VIRTUAL BURGLARY: EXPLORING THE POTENTIAL OF VIRTUAL REALITY TO STUDY BURGLARY IN ACTION

(in press Journal of Research in Crime and Delinquency)

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ABSTRACT

Objectives. This article explores the potential of virtual reality to study burglary by measuring user responses on the subjective, physiological and behavioral levels. Furthermore, it examines the influence of individual dispositions, such as sensation seeking and self-control, on behavior during a virtual burglary event.

Methods. Participants, male university undergraduates (*N*=77), could freely move around a virtual neighborhood wearing a virtual reality headset and using a game controller, and were instructed to burgle one of the houses in the neighborhood. Participant movement, items stolen from the house, and heart rate were recorded throughout the burglary event. Individual dispositions were measured before, and subjective user responses were measured after, the event. Additionally, we experimentally varied whether there was an alarm sounding, and participants' beliefs about the chance of getting caught (deterrence).

Results. Participants reacted subjectively to the burglary event by reporting high levels of presence in the virtual environment and physiologically by showing increased heart rates. In terms of behavior, high deterrence resulted in fewer items being stolen and a shorter burglary. Furthermore, sensation seekers stole more valuable items, while participants high in conscientiousness stole fewer items.

Conclusions. The results suggest that virtual environments have substantial potential for studying criminal behavior.

Watching burglars in action would be an excellent way to increase our knowledge of burglary. In practice this is only rarely possible, however, and even less so in a controlled setting that allows for systematic study. By virtue of its illegal nature, burglary, analogous to other serious offenses, occurs out of sight and hence is hard to observe and examine 'in the wild'. Even in those cases that would allow for direct observation, ethical considerations generally militate against it. Consequently, our knowledge of burglary relies in large part either on studies examining targeting patterns and target characteristics, or on studies using retrospective methods, such as offender interviews and surveys. The former type of research has yielded crucial insights on areas where burglaries are likely to take place (e.g., Johnson and Bowers, 2004; Townsley, Homel and Chaseling, 2003) and offending trajectories taken (e.g., Bernasco, 2010), but offers little in the way of burglar decision-making processes while committing the offense (Coupe, in press; Wright and Decker, 1994).

Interview studies have provided valuable insights into offender decision-making (e.g., Cromwell and Olson, 2004; Cromwell, Olson and Avery, 1991, 2010; Nee and Taylor, 1988; Wright and Decker, 1994; Wright, Logie and Decker, 1995) but are prone to a different set of limitations. Narrator inaccuracy may, for example, be intentional by exaggerating or downplaying actions rather than recounting facts as they occurred (Elffers, 2010; Kearns and Fincham, 2005). But even for offenders committed to reporting truthfully about how they executed their crimes, the reconstructive nature of interviews is prone to a range of retrospective biases. Important events may, for instance, be forgotten, sequences reversed, and timing distorted (Bradburn, Rips and Shevell, 1987; Nisbett and Wilson, 1977). One way in which the reliability of interviews can be increased is by interviewing burglars in the places where they committed their burglaries (e.g., Cromwell et al. 1991; Maguire and Bennett 1984; Nee and Taylor 2000; Wright and Decker 1994). However, although such cues can improve participant recollection, much human decision making—and by implication offender decision making—occurs automatically and below the threshold of consciousness, and is therefore not subject to deliberate retrieval from memory (e.g., Kahneman 2010; Nee and Ward 2015; Van Gelder 2013; Wilson and Bar-Anan 2008). In this article, we capitalize on the possibilities of novel technology to study burglary as it takes place using an experimental approach that can bypass several limitations of conventional methods.

A Novel Method for Burglary Research

The term virtual reality (VR) is generally used to refer to an artificial or computer-generated, three-dimensional representation of reality, which is experienced through the senses and which is interactive, i.e., in which the user' s actions (co-)determine the course of the interaction (Van Gelder, Otte and Luciano 2014). A virtual environment (VE) is a digital space in which a user' s movements are tracked and his or her surroundings rendered, that is digitally recomposed and displayed back to the user in accordance with those movements (Fox et al. 2009). A VE can be experienced on a computer screen (think of a game computer such as the Xbox or PlayStation or online platforms such as Second Life) but also in an immersive way. In case of immersive virtual reality (IVR), which is the focus of the present study, the virtual environment perceptually surrounds a user and his/her awareness of the real world is minimized (Loomis, Blascovich and Beall 1999; Ticknor and Tillinghast, 2011). As real world sensory input is blocked, this can generate the impression that one has actually stepped inside the virtual environment and create an illusion of involvement with the artificial world (Witmer and Singer, 1998). Immersive virtual reality is typically achieved by having participants wear a head-mounted display.

VR technology allows for the development of simulated environments that resemble their real-world analogues, and therefore enables the study of offender behavior during the (simulated) criminal event *as it unfolds*. VR therefore provides, at least potentially, a useful platform to increase our understanding of crime and to inform crime prevention efforts. Particularly relevant for the present purposes is the potential of advanced VR technology to gain a deeper understanding of criminal decision-making processes, due to the combination of high levels of realism and the possibility of near-complete researcher control over the research environment. Additionally, virtual environments can be systematically varied and thus enable the use of experimental research designs (Fox, Arena and Bailenson, 2009) and can generate large amounts of standardized statistical data in a nonintrusive manner (Bainbridge, 2007).

The virtual environment developed for this study consists of the exterior and interior of a set of adjacent houses and their immediate environment (Figures 1a-1d). The environment enables participants to freely move around its streets, enter and search a designated house, and finally exit with the stolen goods. Wearing a virtual reality headset and headphones, participants are effectively shut off from all real-world information, and completely immersed in the computer-generated environment that they navigate through the use of a game controller.

Besides overcoming several limitations of traditional methods used in burglary research, the use of VR carries an important additional benefit. When it comes to our understanding of individual difference variables in relation to criminal behavior, we know much about how these variables predict the choice for, or involvement in, crime. However, due to the retrospective and indirect nature of traditional research methods, we know much less about how these variables predict offender behavior during the crime event itself. Extant research has for example shown self-control to be a very consistent predictor of criminal involvement (Gottfredson and Hirschi 1990; Pratt and Cullen 2000), but few studies have actually examined whether it also influences how offenders go about performing their crimes. Crime research is still in its infancy when it comes to understanding the cognitive and emotional processes that operate at the scene of the crime. A better understanding of how individual characteristics manifest and impact behavior can help improve both situational crime prevention efforts and provide relevant input for the rehabilitation of offenders (Ekblom, 2007; Nee 2015; Van Gelder 2013). Studying offenders' behavior by simulating the context of the crime through virtual environments might be a potentially productive and ethical way to achieve this.

The aim of the present study is twofold. First, we examine to what extent our virtual environment can be usefully applied to examine burglary. Our second aim is to explore how several established individual-difference correlates of crime and delinquency predict decision making *during a burglary event*. Below, we first discuss research relevant to the present purposes that has utilized VR technology. Then, we summarize research linking individual dispositions to crime prior to formulating our hypotheses. In the discussion section, we return to the potential of VR for studying burglary, and criminology more generally, and identify several potentially productive avenues for future research.

Virtual Reality as a Research Method

Even though VR has not yet seen widespread application in criminology (but see Nee et al. 2015; Park et al. 2012; Toet and Van Schaik 2012; Van Gelder, Hershfield, and Nordgren 2013), there are established VR research traditions in other social scientific fields, most notably social and clinical psychology, that can provide valuable input. This research has *inter alia* demonstrated that the manipulation of different characteristics of a virtual environment can have significant user impact, both psychologically and physiologically. For example, studies on treatment effectiveness for people suffering from specific phobias have shown that VR-based exposure treatment can be as effective as traditional forms of exposure therapy (Parsons and Rizzo 2008; Powers and Emmelkamp 2008). Importantly, findings from VR research suggest that virtual environments can be usefully employed as substitutes for real-world settings when practical or ethical considerations militate against using their real-life equivalents, as behavior in virtual environments can closely mimic behavior in comparable real-world settings (Slater et al. 2006 2013; Van Gelder, Otte, and Luciano 2014).

In one study (Slater et al. 2006), researchers sought to replicate Milgram's classic obedience experiment using a virtual environment. Milgram (1963) aimed to understand obedience by demonstrating that people were willing to administer severe and dangerous electric shocks to a stranger during a word association memory test when instructed to do so by an authority figure. In their 'virtual reprise', Slater et al. (2006) employed a similar paradigm to the Milgram study, using an immersive virtual environment instead. In the Slater et al. experiment, participants delivered the 'electric shocks' to a virtual 'trainee' when she made errors on the test. Even though participants were fully aware that neither the trainee nor the shocks were real, they tended to respond to the situation at the subjective, behavioral (e.g., withdrawal from the experiment) and physiological (e.g., heart rate, skin conductance) levels as if they were actually delivering shocks. In other words, participants in this study displayed signs of distress and behaviors suggesting that the virtual person was being treated as if it were real.

In another recent experiment, Slater et al. (2013) examined the bystander effect (Daley and Latané 1968) in a VR setting by having participants, fans of a particular soccer club, witness a violent incident between two people in a bar. The researchers were interested in the number of verbal and physical interventions by participants during the violent argument. They found that the number of interventions was higher when the victim was a supporter of the same soccer club as the participant, i.e., was an in-group member, compared to when no reference to club allegiance was made. The more participants perceived that the victim was looking at them for help, the higher the number of interventions if the victim was an in-group member, but not if the victim was an out-group member. In a nutshell, this study too shows that VR technology enables the elicitation of responses that resemble people's behavior in real world situations.

Of particular relevance for the present research is a study by Nee and colleagues (2015) who compared a small sample of ex-burglars with a sample of university students on a mock burglary using both a real and a simulated environment to examine how differences in expertise influenced how these groups went about breaking into a house. The authors had a group of six experienced ex-burglars and a group of six students with no prior offending histories undertake mock burglaries in a real house and in a replica of the same house in a simulated non-immersive virtual environment. The study aimed to test how differences in expertise would influence how novice and expert burglars go about burglarizing houses. The main assumption was that burglars would take fewer but higher value items, but also that they would navigate the house in a more systematic way. Importantly, Nee and colleagues also aimed to investigate whether findings from the burglaries of the real house would be replicated in the virtual house. Besides support for the expertise hypothesis, results indicated that differences in the way in which burglars went about burglarizing the real house and the simulated house were few. Although it is of course impossible to fully mimic all the details of an actual burglary in a simulated setting (e.g., participants do not risk real time in prison), these findings do provide initial support for the idea that virtual environments can be usefully employed to study burglary in action.

In sum, these studies suggest that virtual reality, in spite of its artificial nature, can elicit responses from participants that resemble those that one would expect in similar real-world settings. Moreover, virtual environments have the potential to reliably study social phenomena that are difficult to experimentally examine in the real world for either practical or ethical reasons. In the next section, we discuss the ability of VR to shed light on the relation between individual dispositions and decisions during a criminal event.

Personality Correlates of Crime: Criminal Involvement versus Crime Commission Decision Making

Despite their often chaotic and impulsive lifestyles (e.g., Katz 1988; Lofland 1969; Shover 1996; Topalli and Wright 2013; Wright and Decker 1994), research suggests that various types of offenders are able to display considerable expertise and proficiency in committing crime. This raises the question whether individual characteristics that contribute to the development of a criminal career, i.e., involvement decisions (Clarke and Cornish 1985; Clarke 2013), also impact on the actual performance of the crime, i.e., commission decisions. Extant research reveals that individual dispositions such as self-control (e.g., Gottfredson and Hirschi 1990; Wilson and Herrnstein 1985), sensation seeking, (Zuckerman 1979, 2007) and conscientiousness (Goldberg 1990; Lynam and Miller 2001) are robust predictors of criminal involvement. Yet research on how these factors actually impact behavior during the crime event is more limited. To address this gap in the literature, the present study capitalizes on the opportunities that VR technology offers to examine behavior during the criminal event. We focus on individual-level correlates of crime that reflect people's propensity for risky behavior, e.g., sensation seeking, their capacity for planning, exercising restraint and self-discipline i.e., self-control and conscientiousness, and their integrity, i.e., Honesty-Humility.

Sensation seeking has been associated with a wide variety of problem and risky behaviors, such as reckless driving, heavy drinking, drug use, unprotected intercourse, and also delinquency (Portnoy et al. 2014; Zuckerman 1979, 2014; Zuckerman and Kuhlman 2000; Steinberg et al. 2009; De Vries, De Vries and Feij 2009). Sensation seeking refers to the need of individuals for varied, novel, and intense sensations and experiences, along with the willingness to take physical, social, financial, and legal risks for the sake of such experiences (Zuckerman

2000). Their tendency to seek thrills and be less anxious might render sensation seekers not only more likely to get involved in various types of deviant or criminal behavior but, we argue, also to take more risks as the events they engage in, such as crime, unfold. For instance, in the context of burglary, sensation seekers may not only choose a riskier target to burgle but may also, once committed to their target, take more risk during the burglary as reflected in taking more time in the house to steal more and more expensive objects.

Another individual disposition related to crime is the ability to exert self-control. Self-control, which is probably the most robust and widely described individual-level correlate of criminal behavior (see Pratt and Cullen 2000), shares considerable conceptual and empirical overlap with the Conscientiousness personality trait which relates to the ability to control impulses, to plan, organize and complete tasks, and exert self-discipline, as well as demonstrating carefulness, thoroughness, and diligence (Miller and Lynam 2001; De Vries and Van Gelder 2013; Tangney, Baumeister and Boone 2004; Jones, Miller and Lynam, 2011; Wilson and Herrnstein 1985). The question how both self-control and conscientiousness relate to burglary behavior is interesting as low scores on both dispositions are associated with poor job and task performance (Tangney, Baumeister and Boone 2004; Barrick and Mount 1991). Paradoxically, this would imply that although being negatively related to criminal involvement, they might be positively related to success in crime commission, an assumption that resounds with work on burglar expertise (Nee and Meenaghan, 2006).

Finally, recent research (Van Gelder and De Vries 2012, 2014; De Vries and Van Gelder 2013), has found people's integrity, measured through the Honesty-Humility personality trait (Ashton et al. 2004), to be an important predictor of criminal choice. Honesty-Humility refers to individual differences in the tendency to be interpersonally genuine, to be unwilling to take advantage of others, to avoid fraud and corruption, to be uninterested in status and wealth, and to be modest and unassuming (Lee and Ashton 2004). The more greedy and materialist nature of people scoring low on Honesty-Humility, we speculate, may be associated with a better awareness of the value of items, and with implicit mental maps of how opportunities for material (and illicit) gain can be exploited. Hence these individuals could make for more effective burglars in the sense that they steal more and more valuable items.

THE PRESENT RESEARCH AND HYPOTHESES

The present study has two goals. The first and main goal is to assess to what extent our virtual environment is a valid tool for studying burglary by measuring user responses on the subjective, physiological and behavioral levels. The second and subsidiary goal is to explore how several established individual-level correlates of crime influence behavior during a (virtual) burglary.

A first requirement to ascertain that a virtual environment elicits responses that resemble those in the real world is whether participants actually subjectively experience immersion in the computer-generated virtual environment. That is, they need to feel physically and psychologically present within the virtual environment rather than in the actual physical place where their body is located (Draper, Kaber and Usher 1998). This psychological sense of "being there" is referred to as "presence" in virtual reality research and needs to be considerable to elicit valid user-responses. We therefore measure the amount of presence participants experience during their immersion in the virtual environment immediately after they have finished their burglary.

However, questionnaire-based measures cannot rule out the possibility that any reported subjective presence reflects acquiescence or other forms of response bias (Slater 2004: 484). We therefore also use several cardiopulmonary measures, such as heart rate, that reflect people's objective physiological response to their experiences in the virtual environment. We argue that these measures should show a change in response to the burglary. Participants' heart rate should for example show an increase during the actual burglary compared to when they are just walking around the virtual neighborhood and have not yet started committing their crime (Wiederhold et al. 2002; Meehan et al. 2002). Upon exiting the virtual house and hence termination of the burglary, however, heart rate should be similar to baseline.

Finally, we employ a behavioral measure that reflects the extent to which participants respond to the virtual burglary in ways similar to what can be expected for real-world offending. Prior to the experiment, participants are either warned that the chance of being caught (deterrence) was high or low, and either had an alarm sound after spending a particular time in the house or not (alarm), resulting in a 2 (Deterrence: high vs. low) x 2 (Alarm: present vs. absent) factorial design. If participants take the burglary seriously, they should be responsive to the possibility of being caught and hence spend less time in the house. Furthermore, the sounding of an alarm should result in a shorter time spent in the house, as participants can be expected to exit the house upon hearing it.

The second goal of this study is to explore whether and to what extent several individual-level correlates of crime involvement, which were discussed earlier, also influence behavior during a (virtual) burglary. We expect that the propensity to seek risks and thrills makes sensation seekers more likely to spend more time in the house during a burglary, which implicates a larger probability of getting caught compared to low scorers. Furthermore, we expect participants who score higher on self-control and conscientiousness to be more effective as burglars, as they work more systematically and are therefore able to steal more items compared to participants who score low on these dispositions. However, we also expect that their tendency to be more prudent, will lead them to spend less time in the house compared to low scorers on these dimensions. Finally, we predict that people who score lower on Honesty-Humility, and who are therefore lower in integrity, are better burglars in the sense that they are likely to steal more valuable items as they have a better awareness of the monetary value of items, compared to participants scoring high on this dimension.

METHOD

Participants

A total of 77 male undergraduate students (age range 18-30, M_{age} = 21.41, SD_{age} = 2.9) participated. We opted for a male-only sample given the greater propensity for crime in males compared to females. The fixed compensation for participation was €5,-. Furthermore, to mimic the payoff structure of a real burglary as closely as possible, participants could make an additional €5,- based on the total value of the goods that they stole during their burglary. Each item had a value that was a function of its resale value on various online auction websites (e.g., eBay). Getting caught implied losing the goods that were stolen, and with it, the additional payment. Participants were randomly assigned to one of the four experimental conditions. As our central aim was to make a preliminary assessment of the virtual environment in terms of its ability to elicit predictable psychophysiological and behavioral responses, it was seen as acceptable to use a student population for this study rather than convicted offenders.

Materials

Virtual environment. The virtual environment was developed with the Unity Pro (version 4.2) engine, and designed to resemble a middle-class neighborhood during mid-day (see Figure 1a-1d). Because presence is, at least in part, a function of the level of immersiveness of a VE (Gorini et al., 2011), we used a head-mounted display with stereoscopic view (Oculus Rift DK2) rather than a computer monitor. These head-mounted displays track users' head movements by an internal accelerometer and display it back to the user in accordance with those movements, which allows for viewing in all directions. Besides visual immersion through the VR headset, immersive audio delivered through stereo headphones with naturalistic environmental sounds (birds whistling, cars in the background, etc.) and user sounds (e.g., a door clicking when opened) were intended to further add to the realism of the experience. The use of multimodal VR systems that include realistic sound have been shown to result in higher presence (Taffou et al., 2012). The same applies to enabling active navigation within the VE (Freeman et al., 2005). Participants could therefore freely navigate our virtual environment using a console-type game controller.

Figure 1 about here

The house participants were to burgle could be entered through the front door, through the back door accessible from the back yard, or through an open window on the second floor, which was accessible by climbing a drainpipe. The house had a ground floor, first floor and second floor, each consisting of several rooms. Throughout the house, household objects were distributed that participants could steal, including valuable items such as jewelry, a guitar, a passport, and various types of electronic equipment (e.g., flat screen television, personal computers, tablets, and printer), as well as less valuable items such as groceries, pens, canned food, picture frames, books, kitchenware, etc. Furthermore, some of the items were in clear sight (e.g., television), whereas others were more hidden (e.g., a tablet in a backpack). Doors, closets, cupboards, drawers, etc. could all be opened and their contents inspected. Items chosen for the interior of the house were based on the research team's extensive knowledge of the household items targeted in residential burglary from their own research and that of others (Bennett and Wright, 1984; Nee and Meenaghan, 2006; Nee and Taylor, 2000; Wright and Decker, 1994; Nee et al, 2015). In total, 166 items in the house could be stolen.

An invisible timer started as soon as participants entered the house. Participants in the alarm condition would hear an audible alarm at exactly 3 minutes after entering the house, and any participant still in the house 6 minutes after entering it would be informed that they had been "caught" by a text message appearing on the screen. The VR system recorded user movement, items picked up, i.e., stolen, and the time when they were picked up. From this we computed four different outcome measures: total time spent in the house (henceforth: Time in House), total number of objects stolen (henceforth: Objects Stolen), total monetary value of the items stolen (henceforth: Monetary Value), and the total monetary value divided by the total number of objects (henceforth: Object/Value Ratio).

*Cardiopulmonary measures***.** Three different cardiopulmonary measures were used to collect physiological data: heart rate (HR), pre-ejection period (PEP), and Respiratory Sinus Arythmia (RSA). All three were collected using VU-AMS devices (De Geus, Willemsen, Klaver, and Van Doornen 1995). While heart rate is a general measure of arousal, an increase in heart rate may occur for somatic reasons (e.g., because a participant is engaged in a physical activity, such as running), or because of sympathetic nervous system activation as the result of psychophysiological stress (e.g., engaging in an illicit activity, such as a burglary). Next to heart rate we therefore also measured pre-ejection period (PEP), which is the period of time between the electrical activation of the heart and the ejection of blood from the left ventricle. PEP has been shown to decrease in times of psychophysiological stress specifically (Newlin and Levenson 1979). A low score on PEP thus indicates that participants experienced high levels of stress, whereas a high score indicates that stress in participants was low. The third cardiopulmonary measure, RSA, reflects the intervals between heartbeats, which have been shown to lengthen and shorten in conjunction with breathing out and breathing in respectively (Berntson, Cacioppo and Quigley 1993). This fluction in interaction between inter-beat intervals of the heart and respiration has been shown to decrease in times of psychological stress (see Berntson et al. 1993, De Geus et al. 1995).

In order to calculate differences six separate time windows were calculated for all three cardiopulmonary measures: (1) from the moment the participant began completing a series of questionnaires and ending when the questionnaires were complete (baseline), (2) following the completion of the questionnaires, and ending after calibration of VR equipment and instructions for the virtual environment, (3) beginning with participants' entry into the virtual environment and ending with the beginning of their virtual burglary (entering the house), (4) beginning of the virtual burglary and ending after three minutes, when the alarm would sound if participants were in the alarm condition, (5) the beginning of the period where the alarm would sound if participants were in the alarm condition and ending with the end of the burglary, and (6) from the moment the burglary ended until participants had completed the and final second set of questionnaires (second baseline).

Questionnaires

Conscientiousness, Honesty-Humility and Sensation seeking were assessed using the 104-item version of the HEXACO personality inventory revised (Lee and Ashton, 2008). Both Conscientiousness ($\alpha = .72$), e.g., "I plan ahead and organize things, to avoid scrambling at the last minute", and Honesty-Humility ($\alpha = .87$), e.g., "Having a lot of money is not especially important to me", are represented in the HEXACO structure as main dimensions and each measured with 16 items on five-point (*strongly disagree–strongly agree*) scales. Sensation seeking (α = .84), e.g. “I don’t care if I have to do dangerous work”, represents an interstitial trait, i.e., pertains to blends of factors, in the six-dimensional HEXACO personality space. We followed the procedure by De Vries, De Vries and Feij (2009) to construct the HEXACO Sensation Seeking Scale, which is based on the original scale developed by Zuckerman (1979). Means and standard deviations for all scales are reported in Table 1.

Self-control was measured using the 11-item Brief Self-Control Scale (α = .69), e.g. “I can resist temptation” (Tangney, Baumeister, and Boone, 2004) and measured using five-point (*strongly disagree–strongly agree*) scales.

Presence was measured using an adapted version of the 14-item Igroup Presence Questionnaire (Schubert, Friedmann and Regenbrecht 2001)(α = .73) (IPQ) which consists of the subscales Spatial Presence, e.g., “I felt present in the virtual space”, Involvement, e.g., “I was not aware of my real environment”, and Experienced Realism “The virtual world seemed more realistic than the real world”. The phrasing of several items was altered to fit the ‘strongly disagree–strongly agree’ answering format.

Gaming experience. A questionnaire that included items such as ”Do you ever play first-person shooter games?” and (if yes) “Please indicate how many hours per week you spend playing these games” assessed (video) gaming experience.

Procedure

Data collection took place in the research lab of the Faculty of Behavioral and Movement Sciences (FGB), VU Amsterdam. Participants were recruited via flyers, which explicitly stated that they were expected to perform a burglary in virtual reality using the Oculus Rift headset and which mentioned the use of heart rate measures and the financial compensation for participation. Participants were asked to make an appointment with the experimenters via e-mail or to appear at the research lab to sign up for the study.

Prior to participation, participants were given consent forms to read and sign, and subsequently randomly assigned to one of the four experimental conditions (low/high deterrence x alarm/no alarm). They were then led to a cubicle with a closing door, where they were fitted with electrodes for the purposes of collecting cardiopulmonary data, after which they were asked to complete the 104-item HEXACO PI-R and the Brief Self-Control scale. During this period, baseline cardiopulmonary data were collected. The final screen of the questionnaire informed participants that they would enter a virtual neighborhood in which they were to burglarize a house and that there was either a high (high deterrence condition) or a low (low deterrence condition) chance of being caught, and explained the payoff structure of the virtual burglary. Participants were explicitly instructed to go about the burglary as they would in the real world.

Participants were then briefed about how to use the virtual reality hardware, how to move about in the virtual environment and interact with it, and were given instructions on how to burgle the house. Specifically, the experimenters explained that participants were to receive extra compensation for each item they stole according to its resale value, provided they were not "caught". In order for stolen items to be counted towards their extra compensation, participants were instructed to drop the stolen items in a "drop zone" located in the entrance hall of the house, immediately behind the front door. Experimenters then explained that there was only one house that could be burgled, that the burglary would begin once they entered the house, and that it would end the moment they left the house or if they were caught within the house. It was explained that they would know they had been caught when the message "You have been caught" appeared on the screen, although no specific information about how or when they could get caught was conveyed.

After receiving instructions, the Oculus Rift headset was calibrated for the participant and they entered the virtual environment. Participants were allowed to move freely around the virtual neighborhood in order to get used to the controls and the environment. Participants were then shown the house they were to burgle, and the instructions were repeated. If participants had no further questions, they were instructed to begin the burglary.

Upon completion of the burglary, participants were asked to complete an exit questionnaire containing the IPQ and items assessing gaming experience. Upon completion, the experimenters removed all electrodes, and paid the participant according to his performance. The entire experimental session took around 40 minutes in total.

Table 1 about here

RESULTS

As some individuals are known to experience discomfort when using virtual reality hardware, so-called ‘cyber sickness’, we first examined whether it caused discomfort in our participants. Sixty of the participants were asked to rate the discomfort they experienced during the period they spent in the virtual environment on a five-point scale (*not at all uncomfortable-extremely uncomfortable*).[1] Mean discomfort was 2.58 (SD = 1.03). We calculated correlations with all four behavioral outcome variables. The experienced discomfort was negatively related to Monetary Value, r = -.287, p = .026, but not to the other three outcome variables, i.e., Objects Stolen, r = -

[1] The experimenters only started to collect data on discomfort after initial reporting by some participants that they experienced some discomfort during the time they spent in the virtual environment. Hence, data on discomfort were collected for 60 participants instead of all 77 participants.

.123, *p* = .351, Time in House, *r* = -.158, *p* = .227, or Object/Value Ratio, *r* = -.067, *p* = .618. These findings suggest that although immersion in our virtual environment elicited some discomfort, the level of discomfort was too small to influence the results appreciably.

The remainder of this section is structured into two parts. In the first part, we examine user responses on the subjective, physiological and behavioral levels, as reflected by participants' reported levels of presence, the cardiopulmonary measures, and participant behavior respectively. In the second part, we examine the relations between the personality variables and the behavioral outcome measures.

User responses on the subjective, physiological and behavioral levels

Presence

First, presence as reported by the participants on the IPQ was assessed. The mean score on the IPQ was 3.85 (*SD* = 0.52) out of a maximum score of 5, indicating that as expected participants felt psychologically present in the virtual environment. To rule out whether previous gaming experience influenced presence, the correlation between the amount of games played and presence was calculated. No significant correlation emerged, *r* = -.159, *p* = .171 (for an overview of these correlations and scale descriptives, see Table 1), indicating no difference in presence between frequent and non-frequent game playing.

Figure 2 about here

Cardiopulmonary measures

To assess whether participants also responded to the act of burglary on the physiological level, we assessed differences in the cardiopulmonary measures, i.e., heart rate, PEP and RSA, over the six time windows (see Figures 2-4). A repeated measures ANOVA with a Greenhouse-Geisser correction on average heart rate indicated significant differences for heart rate between the chosen time points, $F(2.425, 150.355) = 45.283$, $p < .001$, $\eta_p^2 = .422$. Post hoc tests using Bonferroni correction revealed that heart rate increased significantly ($p < .001$) at the moment of entering the house, and hence when commencing the actual burglary, (*M* = 83.84, *SD* = 13.50) compared to when entering the virtual environment (*M* = 76.93, *SD* = 11.05). Furthermore, a significant increase ($p = .015$) in heart rate was found between the start of the burglary (*M* = 83.84, *SD* = 13.50) and the moment the alarm sounded (*M* = 87.82, *SD* = 15.71). Heart rate did not increase ($p = 1.000$) between baseline (*M* = 75.41, *SD* = 12.89) and the moment participants entered the virtual environment (*M* = 76.93, *SD* = 11.05). In support of our hypothesis, the changes in heart rate over time clearly indicate that the virtual burglary, rather than experiencing virtual reality, causes increased physiological arousal.

Figure 3 about here

We performed a similar set of analyses for the pre-ejection period of the heart (PEP). The results indicated significant differences in PEP over the different time points, $F(3.506, 220.881) = 3.99$, $p = .006$, $p\eta^2 = .060$ (see Figure 3 for a graphical representation). Post hoc tests using Bonferroni correction revealed that PEP did not decrease significantly ($p = 1.000$) when starting the actual burglary (*M* = 80.19, *SD* = 43.86) versus when entering the virtual environment itself (*M* = 83.96, *SD* = 41.87). PEP was also not significantly different ($p = 1.000$) at baseline (*M* = 87.27, *SD* = 38.60) compared to when entering the virtual environment (*M* = 83.96, *SD* = 41.87). These non-significant ($p = 1.000$) findings were also found comparing the PEP starting the actual burglary (*M* = 80.19, *SD* = 43.86) and PEP during the alarm (*M* = 77.82, *SD* = 42.71). A significant effect (p = 0.01) did emerge between baseline (*M* = 87.27, *SD* = 38.60) and the alarm phase (*M* = 77.82, *SD* = 42.71). A marginally significant difference was found (p = .06) comparing the alarm phase (*M* = 77.82, *SD* = 42.71) and the second baseline phase (*M* = 87.04, *SD* = 39.71), indicating that psychological stress decreases when exiting the environment. Together these results indicate that the development of PEP, a measure of psychological stress, follows the expected pattern, being lowest at the time of the alarm and then returning to values similar to baseline after the burglary has ended.

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Figure 4 about here

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We also performed a repeated measures ANOVA with Greenhouse-Geisser correction for the respiratory sinus arhythmia (RSA). The results indicate significant differences in RSA over the different time points, $F(3.565, 224.607) = 20.81$, $p < .001$, $\eta_p2 = .248$ (see Figure 4). Post hoc tests using Bonferroni correction revealed that RSA was not significantly different (p = 1.000) from baseline (*M* = 87.27, *SD* = 38.60) compared to when entering the virtual environment (*M* = 77.75, *SD* = 30.69). However, there was a significant decrease in RSA ($p < .001$) from the moment of entering the virtual environment (*M* = 76.14, *SD* = 38.33) and the start of the actual burglary (*M* = 59.23, *SD* = 27.29). There were no significant differences (p = 1.000) between RSA at the moment of entering the house (*M* = 59.23, *SD* = 27.29) compared to RSA during the alarm phase (*M* = 58.14, *SD* = 27.10). In line with expectations, these results indicate that cardiac parasympathetic activity, a measure of relaxation, varies due to the actual burglary, and not due to the virtual environment itself.

In sum, heart rate and the associated cardiopulmonary measures PEP and RSA showed predictable variations during the time participants were in the virtual environment and performed their virtual burglary indicating significantly different levels of stress depending on the stage of the burglary.

Deterrence, Alarm, and Burglary Behavior

To assess whether Deterrence and Alarm influenced participants' burglary behavior, we ran a 2x2 MANOVA on the four outcome measures, Time in House, Objects Stolen, Monetary Value, and Object/Value Ratio (see Table 2 for means and standard deviations). We expected that participants in the high deterrence condition, which were told there was a high probability of being caught, would leave the house sooner, take fewer objects, and would therefore end up with a lower total value, than participants in the low deterrence condition. We also expected that participants in the alarm condition, would leave the house sooner, take fewer objects, and generate a lower total value. An interaction between the two conditions was expected for Time in House: participants with a high chance of getting caught and hearing the alarm were expected to leave the house sooner compared to the other conditions.

Table 2 about here

Whilst controlling for discomfort and game experience, a significant main effect was found for Deterrence on Time in House, $F(1, 53) = 4.41$, $p = .041$, $\eta_p^2 = .08$. Time spent in the house was, as predicted, significantly shorter for those with a higher chance of getting caught (*M*

= 274.27, *SD* = 13.24) compared to those with a low chance (*M* = 313.93, *SD* = 13.03). A similar effect was found for deterrence and Monetary Value, $F(1,53) = 5.65$, $p = .021$, $\eta_p^2 = .096$, which was significantly lower for those with a high chance of getting caught (*M* = 1676.99, *SD* = 147.48) compared to those with a low chance of getting caught (*M* = 2176.95, *SD* = 145.10). In contrast to expectations no significant effects emerged for Alarm. Hearing an alarm go off in the virtual environment had no significant effect on the participants on any of the four outcome measures, nor was the interaction between alarm and deterrence significant.

Individual dispositions and burglary behavior

Finally, the second part of the analyses focuses on the relation between individual dispositions and burglary behavior. Specifically, we used correlation analyses to examine relations between Sensation Seeking, Self-Control, Conscientiousness, and Honesty-Humility and the four outcome measures (Time in House, Monetary Value, Total Objects, and Object/Value Ratio) (see Table 1).

The results show that Sensation Seeking was positively related to Monetary Value, $r = .225$, $p = .049$. High Sensation Seeking was associated with increased stealing of valuable items. Furthermore, a significant negative correlation between Conscientiousness and Monetary Value emerged: $r = -.227$, $p = .047$ indicating that participants high in Conscientiousness tended to take less valuable items. No other significant correlations emerged between the individual dispositions and the four behavioral outcome measures.

DISCUSSION

What is arguably the most defining characteristic of criminological research is that its topic of study, by its inherent nature, is hard to observe ‘in the wild’, let alone in such a way as to allow for systematic study (Van Gelder and Van Daele 2014). The present study explored the possibilities of immersive VR for studying burglary in action. We argued that virtual environments can be used as substitutes for real-world situations and potentially tell a great deal about behavior *during the criminal event*, i.e., about commission rather than involvement decision making, and bypass several issues that have traditionally plagued offender decision making studies.

Our study had two goals. The first goal was to examine whether participants responded in predictable ways at the subjective, physiological and behavioral levels to the virtual burglaries they committed. The second goal of the study was to examine the relations between several individual dispositions and behavior during the burglary event. More specifically, measures of sensation seeking, self-control, conscientiousness, and honesty-humility were included to examine if, and to what extent, these factors influenced burglary behavior.

With respect to the first goal, the results suggest that our virtual environment was successful in mimicking the context of a real criminal event, as indicated by three key findings. Firstly, participants reported feeling subjectively present within the virtual environment as indicated by their relatively high scores on the presence measure. Second, participants showed the predicted variations in the cardiopulmonary measures, e.g., increases in heart rate, while committing their burglaries. Thirdly, warning participants about the chance of apprehension successfully induced a deterrence effect, in that those who felt they might be caught undertook shorter and less successful burglaries in terms of gain. In contrast to expectations, respondents did not react to the sounding of an alarm in the house. Although drawing firm conclusions about this lack of effect is not possible with the present data, several participants reported after the experiment that they did not expect anything to happen when the alarm sounded and hence did not see much reason to quickly exit the house. We speculate that the absence of human avatars in the virtual environment may have triggered this lack of expectation. Therefore, future VR studies on burglary could also make use of avatars and more systematically inquire about participant expectations to gain more insight into them (see also below).

With respect to the relation between individual dispositions and burglary behavior, the second goal of the study, the virtual environment elicited some predictable behaviors in those high in sensation seeking. Participants scoring high on this dimension spent more time burgling to maximize their gains, while simultaneously incurring a greater risk of apprehension. The absence of a significant relation between self-control and the outcome measures suggests that although important in predicting the choice for crime, this construct may not be as important for explaining behavior during a criminal event. Although it should also be noted that this might depend on the nature of the event, tasks involving more skill or require more inhibition may in fact show this factor to be important in these cases. No relations between Honesty-Humility and burglary behavior emerged which also suggests that while being predictive of the choice for criminal involvement, people's integrity may be less influential in explaining differences in how they go about their criminal acts once they are committed to executing them. Similar to self-control, this may also depend on the nature of the task at hand. Unexpectedly, conscientiousness was negatively related to the total value of the items that were stolen. This finding could in principle be explained by the greater tendency to be careful of people who score high on this dimension. However, if carefulness would be driving this effect, we would also expect participants high in conscientiousness to spend less time in the house, which was not the case. Alternatively, it is conceivable that their tendency towards perfectionism means that high scorers work slower and hence were less effective in collecting valuable items. Nevertheless, in this case too we would expect a similar finding for the number of items they stole, which was not the case.

Future research using offender samples is necessary to determine whether this finding is robust or should be attributed to chance.

Limits

Despite the promising results, we consider the present study to be only a first and still tentative step in paving the way for virtual reality as a method for studying criminal decision making, and acknowledge that it was prone to various limitations that need to be taken into account when considering the results. First and foremost, our sample consisting of university undergraduate students does not resemble actual burglars, or even general offender populations. Although there is evidence of considerable levels of offending behavior in university populations in self-report surveys (e.g., Garwood 2011; Hasler and White 2008; Holtfreter, Reisig, Piquero and Piquero 2010), it is unlikely that significant proportions of our sample would be prolific offenders. As pointed out by Nee et al. (2015), there are important differences in how students and experienced (ex-) burglars go about committing burglary, both in the real world and in simulated environments. A similar point applies specifically to the relation between individual dispositions and behavior during the burglary. While it stands to reason that the relations between individual dispositions and behavior during the burglary are similar for non-offender and offender samples alike, future research among actual burglars is required to ascertain whether the found relations indeed also hold for the latter group. Thirdly, the weight and bulkiness of items were not factored in in our environment even though both play an important role in offender decisions regarding what items to steal (Cohen & Felson 1979). Future research should therefore include item weight and add a corresponding slow-down factor in user-movement in VR simulations and ideally also incorporate the bulkiness of goods.

Furthermore, as this was a first-stage assessment of the virtual environment focusing on behavior during a burglary rather than target choice, participants were instructed to enter a designated house and burgle it. Future research should allow participants to explore a residential neighborhood, and to freely select a property from the different houses in the neighborhood. Such an approach generates a more encompassing view of burglar cognition and behavior in relation to a larger number of aspects of burglary, such as the journey to crime and the impact of potential reward; attractiveness of different targets; and variations in undertaking burglaries in different parts and properties in the neighborhood. Aside from target choice and the undertaking of the crime, most of these aspects have been ignored in research (Decker, Wright and Logie 1993; Nee 2015).

Also technologically there is room for improvement. As noted previously, some participants reported experiencing physical discomfort as a consequence of immersion in our virtual environment ("cyber-sickness"). This discomfort is in all likelihood caused by minor discrepancies in the sensory inputs that people get in the virtual versus the real world. Specifically, the brief time lag between actual (head) movement of participants and the digital rendering of such movement in the head-mounted display is a known cause of cyber-sickness. In the present study, we tried to minimize this concern by carefully calibrating the equipment for each participant, and by measuring their discomfort in order to control for it in the analyses. The results suggest that this concern did not compromise our main conclusions. Nevertheless, a future challenge is to further develop this technology by reducing the sensory discrepancies between the virtual and the real world to an absolute minimum. Increasing computer-processing capacity, more efficient programming and developments in VR software can each contribute to reaching that goal.

Future Research

Although the findings of this study need to be replicated in and extended to samples of actual burglars, we can nonetheless conclude that they are encouraging for the future development of VR methods in the study of criminal behavior. We are particularly strengthened in this belief by the fact that this study did not just rely on what our participants reported, but also on their actual behavior and their physiological responses to the crime event and that all three point in the same direction. If these findings can be achieved using a relatively small, student sample that are unlikely to have experience of prolific offending, we are confident that further development of this methodology with convicted offenders will produce findings offering considerable insight and value for both academics and practitioners working in the field of crime and law enforcement.

A productive avenue for future research into virtual burglary is the addition of avatars to the virtual environment. Recent research has shown the importance of informal guardianship as a deterrent for burglary (e.g., Reynald, 2010; Wilcox, Madensen and Tillyer, 2007). As was mentioned earlier, the combination of high degrees of realism with high levels of experimental control VR offers allows for an unprecedented degree of accuracy in determining how burglars behave and what attracts and deters them. Future VR research can address how the sense of guardianship in a neighborhood and in and around a house can be increased by experimentally varying cues that signal guardianship and how this, in turn, affects burglary. For example, research can examine how most use can be made of neighborhood residents, represented by avatars in the virtual environment, to act as guardians, and how this affects the willingness of offenders to burgle in a neighborhood. This can be achieved not only by varying the amount and type of people walking around (e.g., people walking their dog, mothers with buggies) but also how people, i.e., avatars, look at suspect individuals in the neighborhood (e.g., by looking at them versus looking away) or address them and how such behavior is interpreted by burglars in terms of the level of guardianship.

We are convinced that VR also has clear potential for the study of a range of other crimes besides burglary. We therefore close this article with the identification of several areas for which we think VR has much to contribute to advance our knowledge of crime, criminal decision processes in particular. As was already mentioned in the introduction, the possibilities of VR in the context of crime research are particularly relevant for studying situations in which practical or ethical considerations militate against using real-world equivalents. The combination of realism, which will only continue to grow in the coming years, and almost complete researcher control VR offers, allows for the creation of scenarios and situations that closely resemble their real-world counterparts and the meticulous and experimental study of what specific elements of these situations drive offender decision making. Street crimes, including robbery, assault and drug dealing, are prime examples in which the appraisal of the physical environment and potential victims, plus the arousal and reward systems of offenders, can be studied as they occur. Security scenarios, perception of threat in aggressors, perception of opportunities for shoplifting and pickpocketing are other examples that lend themselves well for VR-based research designs.

VR can also increase our understanding of the automatic decision processes in the chain of events that result in crime. For instance, the 'seemingly unimportant decisions' of some child sex offenders in the events leading up to their offending as suggested by Ward and Hudson (2000) can be empirically examined with this methodology. Ward and Hudson (2000) argued that much of the thought processing of these individuals leading up to and during the criminal event occurs at the unconscious and automatic level. They give the example of a sex offender who decides to get some exercise and seemingly unintentionally chooses to take a walk close to a school at the end of the school day only to find himself in a situation conducive to his offending.

The use of VR, possibly in combination with eye-tracking technology and physiological measures, opens up a considerable range of ethnographic and neurophenomenological research opportunities in this area (for a more extensive overview of the different ways in which VR can be used in crime research, see Van Gelder, Otte and Luciano 2014).

A useful way to go about planning future VR simulations, and also to get a handle on unconscious mental processes guiding offender behavior, is the use of crime scripts (Cornish, 1994), which detail the sequential steps taken by offenders to execute their crimes. Crime scripts provide a framework for analyzing the different stages of the crime-commission process of a specific crime, the decisions and actions that must be taken at each stage, and the resources that are required for its successful completion. As such, crime scripts can assist researchers in identifying intervention points for situational crime prevention (Cornish 1994). By making the decision points of offenders explicit, crime scripts can also be helpful for developing VR simulations and to better understand the choice process at different stages of crime commission, including decisions to abort crimes or change direction. In combination with the aforementioned possibility of using experimental variation to research designs, this opens up a new array of possibilities and can enhance situational crime prevention policies by drawing attention to a fuller range of possible intervention points.

Reverting back to the act of burglary, using a crime script approach allows researchers to enlarge the scope of study to also include offender exploration of a residential neighborhood, target selection, breaking and entering a house, search processes and patterns, and exiting and for each of these elements break down the deliberate and automatic decisions involved. The relative value of prevention measures (guardians, alarm systems, fencing, lighting, dogs, location of valuable items, etc.) then immediately becomes apparent by observing offender behavior and decisions as these unfold. Also, VR allows for examining the accuracy of crime scripts that have been elicited through narrative accounts, by not relying on the retrospective correctness of such accounts but instead by observing behavior as it takes place (Van Gelder, Otte and Luciano 2014). Such a VR crime script approach explicitly encourages the researcher to consider all aspects of the crime-commission process, not just those suggested by offenders' reports (Cornish 1994).

More than twenty years after publication of Wright and Decker’s classic ‘Burglars on the Job’, virtual reality technology has evolved to a point in which it is actually possible to observe burglars in action in a controlled setting. We conclude that for the study of burglary, and also other types of criminal behavior, immersive virtual reality has a lot to offer to our field and hope that criminologists will venture into this new exciting area of research to capitalize on the many possibilities it offers.

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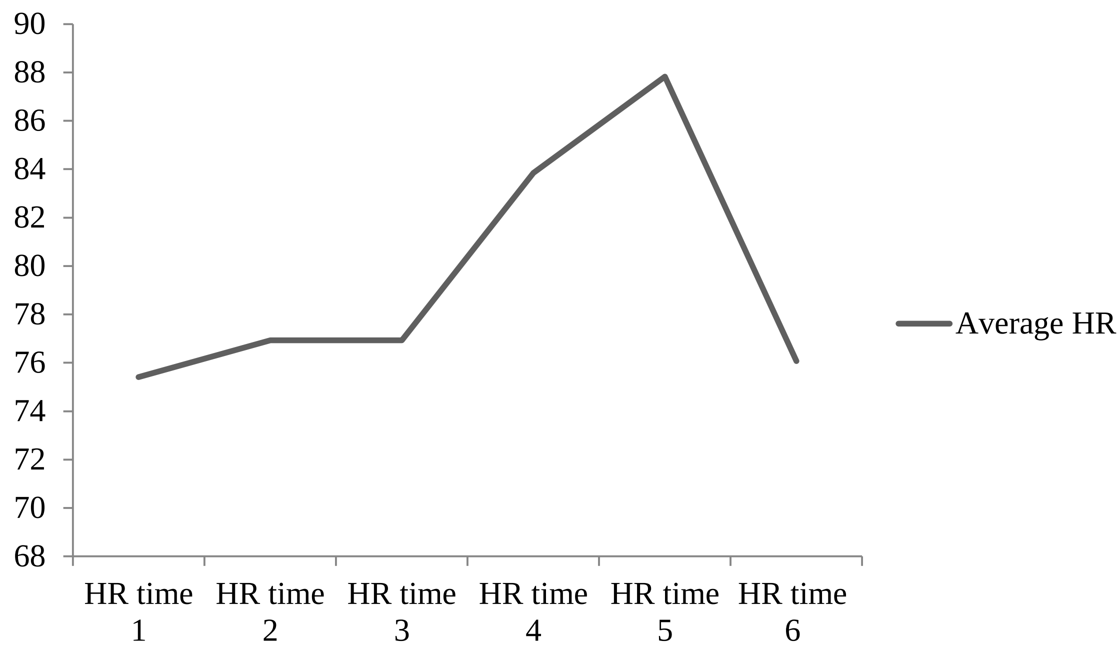
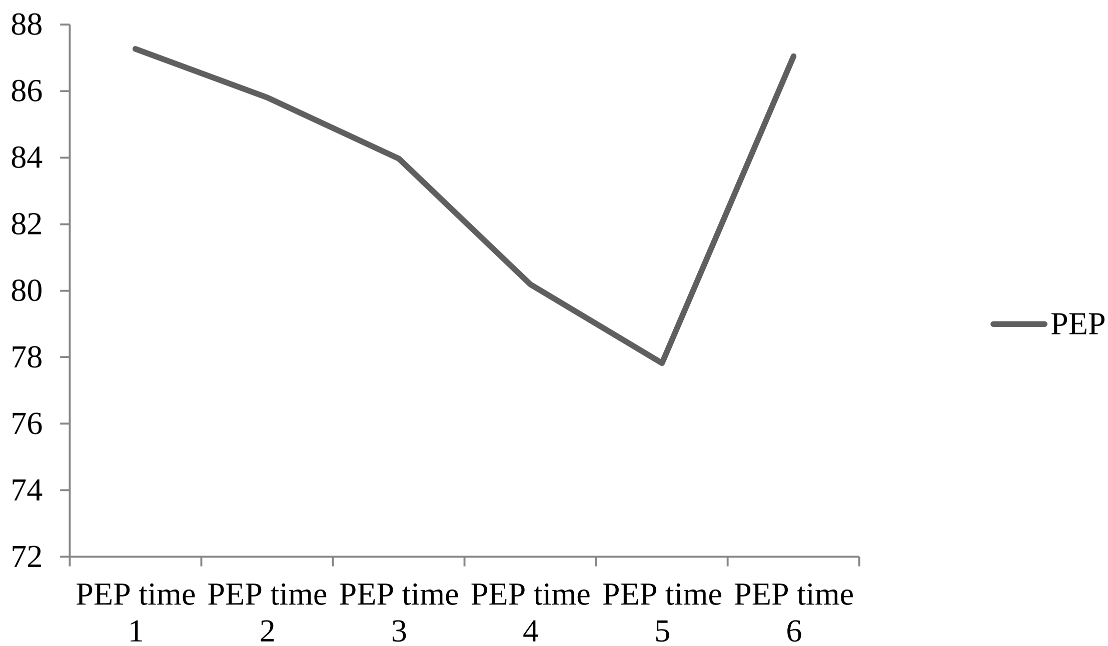
Figure 1a-d. Images of the exterior and interior of houses in the virtual environment

Figure 2. A line graph version of the average heart rate (HR) before, during, and after the burglary



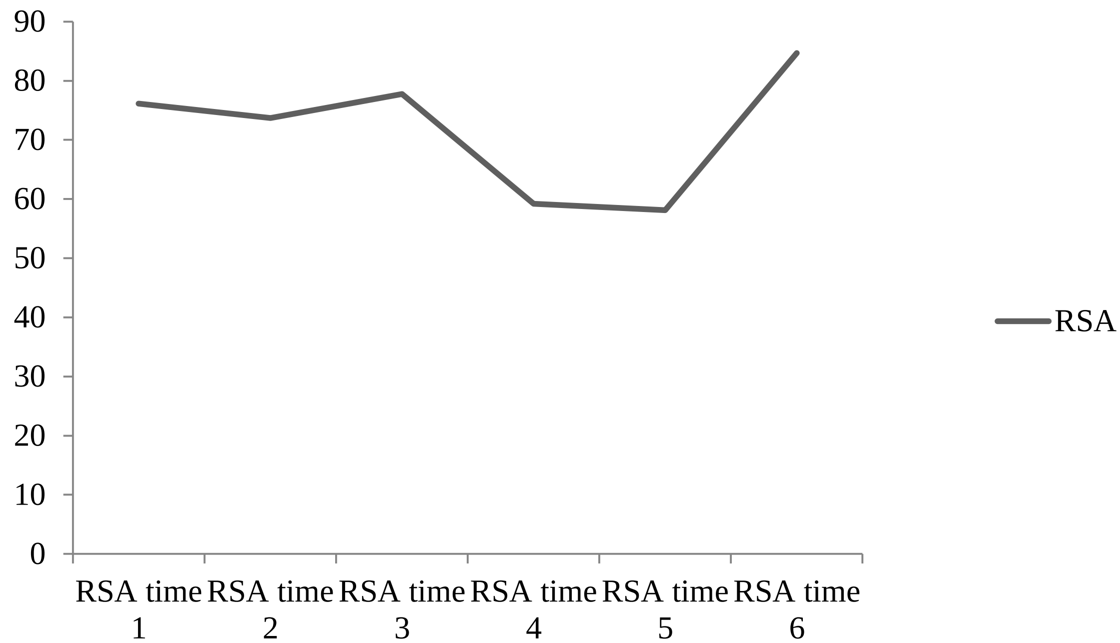
Note. Time 1=first set of questionnaires (baseline), Time 2 = calibration of VR equipment, Time 3 = entering virtual paradigm, Time 4 = entering the house, Time 5 = start of alarm phase, Time 6 = second set of questionnaires (second baseline)

Figure 3. A line graph version of the average pre-ejection period (PEP), before, during, and after the burglary



Note. Time 1=first set of questionnaires (baseline), Time 2 = calibration of VR equipment, Time 3 = entering virtual paradigm, Time 4 = entering the house, Time 5 = start of alarm phase, Time 6 = second set of questionnaires (second baseline)

Figure 4. A line graph version of the average Respitory Sinus Arythmia (RSA) before, during, and after the burglary



Note. Time 1=first set of questionnaires (baseline), Time 2 = calibration of VR equipment, Time 3 = entering virtual paradigm, Time 4 = entering the house, Time 5 = start of alarm phase, Time 6 = second set of questionnaires (second baseline)

Table 1. *Descriptives and correlations of Presence, gaming experience, discomfort, Objects stolen, Value of objects, Time in house, Object/value ratio, Sensation Seeking, Self-Control, Honesty-Humility and Conscientiousness*

		1	2	3	4	5	6	7	8	10	11	12
Mean		3.44	3.59	2.58	14.66	1900.81	293.25	176.72	3.34	3.14	3.04	3.32
SD		.46	1.30	1.03	14.13	796.02	71.87	90.34	.42	.41	.67	.42
1.	*Presence*	-										
2.	*Gaming experience*	-.16										
3.	*Discomfort*	-.17	-.21									
4.	*Objects stolen*	.07	-.14	-.12								
5.	*Value of objects*	.04	.04	.29*	.43**							
6.	*Time in house*	-.01	-.02	-.16	.39**	.50**						
7.	*Object/value ratio*	-.05	-.05	-.07	-.54**	-.09	-.22					
8.	*Sensation Seeking*	.22	-.05	-.23	.04	.23*	-.06	-.02				
10.	*Self-Control*	.01	-.06	-.08	.04	.08	.10	.16	-.02			
11.	*Honesty-Humility*	-.07	-.16	-.04	-.12	-.14	.09	.15	-.44**	.01		
12.	*Conscientiousness*	.04	.11	-.11	.01	-.23*	-.01	.07	-.28*	-.22	.30**	

Note. * $p < .05$, ** $p < .01$; $N= 77$

Table 2. *Descriptives of the outcome measures in the alarm and deterrence conditions*

	Objects stolen	Value of objects	Time in house	Object/value ratio
Alarm condition				
No alarm	15.30 (17.63)	1928.41 (792.86)	307.33 (69.77)	186.17 (101.06)
Alarm	14.08 (10.07)	1875.28 (808.17)	280.23 (72.17)	167.75 (79.13)
Detterence condition				
Low deterrence	16.17 (11.83)	2114.66 (670.81)	308.65 (63.07)	178.08 (89.89)
High deterrence	12.94 (16.36)	1657.25 (864.32)	275.71 (77.96)	175.16 (92.14)
Interactions				
No alarm x low deterrence	15.40 (13.21)	2201.25 (721.94)	328.04 (47.11)	194.25 (101.47)
No alarm x high deterrence	15.18 (22.17)	1607.41 (770.02)	282.95 (84.57)	176.65 (102.83)
Alarm x low deterrence	16.90 (10.63)	2032.19 (624.66)	290.18 (71.51)	162.69 (76.61)
Alarm x high deterrence	10.95 (8.64)	1701.84 (959.74)	269.24 (73.21)	173.67 (83.80)