Exposure to and recall of violence reduce short-term memory and cognitive control

Francesco Bogliacino[a], Gianluca Grimalda[b,c,d,1], Pietro Ortoleva[e,2], and Patrick Ring[b]

[a]Facultad de Ciencias Económicas, Universidad Nacional de Colombia, Bogotá, Colombia; [b]Social and Behavioral Approaches to Global Problems, Kiel Institute for the World Economy, 24105 Kiel, Germany; [c]Department of Economics, Universitat Jaume I, 12071 Castellón de la Plana, Spain; [d]Centre for Global Cooperation Research, University of Duisburg-Essen, 47059 Duisburg, Germany; and [e]Department of Economics, Columbia University, New York, NY 10027

Edited by Susan T. Fiske, Princeton University, Princeton, NJ, and approved June 26, 2017 (received for review March 21, 2017)

Previous research has investigated the effects of violence and warfare on individuals' well-being, mental health, and individual prosociality and risk aversion. This study establishes the short- and long-term effects of exposure to violence on short-term memory and aspects of cognitive control. Short-term memory is the ability to store information. Cognitive control is the capacity to exert inhibition, working memory, and cognitive flexibility. Both have been shown to affect positively individual well-being and societal development. We sampled Colombian civilians who were exposed either to urban violence or to warfare more than a decade earlier. We assessed exposure to violence through either the urban district-level homicide rate or self-reported measures. Before undertaking cognitive tests, a randomly selected subset of our sample was asked to recall emotions of anxiety and fear connected to experiences of violence, whereas the rest recalled joyful or emotionally neutral experiences. We found that higher exposure to violence was associated with lower short-term memory abilities and lower cognitive control in the group recalling experiences of violence, whereas it had no effect in the other group. This finding demonstrates that exposure to violence, even if a decade earlier, can hamper cognitive functions, but only among individuals actively recalling emotional states linked with such experiences. A laboratory experiment conducted in Germany aimed to separate the effect of recalling violent events from the effect of emotions of fear and anxiety. Both factors had significant negative effects on cognitive functions and appeared to be independent from each other.

violence | cognitive control | executive functions | memory | field experiments

Violence and warfare are a persistent characteristic of most human societies, from the lowest levels of complexity (1). Approximately 650,000 people are estimated to have been victims of homicide around the world in 2010 (2). In addition to its direct economic costs (3), exposure to violence (ETV) has significant negative effects on both physical and mental health (4–6). Approximately 5% of male and 10% of female US citizens suffer from posttraumatic stress disorder (PTSD) after ETV (4, 5). ETV has significant effects on a wide array of individual behavior and socioeconomic outcomes (7), ranging from changes in risk preferences (8, 9), to higher temporal discounting and impulsivity (9), higher prosociality (8, 10, 11), and increased political participation (12).

This study addresses the direct impact of ETV on short-term memory and cognitive control. Short-term memory is an individual's capacity to store information. It is distinct from working memory, which requires both storing and a mental manipulation of information (13). Short-term memory is a valid predictor for job and training performance (14). Better forward digit span as a measure of short-term memory at preschool age predicts better math and reading abilities during the first years of primary school (15). Deficits in short-term memory, by contrast, are associated with several medical conditions, such as Alzheimer's disease (16) and PTSD (4–6, 17).

Cognitive control, also referred to as executive function, has been defined as a family of top-down mental processes needed when one has to concentrate and pay attention, when going on automatic or relying on instinct or intuition would be ill-advised, insufficient, or impossible (13). Extensive empirical research identifies three components of cognitive control that seem crucial in problem-solving. These components are inhibitory control (which can be broken down into self-control and selective attention), working memory, and cognitive flexibility. These three components of cognitive control, in turn, enable fluid intelligence (13). Cognitive control, in general or in some of its components, is positively associated with and temporally precedes a wide array of aspects of individual well-being and indicators of societal development. Lack of cognitive control is correlated with and precedes mental disorders (18), unhealthy behavior (19), and early mortality (20). Cognitive control predicts school readiness and positive educational attainment (21). Self-control in children has been shown to predict physical health, personal wealth, and criminal offenses 30 y later (18). Low cognitive control also predicts unemployment and affects wages (22). Specific neural systems are activated when individuals exert self-control (23), and these neural systems are linked to genetic components that have also been associated with violent behavior (24). Ascertaining the impact of ETV on cognitive

Significance

Research on violence has mainly focused on its consequences on individuals' health and behavior. This study establishes the effects of exposure to violence on individuals' short-term memory and cognitive control. These are key factors affecting individual well-being and societal development. We sampled Colombian civilians who were exposed either to urban violence or to warfare. We found that higher exposure to violence significantly reduces short-term memory and cognitive control only in the group actively recalling emotional states linked with such experiences. This finding demonstrates and characterizes the long-lasting effects of violence. Existing studies have found effects of poverty on cognitive control similar to those that we found for violence. This set of findings supports the validity of the cognitive theory underpinning these studies.

Author contributions: F.B., G.G., P.O., and P.R. designed research; F.B. performed research for experiment I; F.B. and G.G. performed research for experiment II; P.R. performed research for experiment III; F.B., G.G., and P.R. analyzed data; and F.B., G.G., P.O., and P.R. wrote the paper.

Conflict of interest statement: P.O. has had no prior contact with the editor of this paper and was not affiliated with Princeton University until July 1, 2017.

This article is a PNAS Direct Submission.

[1]To whom correspondence should be addressed. Email: gianluca.grimalda@ifw-kiel.de.

[2]Present address: Department of Economics, Princeton University, Princeton, NJ 08544; and Woodrow Wilson School of Public and International Affairs, Princeton University, Princeton, NJ 08544.

This article contains supporting information online at www.pnas.org/lookup/suppl/doi:10.1073/pnas.1704651114/-/DCSupplemental.

PSYCHOLOGICAL AND COGNITIVE SCIENCES

control is therefore important to further understanding the social, economic, and health effects of violence.

The main site of our research was Colombia, a country affected by extensive warfare and violence for several decades. In the first experiment, participants were residents of urban areas where violence, street crime, and ordinary criminality are widespread. In the second experiment, participants were internally displaced civilians, living in rural areas that had been the theater of armed conflicts between irregular militia groups up to 10 y ago. Given the variety of these environments, we were able to compare short- and long-term effects of violence, as well as the impact of different types of violence—warfare in the rural sample and ordinary criminality in the urban one.

The key methodology of our research relied on the randomized and experimentally induced recall of experiences of violence in a portion of our sample, and of emotionally neutral or joyful experiences in the remaining portion, before the execution of cognitive tests (9, 25, 26). We analyzed the direct effects of violence recall (VR), ETV, and their combination on measures of short-term memory and cognitive control. This design controlled for confounding factors and allowed us to better investigate the issue of causality.

Psychologists propose a "dual-process" framework in which an "automatic system" and a "reflective system" interact to produce decisions (27, 28). The former is uncontrolled by our conscious thinking, is effortless, follows associations rather than deductions, and is constantly active. The latter requires conscious cognitive control, demands deliberate effort by the individual, and can use deductive logic or rules. Our main hypothesis was that ETV triggers immediate psychological reactions whereby the automatic system becomes predominant over the reflective system. We conjectured that the effects may be long-lasting, especially when individuals are faced with traumatic, life-threatening ETV. Furthermore, we posited that recalling episodes of violence, even many years after their occurrence, may lead to the same effect, especially when the experience that is being reenacted is particularly traumatic. Support for these hypotheses comes from extensive neurobiological and clinical research documenting the effects of traumatizing stress (29, 30) and PTSD (4–6) on the neuroendocrine network underlying cognitive control. In particular, the release of catecholamine induced by acute stressors impairs cognitive control of the prefrontal cortex (PFC) (31), while at the same time enhancing the emotional and habitual responses of the amygdala, which also regulates fear conditioning, and the tonic firing of the noradrenergic locus coeruleus (32, 33). The dopamine system is also involved, because acute stress triggers enhanced dopamine efflux in the medial PFC. Upon modulation by glucocorticoid receptors, this system decreases cognitive control (34, 35). Although most of the above studies involved animals, similar transmission mechanisms seem to operate in humans. In particular, exposure to natural situations of mild distress led to deficits in both attentional control and in dorsolateral PFC functional connectivity with other areas of the fronto-parietal attentional network in humans (36). On the basis of this evidence, we hypothesized that ETV may impair cognitive control through the induction of acute and chronic stress.

Results

Experiment I: Exposure to Urban Violence. We ran our first experiment among residents of the Colombian capital, Bogotá. With a yearly average of 21.6 homicides per 100,000 inhabitants over the period 2008–2011, Bogotá is one of the most violent capitals among developing countries. There exists, nonetheless, large variety in homicide rates among its districts. These rates can range from levels comparable to those of the most violent areas in the world to levels that are eight times lower. We measured individual ETV through the district-level homicide rate in the subject's district of residence (*SI Appendix*, section 1.1.1, Fig. S1, and Table S1). For the ensuing analyses, we divided our sample into two groups, with one comprising subjects living in districts with relatively very high ETV—namely, those whose ETV lies above the 75th percentile. Our sample comprised 308 residents of Bogotá between 18 and 24 y of age, who came from all but two of Bogotá's 19 districts (see *SI Appendix*, Tables S1 and S2 and section 1.3.1 for descriptive statistics). We focused on this age group because we aimed to minimize the risk of self-selection of subjects into districts, as people in this age group can be largely expected to live with their families.

Our dependent variable in this experiment is subjects' responses to a test of short-term memory (37). The task consisted of memorizing a set of colored abstract geometric figures, to be later identified in a sequence of 10 figures presented in succession. The task was monetarily incentivized. We analyze the accuracy rate (i.e., the fraction of correct answers relative to the total number of questions). Crucial to our design is the VR manipulation. At the beginning of the session, a randomly determined subset of the subjects was asked to recall an event that occurred in the last year that caused anxiety or fear, explicitly hinting at violence as a possible cause of such an emotional state (9, 25). We refer to this group as VR. The remaining subjects were asked to either recall a joyful experience or a generic experience devoid of emotional content. Because results never differed when neutral or joyful experiences were recalled (Mann–Whitney–Wilcoxon test, $P = 0.95$, $n = 200$; all tests are two-tailed), we merged the two conditions in the analysis, referring to them as neutral/joy recall (abbreviated NR). In all experiments, the hypothesis that the treatment was exogenous was not rejected (*SI Appendix*, Tables S3–S5 and S39). For simplicity, we present results in the form of a 2×2 factorial design, in which the ETV component—high ETV (abbreviated HV for high violence) and low ETV (abbreviated LV for low violence)—is crossed with the recall component—VR or NR.

As shown in Fig. 1*A*, accuracy on the memory task was on average lowest in the HV group recalling violence ($\bar{A}_{HV}^{VR} = 60.3\%$ where $\bar{A}_j^i$ denotes average accuracy, the upper index $i = \{VR, NR\}$

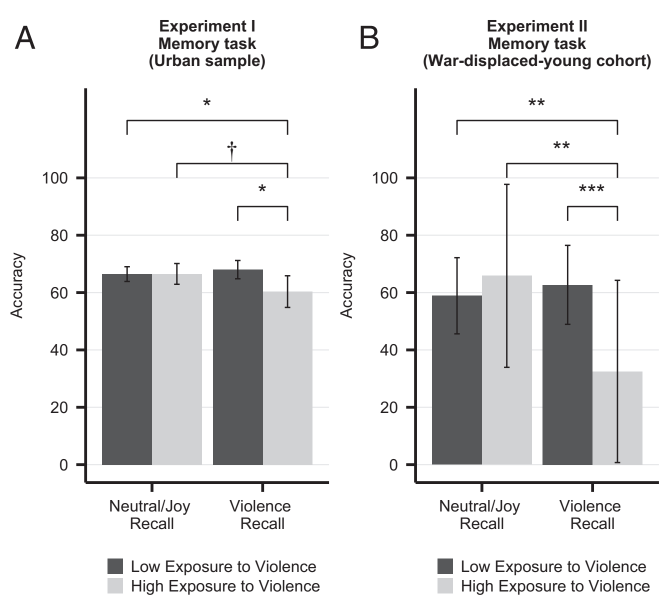

Fig. 1. Impact of ETV on short-term memory. Accuracy levels in the memory task are broken down by recall condition (VR vs. NR) and levels of ETV—high or low ETV. High ETV identifies subjects lying above the distribution's 75th-percentile split of the district-level homicide rate in the urban sample (*A*) and of a self-reported ETV measure for the war-displaced sample (*B*). Error bars reflect ±95% confidence intervals. Top horizontal bars show the statistical significance of tests on the null hypothesis that accuracy is the same in pairs of groups, as per Tobit regression reported in *SI Appendix*, Table S8 (*A*) and *SI Appendix*, Table S14 (*B*). †$P < 0.1$; *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.

denotes the recall condition, and the lower index $j = \{HV, LV\}$ denotes ETV level), whereas it was approximately constant in the other three groups ($\bar{A}^{NR}_{HV} = \bar{A}^{NR}_{LV} = 66.0\%$ for both HV and LV groups in NR and, $\bar{A}^{VR}_{LV} = 68\%$ for the LV group in VR). According to an econometric Tobit model that controls for subjects' demographic characteristics (Table 1 and *SI Appendix*, Tables S6 and S8 and Fig. S2), accuracy by the HV group recalling violence was statistically significantly lower than accuracy by any of the other three groups—albeit weakly in one case ($P = 0.026$ with respect to the LV group recalling violence; $P = 0.075$ with respect to the HV group not recalling violence; $P = 0.047$ with respect the LV group not recalling violence; $n = 281$ for each test). Conversely, accuracy by the HV group not recalling violence was not statistically different from any other LV group (*SI Appendix*, Table S9). These results show the combined effect of ETV and VR. People who had been highly exposed to violence—and recalled violence—performed significantly worse than any other group. Conversely, people who had been highly exposed to violence in real life, but did not recall violence, performed no differently from either of the groups exposed to LV.

District-level homicide rates, our measure of ETV, may be confounded with other variables operating at the district level, such as poverty, education, and quality of public services. In *SI Appendix*, Tables S10 and S11, we show that when district-level measures of these variables replaced ETV as a possible causal factor in our econometric analysis, none of them yielded significant effects on accuracy. We also replicated this analysis using a self-reported measure of ETV, constructed on three items derived from a postexperiment questionnaire. Such items inquired as to whether the subject had been a victim of violence in the recent past. All subjects had some minimal degree of direct ETV. Subjects belonging to the HV group who recalled violence were, again, the worst performers among the four groups formed using this self-reported ETV measure, whereas no significant difference emerged between the HV group not recalling violence and the two LV groups (*SI Appendix*, Tables S12 and S13 and Fig. S3). Finally, we found no interaction effects between ETV and either joy or neutral recall (*SI Appendix*, Table S10). We believe that this evidence is concordant in suggesting that the observed effects were driven by ETV rather than other district-level variables.

Experiment II: Exposure to Warfare and Forced Displacement 14 y Earlier. Colombia is one of the countries with the highest percentage of war-related internally displaced individuals (38). Between 4.9 million and 5.5 million people are believed to be internally displaced. All subjects in experiment II had been displaced in the year 2000 from their homes by attacks and death threats carried out by irregular militia groups. Most people relocated to a settlement ∼10 km from their original residence (*SI Appendix*, section 1.1.2). All of our subjects were officially recognized as victims of the conflict by the Colombian government, upon the conduction of an official inquiry and the provision of factual evidence (see *SI Appendix*, section 1.1.2 and Table S2 for descriptive statistics). As in our urban sample, a randomly determined fraction of subjects was asked to recall episodes of violence; others were asked to recall joyful or neutral experiences. We removed the constraint that the experience of violence had occurred in the last year. The wide majority (87%) of subjects involved in the VR condition talked about their experience of relocation that occurred 14 y earlier.

In this rural sample, we could not rely on an objective measure of violence as in Bogotá. We then constructed an index of ETV based on subjects' self-reported exposure, adapted from previous studies (8). The questionnaire from which this index was derived was administered after the experimental tasks and consisted of 20 items inquiring about the number of times a subject, or a member of his or her family, was the object of violence, such as ambushes, physical or armed attack, kidnapping, forced labor, torture, or robbery, or whether they had to pay a ransom (see *SI Appendix*, sections 1.3.2 and 1.6.2 for questionnaire and details on the index). The prior recall of experiences of violence for subjects in the VR group did not cause overreporting of episodes of violence in the postexperiment questionnaire, in comparison with subjects in the NR group ($P = 0.94$, Mann–Whitney–Wilcoxon test, $n = 221$). Using this measure, we divided the sample in two groups: the HV group that includes the subjects whose ETV score lies above the 75th percentile and the LV group including all others.

We run a version of the memory task adapted from the one conducted in Bogotá (*SI Appendix*, section 1.6.2). For comparability, we restricted our analysis to the same age group used in Bogotá (i.e., subjects between 18 and 24 y of age; $n = 30$). Accuracy followed the same pattern observed in the urban sample (Fig. 1*B* and *SI Appendix*, Fig. S2). Mean accuracy was again lowest in the HV group recalling violence ($\bar{A}^{VR}_{HV} = 32.5\%$). Accuracy in this group was strongly significantly less than accuracy in the LV group recalling violence ($\bar{A}^{VR}_{LV} = 62.7\%$; $P < 0.002$, $n = 30$), in the HV group not recalling violence ($\bar{A}^{NR}_{HV} = 65.8\%$; $P = 0.002$,

Table 1. Analysis of effects of ETV and VR on short-term memory and cognitive control: experiments I and II

	Urban	War-displaced			
Variables	Memory	Memory	Stroop	Raven	All
ETV (VR group)	−7.25* (3.23)	−33.10*** (7.41)	−13.34† (7.90)	−8.80 (10.10)	−12.43** (3.91)
ETV (NR group)	−0.28 (2.52)	7.93 (11.04)	5.89 (4.65)	10.29 (9.13)	1.87 (2.29)
ETV (VR group) − ETV (NR group)	−6.97† (4.01)	−41.03** (11.02)	−19.23* (9.50)	−19.09 (14.32)	−14.31** (4.51)
VR (HV group)	−6.05† (3.38)	−40.10** (11.07)	18.45* (7.82)	−13.36 (11.85)	−13.96*** (3.95)
Observations	281	30	141	67	516
VR (overall)	−1.09 (1.89)	−3.94 (8.24)	−10.05* (3.97)	1.72 (4.57)	−3.29† (1.83)
Observations	281	30	141	88	540
ETV (overall)	−2.56 (2.07)	−4.63 (10.45)	−4.36 (4.89)	0.59 (6.54)	3.68† (2.17)
Observations	281	30	141	67	516

The table reports results from econometric analysis to explain the degree of accuracy on short-term memory (with respect to the urban and war-displaced samples), inhibitory control (Stroop task), and fluid intelligence (Raven task). The last column pools the three tasks and the two samples together. Various Tobit models have been fitted, which also include demographic and treatment controls (see *SI Appendix*, Tables S8, S9, and S14–S21 for full results). The estimated effect on accuracy of ETV is reported for both VR and NR groups, as well as the difference of its effect in the two groups (difference-in-difference). The estimated effect of VR within the HV group only is also reported. Finally, the estimated overall effects of VR and ETV are reported. Robust SEs (clustered at the individual level for regression in the last column) are reported in parentheses. †$P < 0.1$; *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.

$n = 30$), and in the LV group not recalling violence ($\bar{A}^{NR}_{LV} = 62.7\%$; $P = 0.005$, $n = 30$). On the contrary, the HV group's accuracy when not recalling violence was no different from the LV groups' accuracy (Table 1 and *SI Appendix*, Tables S7, S14, and S15). The variation in accuracy appeared much larger in the war-displaced sample than in the urban sample. Presumably, this result may be due to the fact that ETV exerted much larger effects in case of exposure to traumatic and life-threating experience than urban violence. Nonetheless, we cannot rule out that different educational levels and reduced sample size in the war-displaced sample may have also affected the magnitude of the effect.

In this fieldwork, we also ran two additional tasks to measure two aspects of cognitive ability. We measured inhibitory control through the Stroop task (13, 39). This task requires selective attention (focusing on what is relevant and trying to ignore what is not) and vigilantly keeping in mind the rule to successfully execute the task. We used a numeric version of this task (26, 39), suited for a sample with high illiteracy rates. Subjects were given up to 45 numerical sequences. In each, a digit from 1 to 4 appeared one to four times, and subjects were asked to state the number of times this digit appeared. The impulsive answer is the digit that appears in the sequence. The correct answer—which supposedly requires the reflective system to overrule the automatic system—is nevertheless the number of times that such a digit appears. (For instance, the impulsive answer to the sequence "1 1 1" is 1, whereas the correct answer is 3.)

We report results from the sample including all age groups ($n = 141$). Accuracy levels across the groups followed the same pattern observed in the memory tasks. Average accuracy was lowest in the HV group recalling violence ($\bar{A}^{VR}_{HV} = 57.53\%$) (Fig. 2*A* and *SI Appendix*, Fig. S4). According to econometric analysis (Table 1 and *SI Appendix*, Table S16), accuracy in this group was statistically significantly lower, albeit weakly in one case, than accuracy by the LV group recalling violence ($\bar{A}^{VR}_{LV} = 77.39\%$, $P = 0.094$, $n = 141$), the HV group not recalling violence ($\bar{A}^{NR}_{HV} = 88.3\%$, $P = 0.005$, $n = 141$), and the LV group not recalling violence ($\bar{A}^{NR}_{LV} = 80.9\%$, $P = 0.020$, $n = 141$). Conversely, there was no significant difference between the HV group not recalling violence and the LV groups (*SI Appendix*, Table S17).

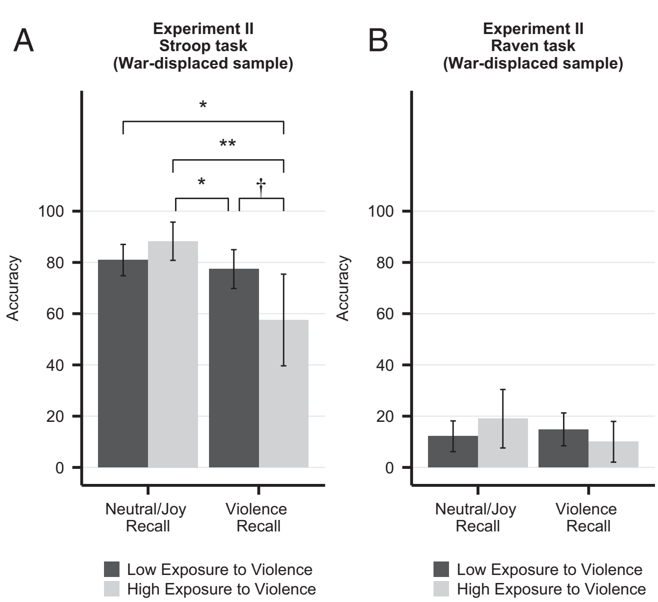

Fig. 2. Impact of ETV on cognitive control. Accuracy levels in the Stroop task and Raven sequential matrices task are broken down by recall condition (VR vs. NR) and levels of ETV—high or low ETV. High ETV identifies subjects lying above the 75th-percentile split of the distribution of the self-reported ETV measure. Error bars reflect ±95% confidence intervals. Top horizontal bars show the statistical significance of tests on the null hypothesis that accuracy is the same in pairs of groups, as per Tobit regression reported in *SI Appendix*, Table S16 (*A*) and *SI Appendix*, Table S18 (*B*). †$P < 0.1$; *$P < 0.05$; **$P < 0.01$.

We also ran a simplified version of Raven's progressive matrices. Raven's task is used to measure "fluid intelligence" [i.e., the capacity to reason, solve problems in novel situations independent of acquired knowledge, and see patterns or abstract relations among items (40)]. Fluid intelligence includes both inductive and deductive logical reasoning and is strongly correlated with the reasoning and problem-solving subcomponents of cognitive control. It can be considered a higher-level form of cognitive control (13). We found an overall pattern that mirrored the one found for the previous measures of cognitive abilities. Accuracy was lowest in the HV group recalling violence ($\bar{A}^{VR}_{HV} = 10\%$; Fig. 2*B* and *SI Appendix*, Fig. S4). Accuracy in this group was less than both accuracy in the HV group not recalling violence ($\bar{A}^{NR}_{HV} = 19\%$; $P = 0.26$, $n = 67$) and accuracy in the LV group recalling violence ($\bar{A}^{VR}_{LV} = 14.83\%$, $P = 0.39$, $n = 67$). However, in this case, the econometric analysis (Table 1 and *SI Appendix*, Tables S18 and S19) failed to find statistical significance in these patterns. This result may be partly due to the fact that accuracy levels were significantly lower for the Raven task than for other tasks, which may have reduced the power of statistical tests.

Experiments I and II: Overall Assessment. We fitted a Tobit model on the pooled sample of observations from the three measures of accuracy reviewed above. Overall, accuracy in the HV group recalling violence was statistically significantly lower than in any other group (*SI Appendix*, Fig. S5; in particular, $P = 0.002$ with respect to the LV group recalling violence; $P < 0.001$ with respect to the HV group not recalling violence; and $P = 0.001$ with respect to the LV group not recalling violence; $n = 516$ for each test). Conversely, accuracy in the HV group not recalling violence was statistically no different from accuracy in the LV group either recalling or not recalling violence (Table 1 and *SI Appendix*, Tables S20 and S21). Shifting from the LV to the HV group in the VR condition reduced overall accuracy on our memory and cognitive tests by 38% of a SD. When not recalling violence, this same shift led to an increase of 6% of a SD. Moreover, recalling violence induced a decrease of 47.2% of a SD in accuracy in the HV group. It is also worth noting that the differential effect of ETV between the VR group and the other group was positive and significant in the pooled sample (Table 1; $P = 0.004$, $n = 516$), as well as for each individual measure, except the Raven task (Table 1 and *SI Appendix*, Fig. S6). The overall effect of ETV on accuracy, without conditioning on the recall group, was negative and at the border of statistical significance in the pooled sample (Table 1; $P = 0.090$; $n = 516$), whereas it was never significant for individual measures (Table 1). Likewise, the overall effects of VR, unconditional on the ETV group, was weak in the pooled sample ($P = 0.073$; $n = 540$) and not significant for the individual measures, except for the Stroop task ($P = 0.013$, $n = 141$; Table 1).

A scatterplot of our data shows that ETV had substantially similar effects in the urban sample ($r = -0.29$, with r being the coefficient of the interpolation line using a continuous measure for ETV) and the war-displaced sample ($r = -0.21$), when violence was recalled (Fig. 3*A*). In the group recalling neutral or joyful experiences, the coefficient was close to zero in the urban environment ($r = 0.02$), whereas it appeared higher ($r = 0.18$) in the war-displaced sample (Fig. 3*B*). Removing an outlier from the latter sample (*SI Appendix*, Fig. S7) reduced the gap between urban and war-displaced samples in the neutral/joy condition.

We replicated the analyses above, defining the HV group as subjects lying above the median split of the respective sample, rather than as those lying above the 75% percentile (*SI Appendix*, Tables S22–S33). We also analyzed ETV measured on a continuous scale (*SI Appendix*, Tables S34–S37). Although the

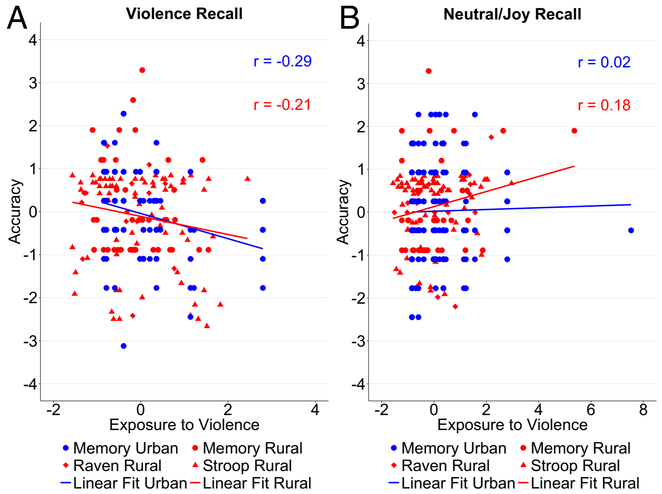

Fig. 3. Intersubject variability of cognitive control measurements (experiments I and II). The scatterplot of ETV (measured on a continuous scale) and accuracy on the three cognitive tests is reported. Linear predictions for experiment I (urban sample) and experiment II (rural environment, war-displaced sample) are also plotted, and their slopes are reported. *A* and *B* report observations in the VR and NR groups, respectively.

qualitative nature of the results remained generally unchanged, the statistical significance of the tests tends to be generally lower. These analyses suggest that the effects of ETV on accuracy were mainly driven by people highly exposed to violence (i.e., those lying in the upper quartile of the distribution of ETV).

Experiment III: Evaluating the Impact of Emotions and Recall. The above results may be due to the recall of experiences of violence, to the emotions associated with the recall, or to a combination of the two factors. The lack of suitable equipment in the fieldwork in Colombia prevented us from disentangling these two factors. For this reason, we ran a replication of the study in controlled laboratory conditions in Germany. Subjects were randomly assigned to four conditions. In the baseline condition, subjects were asked to recall joyful experiences, similarly to the baseline condition in experiments I and II. In the recalled fear (RF) condition, subjects were asked to recall experiences of violence, such as the November 2015 Paris attacks. Personal ETV is extremely rare in Germany; thus, we chose to have people recalling a violent event that created widespread apprehension among Europeans. In the current fear (CF) condition, we experimentally induced emotions of fear and anxiety. This induction was achieved by exposing subjects to the prospect of receiving minor electric shocks to their fingers in the course of the experiment (41, 42). Such electric shocks were calibrated to pose some physical discomfort, but not a painful experience. The anticipation of unpleasant electric shocks leads to an increase in emotional arousal during the anticipation phase (41, 43). In CF, the emotions of fear and anxiety were elicited without any recall of experiences of violence. In a fourth condition (RF&CF), subjects were administered both RF and CF stimuli. Our experiment was designed to compare the impact on cognitive abilities of an emotional state of fear or anxiety—when CF was administered—or by the recall of experiences of violence—when RF was administered. We could thus study the impact of emotions of fear and anxiety in isolation from the recall of violence experiences and compare this effect with that of recall. The full factorial design also allowed us to study a possible interaction between such two factors. Our dependent variable was subjects' absolute accuracy level on a computerized version of the Stroop task administered in experiment II. Our sample comprised students of a German university (*SI Appendix*, Table S38).

Compared with the baseline, accuracy dropped by 5.34% and 6.45%, respectively, when either CF or RF were administered, and by 10.68% when both CF and RF were administered (*SI Appendix*, Table S40 and Fig. S8). The joint impact of the two stimuli was thus approximately equal to the sum of each individual stimulus. An econometric model that controlled for demographic characteristics, college achievement, degree, and fieldwork wave confirmed the statistical significance of such effects (*SI Appendix*, Tables S41 and S42). Accuracy in both CF and RF was statistically significantly lower than the baseline ($P = 0.024$ for CF; $P = 0.010$ for RF; $n = 164$) and was similar in size (t test on the coefficient different being equal to zero: $\beta = 0.83$, $P = 0.83$, $n = 164$). The interaction between the two effects was not significant ($\beta = 0.46$, $P = 0.93$, $n = 164$), which confirms that the combined effect of the two stimuli was approximately the same as the sum of the two individual effects. This evidence suggests that the two effects appeared to be independent.

Subjects' physiological reactions to the stimuli were examined by recording skin conductance responses during the experiment. Raw electrodermal signal was separated via continuous decomposition analysis (44) into a phasic stimulus-driven part and a tonic baseline level. The tonic baseline level is commonly interpreted as an indicator of general arousal, whereas the phasic component captures spikes and deviations from such a baseline level (44, 45). According to our econometric analysis (*SI Appendix*, Table S41), the tonic component was significantly higher for CF compared with the baseline ($P = 0.027$, $n = 164$), but this result did not hold for RF ($P = 0.19$, $n = 164$). Conversely, we found weak evidence that RF induced phasic components ($P = 0.072$, $n = 164$), whereas this result did not hold for CF ($P = 0.40$, $n = 164$). Although the differences between CF and RF were not statistically significant (t test: $P = 0.47$ for tonic; $P = 0.49$ for phasic response, $n = 164$), we note the tendency of physiological reactions to follow different patterns in the two conditions. This pattern appeared to be mirrored in the emotional footprints, because subjects' self-reported emotional states tended to differ across treatments, particularly for the emotion of sadness (*SI Appendix*, Table S43).

Discussion

This study shows differential effects of continuing exposure to higher and lower levels of violence over years on short-term memory and cognitive control in both urban and rural samples from Colombia. We found that higher ETV significantly reduces both short-term memory and cognitive control, but only in the group actively recalling emotional states of fear and anxiety linked with experiences of violence. On the contrary, when such emotional states were not recalled, accuracy on memory and cognitive tasks was no different between groups highly and lowly exposed to violence.

The patterns we found were similar in all of the measures of cognitive abilities that we used—although the results fell short of statistical significance on the Raven test. This set of findings is noteworthy because our samples varied greatly in terms of the type of ETV—street crime violence in the case of Bogotá residents and warfare in the case of the rural sample—as well as the time frame of ETV—short-term in the case of Bogotá and long-term in the case of the rural sample. Research conducted on animals and humans showed that the effects of mild stress is reversible after a few weeks (36). We found that ETV seemed to have cognitive effects even after more than a decade had passed from the main traumatic event that was recalled. The effects of ETV thus seemed to be persistent. Although other studies found significant behavioral differences between groups that have either been exposed to traumatic experiences of violence or that have not been affected by violence (11), in this study, we found effects of ETV within the former group. This finding suggests that not only the mere ETV, but also its intensity, has the capacity to severely affect human behavior.

PSYCHOLOGICAL AND COGNITIVE SCIENCES

Our results have two additional implications. On the one hand, our results suggest that a traumatic experience that is unresolved, and that one keeps bringing up in memory, may significantly negatively affect a person's ability to exercise short-term memory and cognitive control, thus affecting his or her ability to function well in life. In particular, when memories of past trauma are triggered, they might also impact the cognitive functioning of victims who would otherwise not suffer the effects of trauma. Recovering from past traumas, although possible, might be fragile and highly vulnerable. On the other hand, our results also suggest that, even if a person has experienced traumatic violent events, this person's recovery may be helped by not dwelling on these memories, but rather by recalling happier memories. His or her ability to exercise the critical mental skills that we studied will not be affected, allowing him or her to potentially succeed in arenas of life in which these skills are important.

More research is needed to better understand the psychological, but also the social, mechanisms behind our findings. We cannot rule out that the observed effects reflect the combined influence of ETV and other social factors such as poverty. Moreover, our results may be culture- or context-specific. Although the evidence coming from Germany seems to be consistent with what we found in Colombia, replication is needed under different circumstances, in other parts of the world, or for other types of violence to corroborate fully our findings.

Recent research using similar methodologies to ours shows that poverty—understood as the psychological perception of a gap between one's needs and one's material resources—exerts a decay of cognitive functioning and alters preferences (26, 46). Our results demonstrate that ETV appears to have a similar effect to that exerted by poverty. These findings support the robustness of the theory of mind that lies behind these analyses.

Materials and Methods

Sampling procedures, experimental protocol, instructions read to subjects, and ethnographic information are discussed in *SI Appendix*, section 1.

All our econometric analyses of accuracy on cognitive tasks deployed Tobit models. This method takes into account the truncated nature of the accuracy variable. The econometric models controlled for demographic factors—namely, gender, age, education, and socioeconomic status. Our main variable of interest in experiments I and II was the measure of ETV, categorized in two groups of people more or less exposed to violence. Its effects on cognitive performance were analyzed both on the whole sample and separately for experimental treatment. Data from our experiments are shown in Datasets S1–S4. Variables are defined in Dataset S5. The commands to replicate our econometric analyses with the Stata package are reported in Dataset S6.

The research committee of the Konrad Lorenz University granted ethical approval for experiments I and II. The German Psychological Foundation approved the research design of experiment III. Written informed consent was obtained from every subject.

ACKNOWLEDGMENTS. We thank Suelen Castiblanco, Laura Jiménez, and Daniel Reyes for providing research assistance and the community leaders in Montes de María (who prefer to remain anonymous) and the personnel in Cedecampo for providing logistical support. We also thank Barbara Bobba, Benedetto De Martino, and Navah Kadish for comments. This work was supported by Open Evidence Grant 008-Tierra-Colombia; Fundación Universitaria Konrad Lorenz Grant 7INV3131; Universitat Jaume I Grant P1.1B2015-48; Spanish Ministry of Economics and Competitivity Grant ECO 2015-68469-R; and Fondazione Franceschi.

1. Kelly RC (2005) The evolution of lethal intergroup violence. *Proc Natl Acad Sci USA* 102:15294–15298.
2. Ouimet M (2012) A world of homicides: The effect of economic development, excess poverty and income inequality on the homicide rate for 167 countries in 2008. *Homicide Stud* 16:1238–1258.
3. Stewart F (1993) War and underdevelopment: Can economic analysis help reduce the costs? *J Int Dev* 5:357–380.
4. Kessler RC, Sonnega A, Bromet E, Hughes M, Nelson CB (1995) Posttraumatic stress disorder in the National Comorbidity Survey. *Arch Gen Psychiatry* 52:1048–1060.
5. Yehuda R (2002) Post-traumatic stress disorder. *N Engl J Med* 346:108–114.
6. Boscarino JA (2006) Posttraumatic stress disorder and mortality among U.S. Army veterans 30 years after military service. *Ann Epidemiol* 16:248–256.
7. Brunello N, et al. (2001) Posttraumatic stress disorder: Diagnosis and epidemiology, comorbidity and social consequences, biology and treatment. *Neuropsychobiology* 43:150–162.
8. Voors M, et al. (2012) Violent conflict and behavior: A field experiment in Burundi. *Am Econ Rev* 102:941–964.
9. Callen M, Isaqzadeh M, Long J, Sprenger C (2014) Violence and risk preference: Experimental evidence from Afghanistan. *Am Econ Rev* 104:123–148.
10. Gneezy A, Fessler DMT (2012) Conflict, sticks and carrots: War increases prosocial punishments and rewards. *Proc Biol Sci* 279:219–223.
11. Bauer M, Cassar A, Chytilová J, Henrich J (2014) War's enduring effects on the development of egalitarian motivations and in-group biases. *Psychol Sci* 25:47–57.
12. Blattman C (2009) From violence to voting: War and political participation in Uganda. *Am Polit Sci Rev* 103:231–247.
13. Diamond A (2013) Executive functions. *Annu Rev Psychol* 64:135–168.
14. Verive JM, McDaniel MA (1996) Short-term memory tests in personnel selection: Low adverse impact and high validity. *Intelligence* 23:15–32.
15. Bull R, Espy KA, Wiebe SA (2008) Short-term memory, working memory, and executive functioning in preschoolers: Longitudinal predictors of mathematical achievement at age 7 years. *Dev Neuropsychol* 33:205–228.
16. MacDuffie KE, Atkins AS, Flegal KE, Clark CM, Reuter-Lorenz PA (2012) Memory distortion in Alzheimer's disease: Deficient monitoring of short- and long-term memory. *Neuropsychology* 26:509–516.
17. Bremner JD, et al. (1993) Deficits in short-term memory in posttraumatic stress disorder. *Am J Psychiatry* 150:1015–1019.
18. Moffitt TE, et al. (2011) A gradient of childhood self-control predicts health, wealth, and public safety. *Proc Natl Acad Sci USA* 108:2693–2698.
19. Bogg T, Roberts BW (2004) Conscientiousness and health-related behaviors: A meta-analysis of the leading behavioral contributors to mortality. *Psychol Bull* 130:887–919.
20. Kern ML, Friedman HS (2008) Do conscientious individuals live longer? A quantitative review. *Health Psychol* 27:505–512.
21. Duncan GJ, et al. (2007) School readiness and later achievement. *Dev Psychol* 43:1428–1446.
22. Heckman JJ (2007) The economics, technology, and neuroscience of human capability formation. *Proc Natl Acad Sci USA* 104:13250–13255.
23. Hare TA, Camerer CF, Rangel A (2009) Self-control in decision-making involves modulation of the vmPFC valuation system. *Science* 324:646–648.
24. Meyer-Lindenberg A, et al. (2006) Neural mechanisms of genetic risk for impulsivity and violence in humans. *Proc Natl Acad Sci USA* 103:6269–6274.
25. Lerner JS, Gonzalez RM, Small DA, Fischhoff B (2003) Effects of fear and anger on perceived risks of terrorism: A national field experiment. *Psychol Sci* 14:144–150.
26. Mani A, Mullainathan S, Shafir E, Zhao J (2013) Poverty impedes cognitive function. *Science* 341:976–980.
27. Sloman SA (1996) The empirical case for two systems of reasoning. *Psychol Bull* 119:3–22.
28. Chaiken S, Trope Y (1999) *Dual-Process Theories in Social Psychology* (Guilford, New York).
29. Öhman A (2007) Fear and anxiety. Overlaps and dissociations. *Handbook of Emotions*, eds Lewis M, Haviland-Jones JM, Barrett LF (Guilford, New York), pp 709–729.
30. Eysenck MW (2013) *Anxiety: The Cognitive Perspective* (Psychology Press, New York).
31. Roth RH, Tam SY, Ida Y, Yang JX, Deutch AY (1988) Stress and the mesocorticolimbic dopamine systems. *Ann N Y Acad Sci* 537:138–147.
32. Arnsten AF, Raskind MA, Taylor FB, Connor DF (2015) The effects of stress exposure on prefrontal cortex: Translating basic research into successful treatments for post-traumatic stress disorder. *Neurobiol Stress* 1:89–99.
33. Phelps EA, LeDoux JE (2005) Contributions of the amygdala to emotion processing: From animal models to human behavior. *Neuron* 48:175–187.
34. Butts KA, Weinberg J, Young AH, Phillips AG (2011) Glucocorticoid receptors in the prefrontal cortex regulate stress-evoked dopamine efflux and aspects of executive function. *Proc Natl Acad Sci USA* 108:18459–18464.
35. Sánchez MM, Young LJ, Plotsky PM, Insel TR (2000) Distribution of corticosteroid receptors in the rhesus brain: Relative absence of glucocorticoid receptors in the hippocampal formation. *J Neurosci* 20:4657–4668.
36. Liston C, McEwen BS, Casey BJ (2009) Psychosocial stress reversibly disrupts prefrontal processing and attentional control. *Proc Natl Acad Sci USA* 106:912–917.
37. Baddeley A (1990) *Human Memory: Theory and Practice* (Erlbaum Associates, Hillsdale, NJ).
38. UNHRC (2014) *Global Report 2014*. Available at www.unhcr.org/gr14/index.xml. Accessed June 1, 2017.
39. Henik A, Tzelgov J (1982) Is three greater than five: The relation between physical and semantic size in comparison tasks. *Mem Cognit* 10:389–395.
40. Hunt E (2010) *Human Intelligence* (Cambridge Univ Press, New York).
41. Berns GS, Capra CM, Chappelow J, Moore S, Noussair C (2008) Nonlinear neurobiological probability weighting functions for aversive outcomes. *Neuroimage* 39:2047–2057.
42. Singer T, et al. (2004) Empathy for pain involves the affective but not sensory components of pain. *Science* 303:1157–1162.
43. Ring P, Kaernbach C (2015) Sensitivity towards fear of electric shock in passive threat situations. *PLoS One* 10:e0120989.
44. Benedek M, Kaernbach C (2010) A continuous measure of phasic electrodermal activity. *J Neurosci Methods* 190:80–91.
45. Boucsein W (1992) *Electrodermal Activity* (Plenum Univ Press, New York).
46. Haushofer J, Fehr E (2014) On the psychology of poverty. *Science* 344:862–867.