although—as is true for all of the studies reviewed in this section—experimental evidence is needed to strengthen the support for a direct causal link.

Overall, the results from studies comparing habitual VVG players and nonplayers offer behavioural, electrophysiological and fMRI evidence that habitual VVG exposure may cause deficits in certain types of executive control. Of greater relevance to the current study, this literature also suggests that habitual VVG exposure may induce cognitive and affective desensitization to violent stimuli (see also Smith & Donnerstein, 1998).

### Emotion and memory

Although the research reviewed above suggests that VVG exposure may downregulate emotional arousal to violent stimuli, the effects of VVG exposure on memory have not been investigated to date. This is surprising given the known influence of emotion on memory (e.g. Kensinger, 2004; Kensinger, 2009). Emotional arousal is associated with activation of the amygdala and the release of adrenal stress hormones, and has been shown to modulate long-term memory consolidation (see McGaugh, 2004, for review). Indeed, emotional events, such as a wedding day or the death of a loved one, are remembered more vividly than mundane, neutral events, such as breakfast yesterday (Reisberg & Heuer, 2004). Emotional enhancement of memory is not limited to autobiographical events, but has also been observed in the laboratory (for reviews see Hamann, 2001; Levine & Edelman, 2009). The enhancement is often most pronounced for negative stimuli, a phenomenon that has been described with the term 'negativity bias' (e.g.

Dewhurst & Parry, 2000; Kensinger & Schacter, 2006; Ochsner, 2000). Negative stimuli may be prioritized at early information processing stages because they are novel (Mendelson, 2001), or because they are threatening and survival-relevant (Ochsner, 2000; Öhman, 1988), and this processing bias may lead to enhanced long-term memory formation for negative stimuli (Ochsner, 2000). Additionally, ample evidence suggests that response bias during memory retrieval is modulated by emotion, with individuals more likely to classify emotional information as familiar, compared to neutral information (e.g. Dougal & Rotello, 2007; Kapucu, Rotello, Ready, & Seidl, 2008; Spaniol, Voss, & Grady, (2008); Windmann & Krüger, 1998; Windmann & Kutas, 2001). If VVG exposure indeed causes desensitization to negative stimuli, the prediction follows that it should reduce memory and induce a more conservative response bias for these stimuli.

### The current study

The goal of the study was to test the hypothesis that VVG exposure is associated with reduced memory performance for emotional, and particularly for negative, material. Rather than provide participants with short-term VVG exposure in the laboratory, as was done in several studies (e.g. Bushman & Anderson, 2009; Carnagey et al., 2007; Staude-Müller et al., 2008; Wang et al., 2009), we opted to study individual differences in VVG experience. Although laboratory-based VVG exposure offers greater experimental control, this advantage is counterweighed by low external validity. Most VVG players use the games over prolonged periods of time (i.e. months or years) and build up significant expertise. Just as short-term VVG exposure in the laboratory does not produce expert performance, its desensitizing effect may not be on par with that obtained over extensive periods of gaming (see also Bailey et al., 2010; Bartholow et al., 2006; Kronenberger et al., 2005; Mathews et al., 2005).

Similar to previous published laboratory studies of emotional memory (e.g. Bradley, Greenwald, Petry, & Lang, 1992; Charles, Mather, & Carstensen, 2003; Gallo, Foster, & Johnston, 2009; Ochsner, 2000; Talmi, Luk, McGarry, & Moscovitch, 2007), we presented participants with pictures depicting neutral, negative or positive scenes and later assessed recognition memory for these stimuli. Recognition, rather than recall, served as the memory task because it provided data that allowed us to measure both memory and response bias. This was of interest because prior research has shown both of these processes to be sensitive to emotion (e.g. Dougal & Rotello, 2007; Kapucu et al., 2008; Spaniol et al., 2008).

Recognition performance is often analyzed with measures derived from signal detection theory (Green & Swets, 1966), which take into account accuracy but not reaction time (RT). Because of the trade-off between accuracy and RT (Ratcliff, 1978), the simultaneous analysis of both measures may be more informative than the analysis of either measure in isolation. Speed-accuracy tradeoffs may differ for VVG players and nonplayers, given the evidence for enhanced perceptual-motor abilities in gamers (see Messaris & Humphreys, 2004, for a review). Ratcliff's (1978) diffusion model, one of the most widely used sequential-sampling

models, is ideally suited for the analysis of recognition memory data. The model assumes that, during memory search, information accumulates over time towards one of two decision thresholds corresponding to the decision to either endorse an item as old, or to reject it as new. Accuracy and RT depend on the quality of the evidence that drives the decision, the placement of the decision boundaries and on trial-to-trial variability in these parameters. The model yields estimates of perceptual-motor RT, memory and response bias and of within-subject variability in these components (Ratcliff, 1985; Ratcliff & Tuerlinckx, 2002). Additional information about the model is provided in the Method section.

### Hypotheses

In line with the evidence for VVG-related desensitization, reviewed above, we predicted that VVG exposure would be a predictor of emotional memory as observed in an old-new picture recognition task. We hypothesized that VVG playing would be associated with reduced memory or a less liberal response bias for negative stimuli. Whether VVG exposure would also predict memory or response bias for positive or neutral stimuli, or whether there would be a relationship between VVG exposure and other model parameters (perceptual-motor RT, within-subject performance variability), was an open question.

## METHOD

### Participants

One-hundred thirty-four undergraduate students participated for partial course credit. All procedures were approved by the Research Ethics Board at Ryerson University. Participants provided written consent and completed a health questionnaire assessing a history of brain or head injuries, psychiatric illnesses, use of medication and current depression. Eight participants were excluded from the analyses because of responses on the health assessment and four others chose to discontinue the study before completion, resulting in a total of 122 eligible participants (26 male and 96 female). The median age of the sample was 19.0 years, with a range from 17 to 38 years. Of the 122 participants, 45 had a least some video game experience within the last six months with a mean Violence Exposure Score (VES; see next section for details) of 19.5 and a range of 2.0 to 79.2. The remaining 77 nonplayers reported no video game exposure in the past six months. For both male and female video game players, Grand Theft Auto (mean violence rating = 6.8), Final Fantasy ( $M = 2.8$ ) and NHL ( $M = 5.0$ ) were the most commonly listed video games. Male video game players also listed Call of Duty ( $M = 6.5$ ) and Tekken ( $M = 4.5$ ) in their top five, while female video game players preferred Mario Kart ( $M = 4.0$ ) and Guitar Hero/Rock Band ( $M = 1.0$ ). Additional sample characteristics are provided in Table 1.

### Questionnaires

Violent video game exposure was assessed with a video game inventory that has a test-retest reliability ( $\alpha$ ) of .86

Table 1. Questionnaire data and bivariate correlations with VES

Characteristics	Mean ( <i>N</i> = 122)	Correlation with VES
Age (years)	20.8 (4.4)	-0.04
Negative mood	13.2 (3.9)	0.07
Positive mood	28.8 (6.1)	0.21*
AQ	72.2 (16.3)	-0.01
IS	77.8 (17.9)	0.02
TAS-20	46.3 (11.1)	0.08
VES	7.2 (12.5)	1
Neuroticism	18.3 (13.1)	0.49**
Extraversion	26.9 (8.2)	-0.17
Openness	28.6 (7.1)	0.08
Agreeableness	30.6 (6.2)	-0.15
Conscientiousness	32.5 (6.4)	-0.08

Note: Negative mood and positive mood are positive and negative affect schedule scores. AQ = aggression questionnaire; IS = irritability questionnaire. TAS-20 = 20 item Toronto Alexithymia scale. VES = violence exposure score from the video game questionnaire. Neuroticism, extraversion, openness, agreeableness and conscientiousness are from the revised NEO five-factor inventory. Standard deviations are in parentheses. \* $p < .05$ . \*\* $p < .001$ .

(Anderson & Dill, 2000). Participants are asked to name up to 5 of their favourite video games, and to rate on a Likert scale of 1–7 the frequency with which they play each game, as well as the violence of its content and graphics. A VES score was computed for each participant by summing the content and graphics ratings, multiplying the result by the frequency rating, and averaging over the number of listed games. Higher scores indicate a higher degree of exposure to violence. We also administered the 60-item NEO Five-Factor Inventory (Costa & McCrae, 1989), the Irritability Scale (IS; Caprara et al., 1985), Buss and Perry's (1992) Aggression Questionnaire (AQ) and the Positive and Negative Affect Schedule (PANAS; Watson, Clark, & Tellegen, 1988).

### Stimuli and apparatus

The stimuli included 100 positive, 100 negative and 78 neutral images from the IAPS<sup>1</sup> (Lang et al., 1997). Twenty-two neutral images from another source (Spaniol et al., 2008) were added, all of which contained people or faces in order to match neutral and emotional images with respect to this feature. Mean IAPS valence norms for each stimulus group differed significantly,  $F(2,299) = 1294.61$ ,  $p < .001$ , with negative, neutral and positive images receiving average ratings of 2.69, 5.07 and 7.10, respectively. Mean arousal ratings for positive ( $M = 5.58$ ) and negative ( $M = 5.73$ ) images did not differ significantly, but were both significantly higher than arousal ratings for neutral images ( $M = 3.55$ ),  $F(2, 299) = 9.50$ ,  $p < .001$ .

The negative images were further categorized as either *violent* ( $N = 28$ ) or *non-violent* ( $N = 72$ ). Images were considered violent if they portrayed aggressive behaviour, signs of physical abuse, attacks and intimidation or intentional acts causing harm to another living being. There was no significant difference in IAPS valence norms between violent ( $M = 2.55$ ) and negative non-violent ( $M = 2.75$ ) images,  $t(98) = 1.395$ ,  $p = .166$ . IAPS arousal norms, however, were significantly higher for violent images ( $M = 6.09$ ) than for non-violent images ( $M = 5.60$ ).

Two stimulus lists were created, and the assignment of lists to target or distractor status was counterbalanced across participants. The lists were equated for average IAPS valence and arousal norms and for semantic content (e.g. animals, faces, inanimate objects).

The experimental task was created in E-Prime (Psychology Software Tools, Inc.). Stimulus presentation was controlled by a Toshiba laptop with a viewing distance of approximately 50 cm. All study and test stimuli appeared in the centre of the screen against a black background.

### Procedure

The experimental session included a study phase, a filled retention interval and a recognition test. Participants were told that they were completing a study investigating the effect of emotion on brightness perception and were unaware that their memory for the images would be tested later. Prior to the study phase, the health questionnaire and the PANAS were completed. During the study phase, participants viewed a series of 150 images in random order. Each trial started with a fixation cross lasting 750 ms, followed by a 500-ms pause and a 2-s picture stimulus. After the image was presented, participants were asked to rate its brightness on a 7-point scale. Participants were instructed that on this scale, a '1' (not at all bright) corresponded to the amount of light given off by a small night light in a very large room at night, whereas a '7' (very bright) corresponded to the amount of light present on a sunny, cloudless day (Ochsner, 2000). Brightness of the images was not experimentally manipulated. Following the study phase, participants completed the personality assessments.

A surprise recognition test started approximately 1 hour after the end of the study phase. Participants viewed the 150 target images and 150 distractor images, presented in a random intermixed order. The assignment of response keys to the two responses was counterbalanced across participants. Participants were not given specific instructions about prioritizing speed or accuracy, but were told that each stimulus would remain onscreen for up to 5s or until a response was made. Following the recognition test, participants were shown all 300 images again and provided

<sup>1</sup>IAPS numbers: 5833 1440 2070 2080 2154 4220 2530 5910 2550 1811 2216 2388 4660 5594 2208 5470 5631 2299 2598 5623 2370 5010 5781 4599 1604 2391 1722 4520 4607 2510 5300 7220 2655 2303 4676 2344 2030 4681 4574 2358 4150 2000 5628 2630 4598 4490 2605 4572 4100 2594 2620 2435 2394 2580 4300 2485 2518 2235 2980 5390 5621 7096 2351 2575 2305 2357 2445 2191 7058 7550 7207 2038 7056 2214 7041 2397 7050 2840 2595 2493 2780 7130 2383 2446 7186 2230 3210 9402 2104 2810 2206 2681 9360 1019 1200 2661 5972 1930 3250 2110 1090 3022 2399 9005 1274 7359 9330 3160 2717 2710 3215 9007 9600 2053 9900 6415 9560 2352.2 9800 9921 3230 3350 3225 3301 2095 9570 3120 6562 9452 6244 2691 9427 9424 6370 6242 9425 6821 6230 3180 3500 9253 1710 2340 1750 2050 2040 5830 1441 2660 2360 2209 2540 4290 5700 4626 2160 5600 2395 2398 1999 2345 2341 5460 2650 4641 5001 1340 2387 2222 5201 5629 2057 5450 2373 4601 5626 4311 4653 2389 4664 4677 5593 4800 2560 5622 4535 4180 2320 2442 4006 4503 7095 2606 2600 2593 4537 2597 2579 7140 2372 2499 7242 2635 2850 2385 2880 2102 7161 2890 2396 2516 2393 8475 2690 2480 7180 2210 7044 2441 2215 9210 2440 2280 2491 9080 1932 2100 9926 1120 3280 2682 7360 1201 5971 1050 2278 2120 3216 9417 9342 2981 3300 9611 9429 9561 2276 2751 2750 6311 3220 2900 2141 2799 3400 9300 9910 2205 3191 9810 2703 3030 9635.1 2800 3170 1525 8230 6571 6250.1 2683 3550.1 6312 9420 6540 2811 9254 3181 6350 3530.

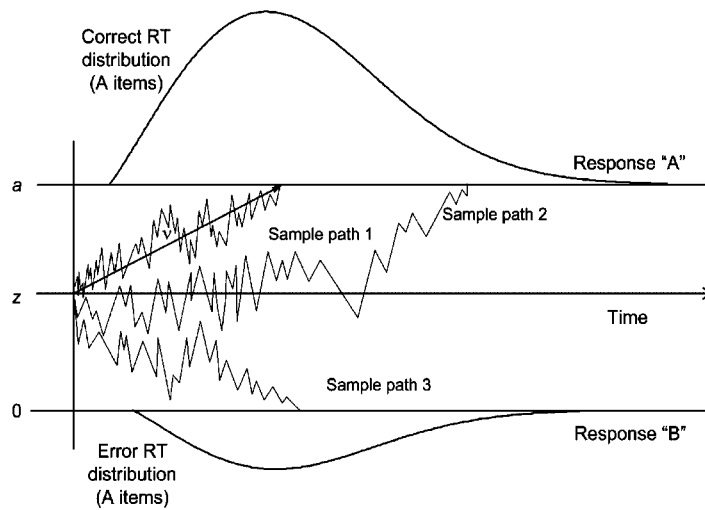


Figure 1. The diffusion model (Ratcliff, 1978; diagram from Spaniol, Madden, & Voss, 2006). Illustration of the diffusion process for the classification of a Category-A item into Category A or Category B. The decision process starts at point  $z$  and moves towards the upper boundary or lower boundary by a drift rate  $\nu$ . In this example, 'A' response corresponds to the upper (and correct) boundary  $a$ , and is driven by a positive drift rate. Three sample paths are illustrated with responses 1 and 2 ending in a correct response at the upper boundary ('A') but path 3 drifts towards the lower boundary  $0$ , ending in an incorrect response 'B'. RT = reaction time

arousal ratings using the Self-Assessment Manikin (Bradley, Greenwald, & Hamm, 1993) on a 5-point scale. At the end of the session, participants completed the VES if they indicated that they had played video games in the last 6 months.

### Analysis of recognition data with the diffusion model

The diffusion model assumes that RTs in two-choice decisions can be broken down into two components: Nondecisional processes involved in stimulus perception and motor response (model parameter  $t_0$ ), and decisional processes. Figure 1 illustrates the process underlying the decisional RT component. In the example, the decision involves discrimination between two stimulus categories, 'old' (upper boundary) and 'new' (lower boundary).

The decision process moves from a starting point (parameter  $z$ ) towards either of two response boundaries. The position of the starting point  $z$  between the boundaries can introduce response bias. If, for example,  $z$  is closer to the upper boundary the individual favours 'old' responses whereas if  $z$  is closer to the lower boundary, a bias for 'new' responses results. Variability in position of the starting point ( $s_z$ ) reflects the inability to hold the starting point of the accumulation of information constant across trials. Large values of  $s_z$  are associated with fast error responses. The starting point, conceptually similar to the response bias parameter in signal-detection theory (Green & Swets, 1966), can be manipulated experimentally, for example, via response-specific payoffs (Voss, Rothermund, & Voss, 2004).

Boundary separation (parameter  $a$ ) is the distance between the lower and upper boundaries and indicates how much information is required on average before a decision is made. Experimental manipulations such as speed-accuracy instructions can affect boundary separation. When accuracy is emphasized, the boundaries are set far apart, so that accuracy is high but reaction times are long. When speed is emphasized, boundaries are moved closer together resulting

in shorter response times, but the accumulation process is now more likely to hit the wrong boundary by accident, which reduces accuracy.

The drift rate (parameter  $\nu$ ) is the rate at which information accumulates towards either the upper or the lower boundary. Once a boundary is reached, the decision process ends and a response is given (i.e. button press). A positive drift rate drives the decision process towards the upper boundary, as illustrated in the example by the single arrow pointing up, whereas a negative drift rate drives the decision process towards the lower boundary. Drift rate captures the strength or quality of the retrieved information, and is similar to signal detection parameter  $d'$ . Unlike  $d'$ , however, drift depends on both accuracy and speed. Steeper (i.e. larger) drift rates are associated with higher accuracy and shorter reaction times. Within-trial variability in drift, illustrated by the jagged lines, contributes to the incidence of error responses, and to variability in finishing times (i.e. RT distributions; Ratcliff & Tuerlinckx, 2002). Drift also varies across trials with a standard deviation of  $s_\nu$  (not depicted in the figure).

## RESULTS

The research questions concerned memory and response bias, processes that were estimated by the parameters of the diffusion model. We therefore focus on the diffusion model results and do not discuss the raw data in detail. Nevertheless, to allow comparison with other studies that have not used diffusion modeling, we report mean hit rates, false alarm rates and the signal-detection index  $d'$  (Green & Swets, 1966) in Table 2. Median RTs for hits and correct rejections are presented in Table 3.

### Model fit

Parameters of the model were estimated for each participant using the *fast-dm* program (Voss & Voss, 2007). Separate

Table 2. Mean hit rates, false alarm rates,  $d'$  and bivariate correlations with VES for all levels of valence

	Mean		Correlation with VES
		Negative	
HR	.75 (.13)		-.28
FAR	.11 (.08)		.10
$d'$	2.09 (.59)		-.11
		Violent	
HR	.74 (.18)		.11
FAR	.09 (.08)		.14
$d'$	2.11 (.70)		.04
		Neutral	
HR	.69 (.16)		-.06
FAR	.07 (.07)		.13
$d'$	2.19 (.69)		-.13
		Positive	
HR	.73 (.14)		.004
FAR	.10 (.09)		.04
$d'$	2.12 (.67)		-.07

Note: HR = hit rate; FAR = false alarm rate. Standard deviations are in parentheses. VES = violence exposure score from the video game questionnaire.

drift rates ( $v$ ) were estimated for targets and distractors at each level of valence (neutral, negative, positive). Diffusion model analysis is optimized for large numbers of observations per experimental condition, per participant. Because the set of negative images contained only 28 violent images, we collapsed across violent and nonviolent negative images for the diffusion model analysis (but see below for non-diffusion analyses in which responses to violent images were analyzed separately). Separate starting values ( $z$ ) were estimated at each level of valence. Non-decision time ( $t_0$ ), boundary separation ( $a$ ), and variance in non-decision time ( $s_t$ ), starting point ( $s_z$ ) and drift rate ( $s_v$ ), were all constrained to be equal across experimental conditions. In total, we estimated 14 parameters per participant.

To estimate the parameters of the diffusion model, we optimized the fit between the predicted and the empirical RT distributions using the Kolmogorov-Smirnov (KS) test statistic (see Voss et al., 2004). The KS statistic indicates

Table 3. Median reaction times for hits and correct rejections (in ms) and bivariate correlations with VES

	Mean		Correlation with VES
		Negative	
Hit	998 (161)		-.01
CR	1,059 (239)		.11
		Violent	
Hit	1,058 (248)		.09
CR	1076 (268)		.05
		Neutral	
Hit	975 (155)		-.02
CR	939 (173)		.04
		Positive	
Hit	999 (174)		.00
CR	1023 (187)		.05

Note: Hit = correctly identifying target as 'old'; CR = correct reject of distractor item as 'old'. Standard deviations are in parentheses. VES = violence exposure score from the video game questionnaire.

the maximal vertical distance between the empirical cumulative RT distribution and the RT distribution predicted by the model. Two theoretical cumulative RT distributions need to be simultaneously fitted to two empirical cumulative RT distributions. One distribution is associated with the lower response boundary (i.e. the *new* boundary in the old-new recognition task), and the other is associated with the upper boundary (i.e. the *old* boundary in the old-new recognition task). A negative sign is arbitrarily assigned to the lower boundary RT distribution (i.e. *new* responses) and the two distributions are concatenated to form a single distribution with negative and positive RT ranges (see Figure 1). A single KS test can then be used to assess model fit. A significant KS statistic (i.e.  $p < .05$ ) indicates poor fit.

Of the 122 participants, 29 participants had poor model fit (i.e.  $p < .05$ ). One possible cause of model misfit is a low error rate, which leads to a noisy error RT distribution that is difficult to fit. Indeed, there was a significant correlation ( $r = .27, p = .003$ ) between the false alarm rate and the model fit index, indicating that participants with fewer false alarms tended to have worse model fit. All analyses were calculated both with and without the 29 participants with poor model fit, without changes in the pattern of results. All 122 participants were therefore included in the analyses reported next.

**Model parameters**

Means of the diffusion parameters are presented in Table 4. VES was significantly correlated with the nondecisional parameter  $t_0$  ( $r = .24, p = .008$ ), but not with any other diffusion parameters.

**Response bias**

The placement of the starting point relative to the response boundaries,  $z/a$ , served as a measure of response bias.  $z/a$

Table 4. Means of the diffusion parameters and bivariate correlations with VES

Diffusion parameter	Mean	Correlation with VES
$t_0$	.63 (.29)	.24**
$a$	1.81 (.37)	.01
$z$		
Neg	1.06 (.28)	.001
Neu	.96 (.37)	.08
Pos	1.04 (.30)	.02
$v_{old}$		
Neg	.83 (.63)	.08
Neu	.83 (.95)	.12
Pos	.92 (.80)	.012
$v_{new}$		
Neg	-1.61 (.66)	-.065
Neu	-2.10 (1.11)	-.147
Pos	-1.77 (.91)	-.01
$s_t$	.23 (.13)	.14
$s_z$	.52 (.28)	-.05
$s_v$	.52 (.30)	.03

Note: Neg = negative; Neu = neutral; Pos = positive. Standard deviations are in parentheses.

\*\* $p < .01$ . VES = violence exposure score from the video game questionnaire.

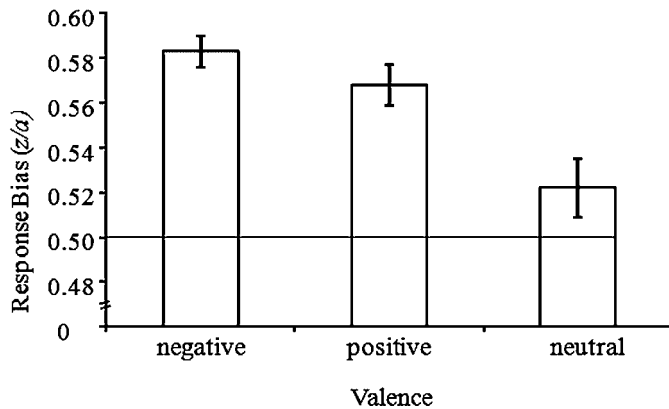


Figure 2. Mean values of response bias ( $z/a$ ) for negative, positive and neutral images. Error bars represent the standard errors. Values above 0.5 (see dotted line) indicate a bias to classify items as 'old', whereas values below 0.5 indicate a bias to classify items as 'new'

values greater than 0.5 indicate a bias towards the response associated with the upper boundary (i.e. 'old'), whereas values of  $z/a$  lower than 0.5 indicate a bias towards the response associated with the lower boundary (i.e. 'new'). The response bias estimates were submitted to a repeated measures analysis of covariance (ANCOVA) with valence (neutral vs. negative vs. positive) as the within-subjects variable and VES as a covariate. Mauchly's test showed the assumption of sphericity to be violated for valence,  $X^2(2) = 20.429$ ,  $p < .001$ , so degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity,  $\epsilon = .86$ . The effects of VES and Valence  $\times$  VES were nonsignificant,  $F(1,120) = .624$ ,  $p = .431$ ,  $MSE = .013$ ,  $\eta^2 = .005$  and  $F(1.727, 207.299) = .655$ ,  $p = .520$ ,  $MSE = .006$ ,  $\eta^2 = .005$ , respectively, but there was a significant effect of valence on response bias,  $F(1.727, 207.299) = 13.69$ ,  $p = .001$ ,  $MSE = .133$ ,  $\eta^2 = .102$ . Participants were more liberal in their responses (i.e. more likely to respond 'old') to negative and positive items compared to neutral items. Figure 2 shows response bias means at each level of valence. One-sample  $t$ -tests indicated that response bias for negative and positive stimuli was significantly greater than .5,  $t(121) = 11.270$ ,  $p < .001$ ,  $t(121) = 7.743$ ,  $p < .001$ , whereas response bias was not significantly different from 0.5 for neutral stimuli,  $t(121) = 1.673$ ,  $p = .097$ .

#### Drift rates: Effects of target/distractor status and valence

The assignment of 'old' responses to the upper boundary and 'new' responses to the lower boundary is arbitrary, resulting in positive average target drift and negative average distractor drift estimates. The following analyses therefore used the absolute values of the drift rate estimates. These drift rates were submitted to a  $2 \times 3$  repeated measures ANCOVA with status (distractor vs. target) and valence (neutral vs. negative vs. positive) as within-subjects variables and VES as a covariate. Mauchly's test indicated that the assumption of sphericity was violated for valence,  $X^2(2) = 12.119$ ,  $p = .002$ , so we used the Greenhouse-Geisser estimate of sphericity ( $\epsilon = .91$ ) to correct the degrees of freedom. There

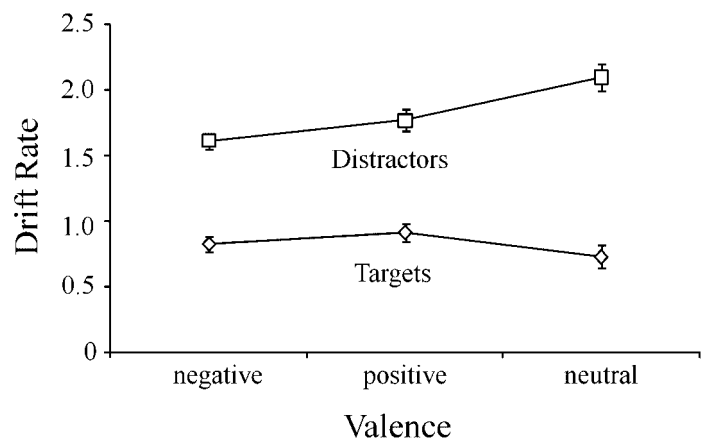


Figure 3. Mean drift rates for negative, positive and neutral items separately for targets and distractors. Error bars represent the standard errors

was no main effect of VES,  $F(1,120) = .624$ ,  $p = .431$ , no VES  $\times$  Valence interaction,  $F(1.823, 218.812) = 2.692$ ,  $p = .075$ , nor a VES  $\times$  Status interaction,  $F(1,120) = .232$ ,  $p = .669$ . There was a main effect of valence, with negative drift rates ( $M = 1.22$ ) significantly lower than positive drift rates ( $M = 1.34$ ), which in turn were significantly lower than neutral drift rates ( $M = 1.47$ ),  $F(1.823, 218.812) = 19.676$ ,  $p < .001$ ,  $MSE = 4.073$ ,  $\eta^2 = .141$ . A main effect of target/distractor status was also present, with drift rates significantly lower for target pictures ( $M = 0.88$ ) than for distractor pictures ( $M = 1.83$ ),  $F(1, 120) = 106.63$ ,  $p < .001$ ,  $MSE = 134.770$ ,  $\eta^2 = .470$ . Finally, the Status  $\times$  Valence interaction was significant,  $F(1.917, 230.071) = 6.33$ ,  $MSE = 2.76$ ,  $p = .002$ ,  $\eta^2 = .050$ . Pairwise comparisons revealed that neutral distractors elicited significantly higher drift rates than negative or positive distractors (see Figure 3).

#### Arousal ratings

Two participants' arousal ratings were not recorded because of equipment failure. For the remaining participants, a repeated measures ANCOVA was conducted on the arousal ratings, with valence (violent vs. negative vs. positive vs. neutral) as the within-subjects variable and VES as a covariate. We entered violent and non-violent negative images separately to assess whether we would replicate the finding of previous studies (e.g. Bradley, Codispoti, Cuthbert, & Lang, 2001) that violent images are more arousing. Mauchly's test indicated that the assumption of sphericity was violated for valence,  $X^2(5) = 113.570$ ,  $p = .001$ . We thus used the Greenhouse-Geisser estimate of sphericity ( $\epsilon = .65$ ) to correct the degrees of freedom. There was no VES  $\times$  Valence interaction on arousal ratings,  $F(1.955, 230.645) = .255$ ,  $p = .770$ ,  $MSE = .052$ ,  $\eta^2 = 0.002$ , but there was a main effect of valence on arousal,  $F(1.955, 230.645) = 316.557$ ,  $p < .001$ ,  $MSE = 98.881$ ,  $\eta^2 = 0.728$ . Repeated contrasts revealed that violent images were rated more arousing ( $M = 3.51$ ,  $SD = .91$ ), than negative images ( $M = 3.24$ ,  $SD = .74$ )  $F(1, 118) = 34.62$ ,  $p < .001$ , negative were rated as more arousing than positive images ( $M = 2.46$ ,  $SD = .74$ )  $F(1, 118) = 498.529$ ,  $p < .001$ , and

positive were rated more arousing than neutral images ( $M = 1.62$ ,  $SD = .44$ )  $F(1, 118) = 218.226$ ,  $p < .001$ .

### Memory for violent versus non-violent negative images

As noted above, the number of violent images was too small to estimate separate diffusion models for this stimulus class. The diffusion model results thus did not speak to the question of whether VVG exposure is associated with sensitization to violent stimuli in particular (Staudé-Müller et al., 2008). We therefore performed a repeated measures ANCOVA on the signal-detection index  $d'$  (Green & Swets, 1966), valence (negative vs. violent vs. neutral vs. positive) as a within-subjects variable and VES as a covariate. VES and valence did not interact significantly,  $F(3, 360) = 1.396$ ,  $p = .244$ ,  $MSE = .289$ ,  $\eta^2 = .012$ . Video game exposure was not associated with reduced  $d'$  for negative non-violent images, nor did it increase  $d'$  for violent images. There was a main effect of valence,  $F(3, 360) = 3.783$ ,  $p = .011$ ,  $MSE = .784$ ,  $\eta^2 = .031$ .

### Supplementary analysis

In the analyses reported above, the VES variable was not associated with any significant effects, except for a correlation with the diffusion parameter  $t_0$  (nondecisional time). To examine the possibility that VES effects had been 'washed out' due to the inclusion of so many nonplayers, we selected 22 'heavy VVG players,' defined as those participants whose scores exceeded the median non-zero VES score of 19.0. The median VES score for VVG players in this group was 28.8 (range: 19.0–79.0). We then contrasted this group with a group of age and gender-matched controls with VES scores of zero (i.e. nonplayers). We compared the groups on old-new recognition memory for negative, neutral and positive images, using the diffusion parameters. No significant group differences emerged on any of the dependent measures.

Finally, because of the scoring used for the VES, it is possible for frequent non-violent video game players to still receive a high score. Restricting the analyses to a sample of 18 VVG players whose high VES scores ( $MD = 30.0$ ) were due specifically to VVG exposure, and their matched controls, did not affect the pattern of results.

## DISCUSSION

The current study aimed to examine the hypothesis that habitual VVG exposure is associated with alterations in long-term memory, specifically, with reduced memory or a less liberal response bias for negative stimuli. This hypothesis was based on prior research that suggested that VVG exposure may lead to desensitization (Bailey et al., 2010; Bartholow et al., 2006; Kronenberger et al., 2005; Mathews et al., 2005) and to reduced emotional arousal (Bartholow et al., 2006; Carnegiey et al., 2007; Staudé-Müller et al., 2008). We tested a large sample ( $N = 122$ ) of young adults with a range of prior video game exposure, and found that this exposure was not

associated with differences in self-reported arousal, memory, or response bias for emotional stimuli.

### Diffusion model results

We used Ratcliff's (1978) diffusion model to obtain separate estimates of the memory and decision processes underlying recognition decisions. Response bias was the decision parameter of interest, and was defined as the relative position of the starting point (parameter  $z$ ) between the 'old' and 'new' decision boundaries of the diffusion model (see Figure 1). Contrary to our hypothesis, response bias for negative stimuli was not modulated by VVG exposure. Similar to previous findings, (Dougal & Rotello, 2007; Kapucu et al., 2008; Spaniol et al., 2008; Windmann & Krüger, 1998; Windmann & Kutas, 2001), however, participants showed a liberal response bias for emotional (negative and positive) stimuli, but not for neutral stimuli. It is not clear why emotional information is more readily endorsed as 'old' than neutral information. One possibility is that emotional stimuli, both negative and positive, are prioritized as part of a response policy that has evolved to avoid the costs of cognitive errors. In everyday life, the negative consequences of failing to recognize previously seen emotional stimuli may be greater than those of committing false alarms to never-before seen emotional stimuli. The lack of an interaction between VES and response bias indicates, then, that even voluntary chronic exposure to violent media does not override response settings that serve an adaptive function dealing with emotional information in everyday life.

Recognition memory was measured with the drift-rate parameter of the diffusion model (Ratcliff, 1978). According to the desensitization hypothesis, VVG exposure should have been associated with reduced drift (i.e. poorer memory performance) for negative stimuli, but we found no support for this prediction. There was also no evidence that VVG exposure somehow modulated memory for violent material in particular (e.g. see Staudé-Müller et al., 2008). In summary, none of the memory measures we examined were sensitive to VVG exposure.

Despite the lack of an association with VVG exposure, drift rates were sensitive to the experimental manipulations, and the drift rate analyses reveal several interesting patterns. First, consistent with previous reports (Ratcliff, Thapar, & McKoon, 2004; Spaniol et al., 2008), distractor drift rates were higher than target drift rates. The distractor advantage may be explained by *diagnostic monitoring* (e.g. 'I would remember that picture if I had seen it... I don't remember it... so it must be new'; Gallo, 2004). When target items are made so memorable that participants feel confident that they would remember them vividly, the absence of recollection provides diagnostic evidence that the item is new (Gallo, 2004; Schacter, Israel, & Racine, 1999; Strack & Bless, 1994). Overall memory performance in our experiment was indeed quite high, and participants were likely making 'old' judgments on the basis of recollection. The absence of recollection may have provided immediate diagnostic evidence that a stimulus was new.



The drift rate analysis also revealed a significant Status  $\times$  Valence interaction. Neutral distractors were processed more efficiently than emotional distractors, whereas target drift rates were not modulated by valence. Perhaps the most important implication of this finding is that the valence manipulation did affect mnemonic processing, as measured by drift rates. The fact that there was no interaction with VVG exposure can therefore not be easily dismissed as an artifact of the particular experimental stimuli or the particular memory measures that we used.

The distractor drift advantage was greater for neutral than for emotional items, suggesting that neutral distractors were particularly easy to reject. This finding fits well with recent reports that emotional pictures may be more conceptually related, thus less distinctive, than neutral items (Gallo, Foster, & Johnson, 2009). Overall, contrary to the predictions of the desensitization account, results from the diffusion model failed to reveal significant relationship with long-term VVG exposure on memory or response bias.

### Arousal ratings

No relationship emerged between arousal ratings for the experimental stimuli and VVG exposure. In contrast, previous studies had reported negative correlations between VVG playing and arousal for negative stimuli (Carnagey et al., 2007; Staude-Müller et al., 2008). However, these studies reported physiological measures of arousal (e.g. heart rate, skin conductance), whereas we assessed subjective arousal via self-report. Although we cannot rule out that physiological measures would have revealed a relationship with VVG exposure (for research on the relationship between physiological and self-report measures of arousal, see Bradley, Codispoti, Cuthbert, & Lang, 2001; Greenwald, Cook, & Lang, 1989), the null finding on self-reported arousal is consistent with the lack of a relationship with memory and response bias, and provides further evidence against the desensitization hypothesis.

### Habituation, desensitization or no effect?

Experimental evidence suggests that playing a VVG for even a short period of time can reduce physiological arousal and alter the categorization of negative stimuli, at least in the short term (e.g. Carnagey et al., 2007; Staude-Müller et al., 2008; Wang et al., 2009). Furthermore, in one quasi-experimental study, chronic exposure to VVGs was associated with a flattened neurocognitive response to violent stimuli (Bartholow et al., 2006), as might be expected if VVG exposure causes desensitization to violent content. These findings led us to hypothesize that VVG exposure should also affect memory for negative stimuli. In contrast, we found no association between VVG exposure and self-reported arousal, recognition memory, or response bias for emotional stimuli. One possible explanation for this discrepancy is that the experimentally induced 'desensitization' effects reported in the literature may in fact have represented habituation effects, that is, temporary changes following acute exposure (e.g. Sestir & Bartholow, 2010). If so, one would not expect habitual VVG players to be

*chronically* underaroused by negative stimuli, and there would likewise be no reason to predict deficits in their long-term memory for this material. However, the finding of reduced P300 amplitude for violent images in chronic VVG players (Bartholow et al., 2006) is not easily attributed to habituation. How then can our results be reconciled with those of Bartholow et al. (2006)?

One interpretation is that the electrophysiological desensitization effects reported by Bartholow et al. (2006) reflect relatively subtle attentional shifts during early ( $\sim 300$  ms post-stimulus) processing which may not be powerful enough to override robust patterns in 'higher-order' cognitive domains such as episodic memory. From an evolutionary perspective, episodic memory, and especially memory for emotional events, is important for survival (e.g. Öhman, 1988). Indeed, current research on adaptive memory (e.g. Nairne, Thompson, & Pandeirada, 2007; Nairne & Pandeirada, 2010) suggests that evolutionary relevance is a strong predictor of episodic memory performance. Experiential factors such as VVG exposure—or even exposure to real-world violence—may do little to alter mnemonic patterns that may have evolved over millennia. However, we acknowledge that this interpretation is speculative, and that more research is needed to resolve the apparent conflict between our data and those reported in previous studies. In particular, there is a need for experimental 'training' studies, with random assignment to various levels of media violence over an extended period of time (for a similar suggestion, see Bailey et al., 2010). Given the heterogeneity in the existing literature, it would further be interesting to assess multiple dependent variables (psychophysiological, cognitive/behavioural and neuroimaging), and especially to chart the time course of VVG effects longitudinally.

### Limitations

Similar to previous video game research, the sample of VVG players came from a university student population, and may therefore not represent the full spectrum of VVG exposure that exists in the general population. We cannot rule out that VVG players from other backgrounds (e.g. members of the military) may have performed differently on our tasks. However, university undergraduates may be more representative of the general population with respect to the amount and quality of VVG exposure, compared with groups that have extremely high VVG exposure.

As with any statistical null finding, it is also possible that the lack of an effect in our study merely represents a chance outcome. On the other hand, the relatively large sample size ( $N = 122$ ) afforded high statistical power ( $1 - \beta = .999$ ; Erdfelder, Faul, & Buchner, 1996) to detect medium effects (Cohen, 1988). Furthermore, the pattern was identical even in an extreme subsample of 18 VVG players with the highest VVG exposure. Finally, we cannot rule out that behavioural and self-report measures may be less sensitive to VVG effects than the psychophysiological and neuroimaging measures used by others in the literature (e.g. Bartholow et al., 2006; Carnagey et al., 2007; Staude-Müller et al., 2008).

## CONCLUSIONS

To our knowledge, this study was the first to investigate the relationship between habitual VVG exposure and memory. Given that violent video games are gaining popularity, and that short-term effects on physiological arousal and cognition have already been demonstrated, understanding the potential long-term effects of these media is vital. The current study suggests that VVG exposure does not affect long-term memory or subjective arousal, thus challenging earlier reports of VVG related desensitization effects. As we pointed out, more research—particularly using longitudinal designs—is needed to reconcile these findings, and to adjudicate between habituation and desensitization accounts of existing data.

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