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# Virtual reality-based retrospective think aloud (VR-RTA): a novel method for studying offender decision-making

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## Abstract

**Objectives** This article describes and tests a novel multi-method approach to examine decision-making: Virtual Reality-Based Retrospective Think-Aloud (VR-RTA). The VR-RTA method taps into the offender perspective and aims to enhance memory recall and information elicitation.

**Methods** We applied VR-RTA among a sample of incarcerated burglars ($N=200$) who scouted virtual neighborhoods to explore opportunities for burglary in immersive VR equipped with integrated eye tracking. Subsequently, they viewed a screen recording of their scouting process and simultaneously "thought aloud" about their assessment of the environment and decision-making strategies. Emerging themes were then further examined in an interview and linked to survey data. Recorded eye tracking data were used to examine burglars' attention towards environmental features to identify deterrent and attracting cues, and were triangulated with the survey and interview data.

**Results** Rich and detailed insights into participants' interpretation of the environment and their decision-making strategies were obtained. VR-RTA assisted in verbalizing automated cognitive processes and increased participant engagement by building rapport.

**Conclusions** As a multi-method approach able to capture in-the-moment considerations underlying decision-making during crime commission, VR-RTA offers potential to develop into an important tool for crime research. It is able to both overcome limitations of studies using retrospective methods, such as interviews and surveys, and contribute to the nascent field of criminological research using immersive technologies.

**Keywords** Decision-making, Mixed methods, Multi-method, Think-aloud protocol, Virtual reality, Eye tracking, Burglary, Offender perspective

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Those with prolific experience with offending are uniquely positioned to provide insight into the development of that behavior (Topalli et al., 2020). In criminology, interviews have long been regarded as the go-to method to tap into this insight (e.g., Maruna, 2001; Brookman et al., 2011; Miller et al., 2013; Sampson and Laub, 2003; Wright & Decker, 1994, Wright et al., 1995). However, interviews are subject to the inevitable degradation of memory recall. As time between crime commission and a subsequent interview passes, memory becomes blurred, details are lost, and timing is warped, diminishing the accuracy and completeness of the information obtained (Nee, 2010; van Gelder, 2023).

Ideally, researchers would be present at the moment an offense takes place and study offenders on the job, but ethical, practical, and safety considerations generally render this option unfeasible. One way to address some of the challenges plaguing retrospective research methods, such as interviews and surveys, is to reinstate the context of that behavior using immersive technologies, such as virtual reality (VR) that allow for studying behavior in real time. This allows for a realistic simulation of criminogenic environments, which offenders can navigate to demonstrate decision-making under circumstances resembling the conditions of a controlled behavioral experiment in a safe and ethical way (van Gelder, 2023; van Gelder et al., 2014). Nonetheless, whereas the rich data VR generates allows for a better understanding of conditions under which certain behavior occurs, by itself it cannot speak to *why* it occurrs. That is, reasoning underlying choice, interpretation of (aspects of) the environment, and offender motivation, are not captured by behavioral VR data, however finegrained these data may be. To tap into these factors, VR needs to be combined with other methods.

In this article, we propose and test a novel multimethod approach, Virtual Reality-Based Retrospective Think-Aloud (VR-RTA), that integrates VR technology with so-called think-aloud protocols, which involve research participants articulating their thoughts while carrying out a specific task or immediately following it (Simon & Ericsson, 1984). This method alleviates some of the constraints affecting interviews and other retrospective methods through its ability to study behavior in real time and reduces the temporal gap between (virtual) crime commission and data collection. Conversely, it enriches behavioral VR data through its ability to tap into reasoning and motivational processes underlying offender decision-making. Our aim is to illustrate the potential of the VR-RTA approach and to explain how it may be applied in crime research. Interview and survey data collected serve to triangulate research findings and provide validation for the proposed method.

We tested the VR-RTA method among a sample of incarcerated burglars who were invited to scout virtual neighborhoods for opportunities for burglary in immersive VR with integrated eye tracking. This process was screen-recorded and played back to them immediately following the scouting task. Throughout the playback, they were asked to "think aloud" about their decision-making during the scouting process. Below, we first describe the cognitive underpinnings of think-aloud protocols and the use of VR technology in crime research, prior to presenting our study and discussing findings. We conclude with a discussion of the more general potential of the VR-RTA method for crime research.

## Think-aloud protocol versus related methods

In research applying think-aloud protocols (TAPs), participants are instructed to think out loud whilst completing a task and to verbalize everything that goes through their minds while doing so (Ericsson & Simon, 1993; Güss, 2018). When individuals are asked to report on their decision-making during an action out of context, as is the case with interviews and surveys, they commonly tend to rely on implicit theories about how the world works in general, which may not accurately reflect how their actual cognitions drive their behavior (Branch 2000; Eccles & Arsal, 2017). By verbalizing thoughts during task performance, this limitation is addressed and real-time insight into the reasoning process is gained (Leighton, 2017). Furthermore, people may provide inaccurate reports about cognitions when asked about them retrospectively because they have only limited conscious access to such cognitions (Nisbett & Wilson, 1977; Wolcott & Lobczowski, 2021). By analyzing thought processes that occur *during* or *right after* an activity, TAPs can reveal important information about the decisions people make, how they interact with their environment, and what factors influence how they reach their goal (Wolcott & Lobczowski, 2021). Lastly, as highlighted by Nisbett and Wilson (1977), people often find it challenging to explain how and why they perceive or remember things. However, people are generally able to describe their own actions around the time they perform them, as occurs during a TAP. Overall, TAPs allow for a more effortless and detailed (re)construction of actions, and can provide a picture of relevant cognitive processes in real time (Reinhart et al., 2022).

TAPs exist in two different modalities: concurrent and retrospective. In concurrent TAPs, people think out loud whilst performing a task, and this is followed by a post-task interview (e.g., Meenaghan et al., 2018). The retrospective think-aloud (RTA) approach, which is the focus of this study, involves people first completing a task and subsequently reflecting on it while a recording of their performance is played back to them (Ericsson & Simon,

1993; Fox et al., 2011; Hertzum et al., 2009). An advantage of retrospective over concurrent TAPs is that the former carry less cognitive load and do not interfere with task performance. The verbal explanations people provide when viewing back the virtual re-enactment of their actions allow for a discussion of motivations and other factors influencing behavior in their real-life experiences, without disrupting the actual process. Consequently, retrospective TAPs allow for the preservation of natural behavior (van den Haak et al., 2004).

Although a common method for studying a range of different behaviors (Gregg et al., 2017; Kesler et al., 2016; Malek et al., 2017), the use of TAPs in crime research has thus far been limited. Some studies have used revisiting recent crime scenes as a method of enhancing participant engagement and ecological validity (Cromwell et al., 1991; Wright & Decker, 1994). However, without the added bonus of the re-enactment of the behavior under study, these methods still remain subject to the well-documented limitations of human memory (Nee et al., 2019). The advent of VR technology has provided novel possibilities to overcome these limitations.

## Moving closer to the action: VR in crime research

Several studies on criminal decision-making using virtual environments have been published in recent years, mostly focusing on burglars (e.g., Meenaghan et al., 2018; Nee et al., 2019; van Sintemaartensdijk 2022; McClanahan et al., 2024a). In one of these studies, Meenaghan et al. (2018) pioneered the use of concurrent TAPs to study incarcerated burglars' experiences while undertaking a simulated burglary on a laptop computer. This study demonstrated how their use can help elicit detailed information on burglar decision-making by facilitating memory retrieval. That is, re-enacting facilitates the mental recall of past incidents (Meade et al., 2019), and re-enactment from a first-person perspective connects such experiences more easily to other memories and relevant sensory information (Glenberg & Hayes, 2016). By scouting virtual residential neighborhoods and engaging in the active navigation of these neighborhoods, participants re-enacted prior behavior, thereby aiding the retrieval of memories related to their past burglaries in the real world. Furthermore, there is evidence that re-enacting behavior in real time using VR methodology can enhance engagement and disclosure among offenders and other groups (Kip et al., 2019; Nee et al., 2019).

The VR-RTA that was developed and tested for the current purposes builds on the work of Meenaghan and colleagues (2018) but takes a retrospective rather than concurrent approach. The retrospective nature of the VR-RTA method reduces cognitive load and minimizes reactivity compared to concurrent TAPs. That is, the verbal explanations offenders provide when viewing back the virtual re-enactment of their actions, allow for a discussion of motivations and other factors influencing their behavior in their real-life burglary activities, without disrupting the actual process. Additionally, instead of using a simulation presented on a computer screen, the present study makes uses of immersive virtual reality, which is experienced through a VR headset that fully immerses the user in the situation of interest, generating the impression they have stepped into it.

### The current study

This study was part of a larger research program, the Virtual Burglary Project (VBP), which studies burglar decision-making using virtual environments.[1] In the present study, we invited a sample of incarcerated burglars to navigate two different virtual neighborhoods with the task of looking for opportunities for committing a burglary.[2] One of the virtual neighborhoods was an exact virtual copy of an existing neighborhood in a city in the Netherlands; the other was designed to resemble a typical middle-class Dutch neighborhood. When the participants had finished navigating both neighborhoods, a screen recording of the scouting process in one of the neighborhoods was played back to them. During the replay, participants were invited to think out loud about the scouting process and to elaborate on the decisions they made throughout this process. The objective was to stimulate disclosure of information and to gain more insight into their thinking while "on the job."

The overall goal of the study was to illustrate some of the merits of the VR-RTA method for the study of crime. We pursue this goal in two steps, each addressing a separate research question: (1) To what extent do the present results align with established findings from prior research? and (2) To what extent does the VR-RTA complement and extend the information extracted from other data sources? To address the first research question, following a thematic approach, we examine to what extent our findings overlap with findings from previous research on burglary cues (for reviews, see Nee, 2015; Peeters, 2013). This work has identified four different categories of cues related to burglar target selection, namely layout, security, occupancy, and affluence. If the same patterns also emerge in the current data, we interpret this as support for VR-RTA and thus contributing to its validity. To

[1] In the Virtual Burglary Project (VBP), incarcerated burglars, and sometimes other groups of participants, are instructed to scope virtual neighborhoods for opportunities to burgle, select a target to burglarize, and/or to commit a burglary in VR (e.g., Nee et al., 2015, 2019; van Gelder et al., 2017; van Sintemaartensdijk et al. 2020, 2022).

[2] In both neighborhoods, different experimental guardianship manipulations were implemented to study their deterrent effects. In the first neighborhood, light and sound manipulations were implemented. In the second neighborhood, the intervention consisted of so-called Watching Eyes signs. Results of these manipulations are reported separately elsewhere.

address the second research question, we explore to what extent information extracted with the VR-RTA method aligns with and adds to eye tracking, interview, and survey data that were also collected as part of the current research effort. The VR system was equipped with an integrated eye tracking system, which recorded what features of the environment the participants focused on and for how long. This allowed for objectively establishing the extent to which specific features, such as burglary deterrents and attractors (see Method section for details), were noticed and paid attention to by the burglars. By way of triangulation, we subsequently examined to what extent the burglars in our study also mentioned such features in the VR-RTA and the interview, and to what extent observation of the burglary deterrents and attractors was related to perceptions of the neighborhood and intentions to burglarize, which were measured in a survey.

## Method

### Participants

Participants were 200 incarcerated male burglars (age range 19–61 years, $M_{age} = 33$ years) with different degrees of burglary experience serving prison sentences for various offenses (not only burglary) in the Netherlands. Participants could be included if they were 18 years or older, had committed at least five burglaries in their lifetime, did not have a history of epilepsy, and were not currently taking heavy medication (such as anti-psychotics). Burglary involvement was established through checking previous conviction data, consulting prison staff, and self-reported offending history. Participants were recruited in four different male-only prisons. Recruitment took place through leafletting prison wings, and through referral by other inmates and prison staff. It was emphasized during recruitment that participation in the study was entirely voluntary, that the researchers were not affiliated with the prison authorities, or the criminal justice system more generally, and that participating or not participating would not have any consequences for their sentence. In exchange for their cooperation, participants were compensated with €5 in line with prison policy. Ethical approval was obtained from the Ethics Committee of Leiden University. All participants signed an informed consent form.

### Procedure

Data collection occurred in a dedicated room in the participating prisons with only the researcher and participant present. Potential subjects received detailed information on confidentiality and were given the opportunity to ask questions prior to participating. After consenting, each participant scouted the two different virtual neighborhoods. For both neighborhoods, they were instructed to scout them for opportunities for committing a burglary there. Following the scouting of the second neighborhood, participants filled out a survey with questions regarding feelings of presence, deterrence, perceived guardianship, intention to burglarize, and other variables relevant to the larger Virtual Burglary Project (results reported elsewhere). This was followed by the think-aloud task. The session ended with a semi-structured interview and a brief survey with questions about burglary expertise. Subject to participant consent (90%), verbalizations during the think-aloud process and interview were audio-recorded (and deleted after transcription). At the end of the interview and survey, participants were debriefed and support was offered in connection with any issues that arose during the process. The entire session took 45 to 60 min.

#### VR-RTA instructions

The virtual scouting process in one of the two neighborhoods was screen-recorded based on random selection (1:1).[3] Before starting the playback of the recording, participants received the following instructions from the researcher:

> *I would like to learn a bit more about how you evaluate a neighborhood. I am particularly interested in what things you find important when you make decisions related to burglary. We will use a method that is called the 'think-aloud' method. I will now show you the recording of your VR experience in the first [second] neighborhood. The idea is that you simply tell me whatever comes to mind when you watch the recording. Just say everything that comes to mind, irrespective of whether you think it is relevant or not. I may also ask you some questions during the replay of the recording.*

The researcher aimed at minimizing interference during this process. Only in cases where participants did not verbalize any thoughts, were prompts used to encourage disclosure. Examples of prompts included questions about the participant's chosen direction, actions taken at specific locations, prolonged periods of non-movement, and reasons for changing direction.

### Materials

#### *Virtual environment*

Both virtual neighborhoods ('Neighborhood A' and 'Neighborhood B') (see Figs. 1 and 2 resp.) were developed using the Unity Pro engine (version 2017.3.1f1) and viewed through the VIVE Pro Eye head-mounted display,

[3] To reduce the burden on participants, the scouting process was recorded for only one of the two virtual neighborhoods.


**Fig. 1** Top view, aerial view, and two angles of the first-person view of Neighborhood A in the virtual environment


**Fig. 2** Top view, three angles of the first-person view of Neighborhood B in the virtual environment

which has built-in eye tracking. Participants wore headphones delivering immersive spatial audio and navigated the virtual environment using a game controller.

#### *Eye tracking*

In both neighborhoods, a set of items (hereafter: "Easter Eggs") that may act as burglary attractors (e.g., open window, ladder, packaging of expensive items) or deterrents (e.g., beware of dog sign, alarm box) were distributed across the neighborhood (see Fig. 3). Eye tracking was used to assess whether these Easter Eggs had been noticed by participants. Eye tracking algorithms use specific criteria to determine where a person is looking, which help us understand what draws a person's attention and what information they are actively processing in their mind.

#### *Survey*

The scouting process for each of the neighborhoods was followed by a brief survey.

Two items were used to assess the likelihood of committing a burglary: "I would break into this neighborhood" and "This neighborhood is not attractive for burglary" (reverse-coded). Five items assessed perceived guardianship, for example, "Residents in this neighborhood are vigilant" and "I had a feeling of being watched

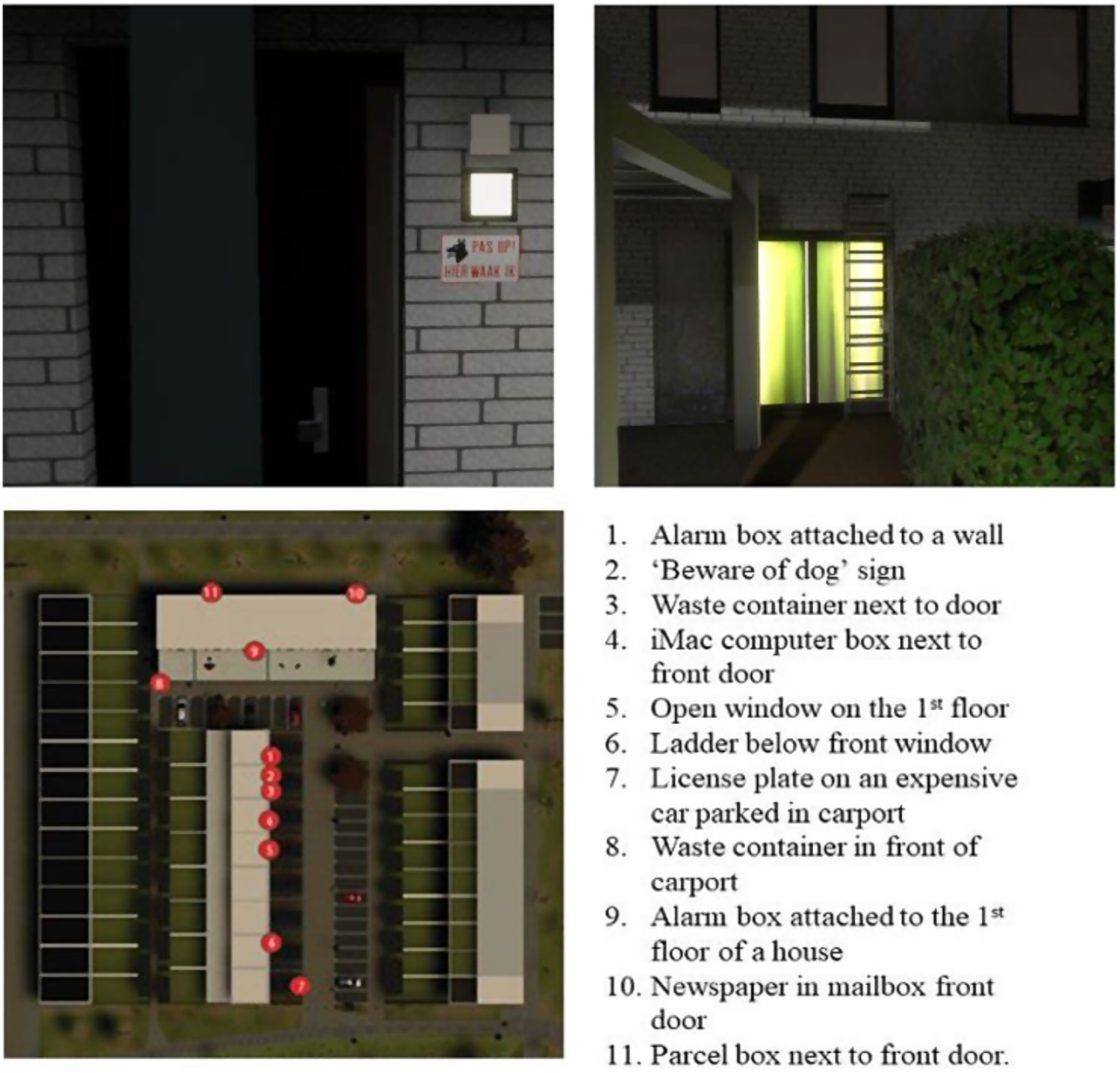


**Fig. 3** Easter Eggs in Neighborhood A. Beware of dog sign, ladder under front window, and the placement of the Easter Eggs

when I walked around." The items were answered on a Likert-type scale ranging from 1 (Strongly disagree) to 5 (Totally agree). Each of the scales showed adequately reliability (Intention, Spearman-Brown = 0.64 / Guardianship, Alpha = 0.65).

#### *Semi-structured interview*

Three of the five questions in the semi-structured interview that followed the VR-RTA asked about participants' approaches to committing burglaries in real life in the period(s) when they were active as burglars prior to incarceration. The interview questions were: "How do you decide on where you burgle?", "What things about a house or neighborhood attract you?", and "What things about a house or neighborhood deter you?".

#### *Coding Strategy for the RTA Data*

RTA data were analyzed following a thematic approach (Braun and Clarke 2006), using MAXQDA 2022 software (VERBI Software, 2021). Coding was performed independently by two coders. Intercoder agreement was 95%, which can be considered very high (Hallgren, 2012). Disagreements between coders were resolved through consensus.

During the coding process, burglary cues, which reflected aspects of the environment that burglars talked about during the RTA task, were classified into codes. The analysis of the burglary cues consisted of six phases (see Fig. 4). Phase 1 involved familiarization with the RTA data and understanding possible patterns emerging from these data. Phase 2 involved the generation of initial codes, i.e., features of the data that seemed of interest and that can be assessed to gain a better understanding of the phenomena under study (Braun and Clarke 2006; Michel-Villarreal et al., 2021). The outcome of this phase consisted of a list of independent codes across the data. Phase 3 entailed reviewing these codes and grouping them into "themes." In this phase, consideration was given to "how different codes may combine to form an overarching theme" (Braun and Clarke 2006:18). Such themes can be described as significant concepts that provide a link to group substantial portions of data together (DeSantis & Ugarriza, 2000). Subsequently, phase 4 consisted of reviewing the "coded data extracts for each theme to consider whether they appear to form a coherent pattern" (Braun and Clarke 2006:9). Phase 5 involved naming and defining the themes to group the coded data, and phase 6 comprised the writing up of the categories and subcategories of burglary cues (see Figs. 5 and 6).

The initial aim of analyzing the RTA data was to investigate whether burglary cues identified in prior research (for reviews, see: Nee, 2015; Peeters, 2013) also emerged in the current study, which would answer our first research question. Additionally, the RTA data was utilized in an exploratory manner to highlight the usefulness of retrospective thinking exercises in supplementing interviews, focusing on burglars' decision-making processes and the characteristics that make houses appealing targets. In this way, the second research question focuses on a descriptive analysis of the advantages provided by the VR-RTA method.

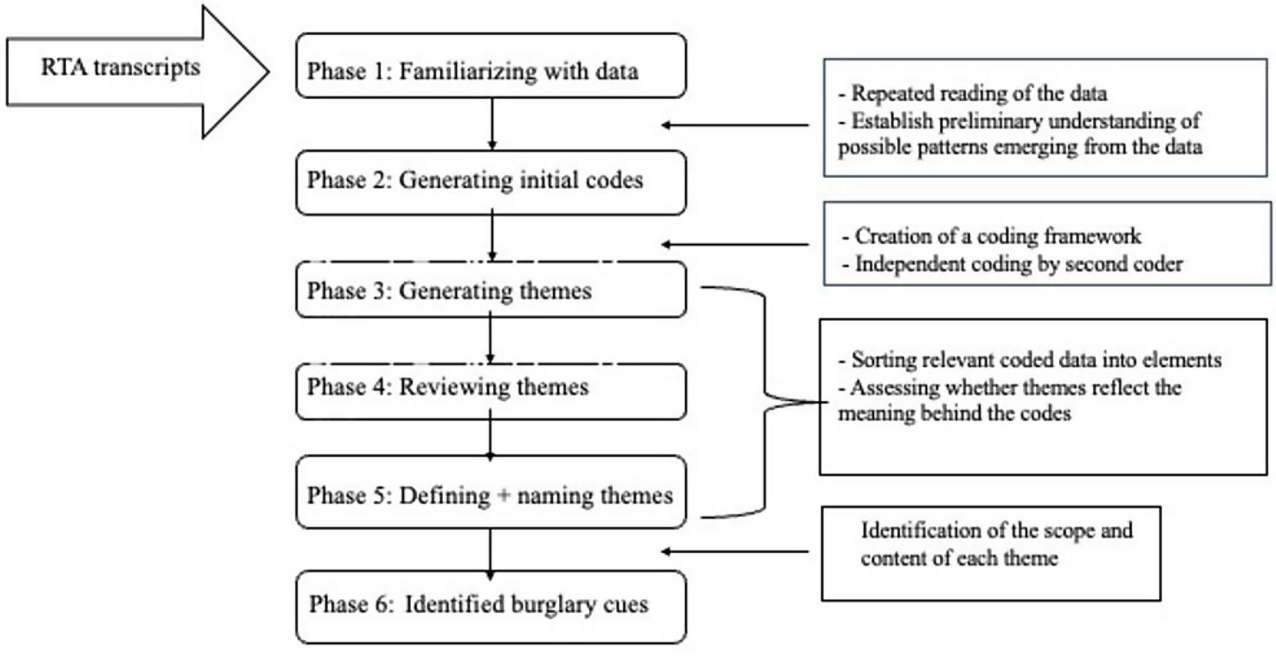


**Fig. 4** Thematic analysis process (adapted from Michel-Villarreal et al., 2021)

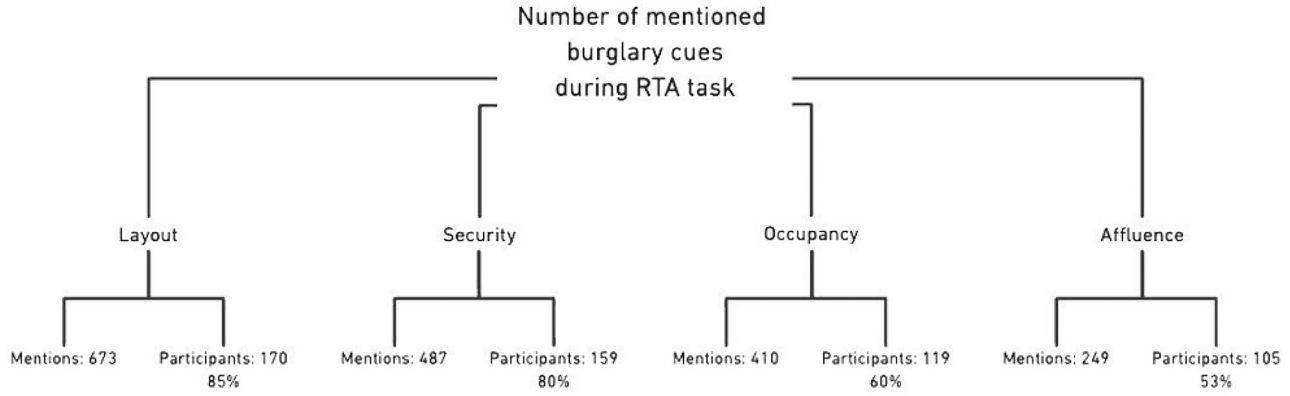


**Fig. 5** Number of mentions per participant (%) and per burglary category, total of 1,991 mentions across participants ($N = 200$)

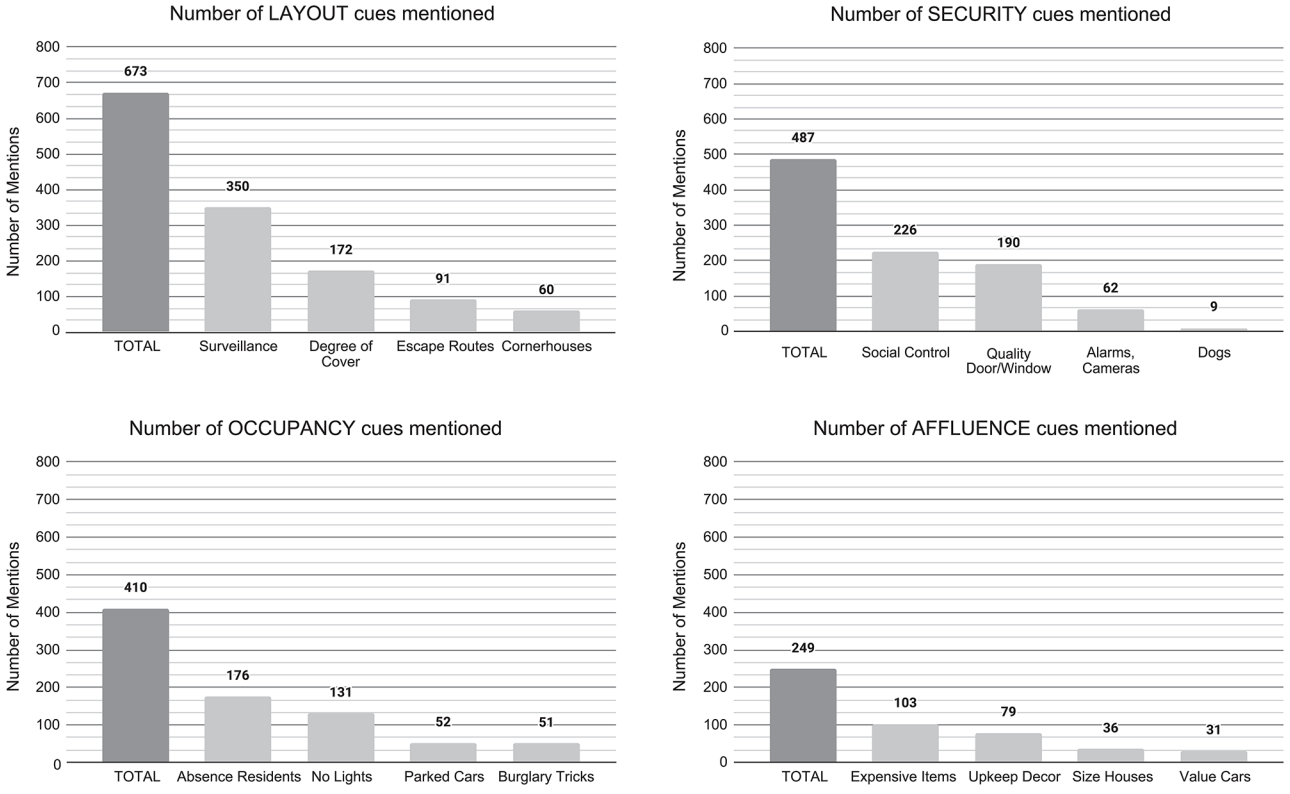


**Fig. 6** Number of mentioned burglary cues of each subcategory across participants ($N = 200$)

## Results

The results are organized into two different parts. In the first part, which addresses research question 1, we examine to what extent our findings regarding burglary cues align with previous research. The second part addresses research question 2 and explores to what extent information extracted with the VR-RTA method complements the interview and eye tracking data.

### Research question 1: Do RTA findings regarding burglary cues align with prior research?

Prior research has identified four different categories of cues related to burglar target selection: layout, security, occupancy, and affluence. Layout cues regard features, such as degree of cover, presence of escape routes, and surveillability. Security cues include features related to security measures and target hardening, such as the presence of alarms and cameras, the quality of doors, and window locks. Occupancy cues are features signaling the presence of people in the immediate environment, such as the presence of a car, or light inside a house. Affluence

cues include the availability of expensive items, the size of a house, and decor. We examined whether and how frequently these cue categories were mentioned during the RTA task. Figure 5 provides an overview of the total number of mentions of the four different burglary categories and shows how many of the participants mentioned them. In addition, Fig. 6 displays the categories and their subcategories, and the percentage of participants that mentioned them.

### Layout

In previous research (e.g., Bennet and Wright, 1984; Langton & Steenbeek, 2017; Nee & Meenaghan, 2006; Wright & Decker, 1994), layout cues were found to significantly influence burglars' decision-making. In the current study, of all four categories, layout cues were mentioned most frequently by participants (170 participants, 85%; see Fig. 5), with cues mentioned predominantly relating to the subcategory *surveillability* (see Fig. 6). Burglars mentioned lines of sight and the ease of being spotted in particular (e.g., by neighbors or passersby). In addition, and related to *surveillability*, *degree of cover* and *escape routes* were also frequently mentioned, often as a first remark upon entering the neighborhood. This aligns with prior work indicating that objects in the environment that provide cover are ideal for burglary, because they reduce visibility, and thereby the risk of apprehension (Bennet and Wright, 1984; Wright & Decker, 1994; McClanahan et al., 2024b). Similarly, the availability of escape routes also increases the chances of a succesful exit following the burglary (Nee and Taylor, 2000).

In this study, frequently mentioned features that provide both cover and allow for escape include distance to and detachment from other properties, availability of side and rear access points, and the presence of alleys (e.g., at the rear of housing rows). Furthermore, (lack of) illumination, amount of vegetation around a house, and structures such as carports or garages were also mentioned as features that provide cover by reducing visibility. Quotes are provided in Table 1.

### Security

Security cues were also mentioned frequently (159 participants, 80% of the sample). Predominant subcategories mentioned related to *quality of doors/windows* (e.g., estimated time required to break open locks, target hardening). These findings are congruent with results reported in the research literature on security cues (e.g., Newton et al., 2008). Furthermore, burglars paid particular attention to *social control* (i.e., the presence of people in the neighborhood who may act as guardians). They talked about social control systems that might be active, such as neighborhood watches, vigilant parents, and

**Table 1** Examples of layout cues mentioned

| |
|---|
| Escape routes |
| "*You should also carefully consider the side streets in a neighborhood; is it located on a busy road or not, how easy is it to escape? You need to determine your escape routes for the car*." (Participant 121) |
| Surveillance |
| "*I noticed this was a difficult neighborhood. There is light everywhere and people are watching you from everywhere. You get that in cities. I used to go to small villages, where houses and farms lie 500 meters apart from each other, so nobody can see you doing things.*" (Participant 20) |
| Degree of Cover |
| "*You just stand out very quickly here, when you walk down that street... the other neighborhood was much darker, there you have more alleyways. More places to hide."* (Participant 168) |
| Corner houses |
| *"Corner houses, actually always, there you only have one neighbor. Furthermore, you also know that corner houses are more expensive."* (Participant 68) |

communication between neighbors. Other security measures, such as cameras, alarms, or the possible presence of a dog were also mentioned, although less frequently (Tables 2, 3 and 4).

### Occupancy

The (possible) presence of residents was mentioned third most (119 participants, 60%), aligning with ample prior evidence indicating that burglars prefer unoccupied houses over occupied ones (Coupe and Blake 2006; Hearndon and Magill 2004; Wright & Decker, 1994). Frequently mentioned subcategories to establish occupancy were lights being on in a house or cars being parked in front of it. Since participants were told prior to entering the VR that it was 5:30 pm in the virtual neighborhood, they indicated that this was a time that many residents would be home or about to come home, making this a sub-optimal time for committing burglary. Additionally, burglars mentioned using tricks or technology to monitor residents' routines, for example by sticking small items (e.g., toothpicks) in the door, using a hidden camera to register residents' routines, or ringing the doorbell with a pretext.

### Affluence

Of the four categories, affluence cues were mentioned least often (105 participants, 53%). In this category, burglars primarily focused on valuable items that were visible from outside a house to determine wealth. Upkeep was also frequently mentioned within this category. House size and the value of parked cars were also remarked on, but less frequently. These findings align with previous research by Peeters (2013), who reported mixed results on how affluence influences burglar risk-taking and target selection.

Combined, the four different categories of burglary cues (i.e., layout, security, occupancy, affluence) that had been identified in earlier research also emerged in the present study. In line with prior work, layout cues were most frequently mentioned, with an emphasis on surveillance. Other frequently mentioned subcategories, such as social control, target hardening, and presence of residents, also aligned with previous work (e.g., Nee et al., 2019; Peeters, 2013).

**Table 2** Examples of security cues mentioned

| |
|---|
| Quality of doors and window locks |
| "*In principle this neighborhood is quite well secured; high doors, fences. You are always looking at which type of locks people have, which type of door. Is it made of wood or plastic? Is there a window open, or casement that is easy access with a screwdriver? These days a lot of houses have plastic window frames, (…) very easy to get in, same with doors. Materials matter a lot.*" (Participant 67) |
| Alarms/Cameras |
| "*People are guarding their homes with a smart doorbell nowadays, and then they will get instant messages on their phone. Those doorbells can also record sound from far away, so you need to always stop talking when you are with others, because then they will have evidence.*" (Participant 22) |
| Dogs |
| (..) "*This house has a clearly visible sign that says, 'Beware of the dog'. This makes people that notice this sign automatically more cautious.*" (Participant 41) |
| Social Control |
| *"(…) because you can just see from this residential area that many people can look out of their windows; those kinds of people live here. People here look out for each other, pay attention to things that stand out."* (Participant 53) |

**Table 3** Examples of occupancy cues mentioned

| |
|---|
| Absent Residents |
| "*I was looking whether I would see indications that someone is at home or not. You can determine that by looking at the lights or if there are parked cars or not. If the lights are off, you assume residents are not at home, but you always check if there is also movement. Lights on are not a direct indication that someone is home, but if the car is there, that is a good indicator, so you always check that first.*" (Participant 26) |
| Burglary tricks |
| *"I would just ring the bell to see if the residents were home. If they would open, I would just ask 'does Johnny live here?' Easy. Or just stick something in the door like a toothpick."* (Participant 80) |
| No lights |
| *"Look, this house has all the lights off in the back and in the front, so no one is home, at least that's what you assume."* (Participant 165) |
| Parked cars |
| *"Well, those parking spaces actually indicated that no one was home or visiting." (*Participant 1) |

**Table 4** Examples of affluence cues mentioned

| |
|---|
| Expensive items |
| "*I saw some iMac boxes laying outside the house. Then you know they are spending money. Who has and who hasn't, that is the first thing you need to find out*" (Participant 119) |
| Upkeep Décor |
| "*Green Egg (BBQ) in the garden, some have a jacuzzi in their backyard, expensive garden furniture. So, these people have money*." (Participant 153) |
| Size Houses |
| "*No man, I wouldn't break into this neighborhood (...). It's a working-class neighborhood. If you're going for burglary, you're going for money, and that's not found here*." (Participant 197) |
| Value Cars |
| *(..) "You also look at the cars, what value they have. Here, I see a beautiful Volvo, and here, a nice Mercedes."* (Participant 64) |

**Research question 2: can VR-RTA complement interview and VR eye tracking data?**

In this section, we focus on exploring how VR-RTA can usefully complement eye tracking, survey, and interview data, and demonstrate some of the advantages of combining VR with think-aloud protocols. This includes a comparison of VR-RTA data with responses to interview questions to explore how the former can be used as a tool for eliciting information.

### Combining VR-RTA with eye tracking and survey data

Eye tracking data provide information about what aspects of a setting or environment people pay attention to, what is noticed, and what escapes attention. In this sense, eye tracking technology allows researchers to see through the eyes of participants in an almost literal sense. Here, eye tracking was used to identify the extent to which items that may act as burglary attractors or deterrents for burglary, "Easter Eggs", that were dispersed throughout both neighborhoods (see Fig. 3), were noticed by participants. Eye tracking data were linked to the think-aloud and survey data to understand gaze patterns and how they are linked to intentions to burglarize, and evaluations of the neighborhood in terms of risk and perceived levels of guardianship which were measured in the survey.

Correlation analyses revealed significant relationships between the number of Easter Eggs spotted and intentions to burgle (Neighborhood A: $r=.25$ $p=.00$; Neighborhood B: $r=.16$, $p=.02$), and between number of Easter Eggs spotted and perceived feelings of guardianship in Neighborhood A ($r=-.16$, $p=.00$). Although providing relevant information burglars use to base their evaluations and decision on, these results by themselves do not speak to the underlying decision-making processes of the burglars. By adding a think-aloud protocol to our VR-design, we were able to uncover more of the rationale behind the eye tracking patterns. In the think-aloud exercise, burglars spontaneously mentioned that the Easter Eggs they spotted influenced their judgments about whether a house or neighborhood was an easy or attractive target for burglary. For example, they inferred from letters sticking out of a mailbox or parcels lying in front of a house, that residents were likely absent, leaving targets vulnerable. Similarly, ladders that were placed in sight around houses or an open window above a carport were interpreted as indications that people felt safe in the neighborhood and/or were careless when it came to security. From this, participants inferred that there were likely also other vulnerabilities that could be exploited (see also the quotes in Table 5).

Considering these findings and considering the combination of eye tracking and VR-RTA in a broader context, the point here is that, whereas the eye tracking data provide a reliable indication that one or more salient features has been noticed (or not), it cannot speak to the importance of the feature(s) as a factor influencing decision-making or provide information on why the feature is important. Here, the combination of methods used provides information not just that specific Easter Eggs were spotted but also the meaning and importance attached to them and hence sheds light on their relevance as burglary attractors or deterrents. The RTA also provided some indication as to how important the Easter Eggs were when scouting a neighborhood because more than half of the participants spontaneously mentioned one or more of them during their RTA task (see Table 5).

Another interesting finding is that the VR-RTA provided information on which other aspects in a neighborhood burglars pay attention to and how they reflect upon them. Many burglars based their assessment of the level of social control in a neighborhood on items lying outside houses (see Table 6). For example, it was mentioned that in neighborhood A people tended to leave valuable items (e.g., kids' toys, unlocked bikes or scooters, building material) lying outside their homes. Burglars interpreted this first as a sign of occupancy and also saw it as

**Table 5** Easter Egg quotes

| |
|---|
| *"The waste containers here are also perfect. You can move them anywhere, climb on things, but also use them to hide behind*." (Participant 149) |
| *"They should never have placed this ladder here, of course. The ladder is an invitation to enter."* (Participant 146) |
| *"This window open here is just stupid. You wouldn't put a carport under an open window to a room, right? That's really foolish, foolish people. That's asking for a break-in."* (Participant 107) |
| *"There are garbage bags outside here, either they're lazy or they haven't been here for a while. I see a parcel box laying outside, I definitely need to see what's inside or has been inside the box. Knowing that you can estimate the value of items the residents have in their house."* (Participant 117) |

**Table 6** Quotes complementing eye tracking data indicating what helps burglars estimate levels of social control

| Items in a neighborhood determining social control |
| --- |
| *"People feel safe in this neighborhood. They're cool with leaving stuff outside. Not too many cars around. It's nice for them, feeling safe and all. For me, it is convenient. People just leave things lying around in this neighborhood. It's the kind of place where they're comfortable, so you can tell from the vibe and all the stuff left outside. So, they will leave everything open, you know?"* (Participant 189) |
| *"Another thing to keep in mind when there are a lot of kids around is that people with children tend to keep an eye on others with kids and their children. So, in this neighborhood there are more eyes on the lookout."* (Participant 183) |
| *"Over here, the area with construction materials – people don't just leave that lying around casually; it's quite noticeable. Either someone is keeping an eye on it, or if not, you could easily get in just with what's here. Look, these folks have bought expensive stuff, so yeah, it's almost inviting me to go inside. They probably aren't paying as much attention to putting things away and locking doors when they've got pricey items."* (Participant 200) |
| *"Young people in this neighborhood, you see toys and stuff scattered everywhere – scooters, it's a residential area. Not an attractive neighborhood, I must say. You can be seen from everywhere. People with kids keep an eye out for suspicious characters in the street, so if you're walking around here, you're easily noticed. It's quieter too, people are indoors earlier, so there are more folks at home. (...) Those who hire people for painting jobs leave their ladders lying around because everything is so safe here. So, if something fishy is going on, people are attentive."* (Participant 197) |

indicating that people trust each other and that there is a considerable level of social control in their area. Toys signaled the presence of small children, which was interpreted as a sign of elevated guardianship, as people with small children and their neighbors tend to keep an eye open to watch over the kids. In sum, burglars seized on multiple items in the neighborhood to determine its attractiveness for committing burglary and gauge levels of social control.

#### Combining VR-RTA with a semi-structured interview

Results discussed in the previous section suggest that the VR-RTA approach helps elicit information that may otherwise be left undisclosed. In this section, we explore whether VR-RTA also enhances participants' motivation to disclose information in addition to points raised in the interview. In principle, similar to the analysis of CCTV footage, VR screen recordings can be replayed, paused, and slowed down an infinite number of times and provide a frame-by-frame account of the events as they unfold (Philpot et al., 2019). As a consequence, they allow for dissecting a decision-making sequence and for asking clarification questions in real time. However, unlike analyzing CCTV footage where researchers do not have access to people featured in it, VR-RTA enables researchers to link observations to other relevant factors pertaining to individuals, including psychological states, motivations, dispositions, and background characteristics (van Gelder, 2023).

In the present study, participants tended to give short, condensed answers during the semi-structured interview when asked about what attracted or deterred them in the virtual neighborhoods. By contrast, during the RTA, information tended to be more detailed, elucidating different steps in the decision-making process without necessarily requiring prompts. The VR-RTA findings also highlight the importance of environmental factors affecting decisions that are difficult to capture in traditional interviews that rely on memory.

By way of example, consider some of the differences between responses to the interview question "What attracts you in a neighborhood?" and the information elicited by the RTA task. In the interview, participant 50 responded: *"I only look at cameras"*. The RTA data from the same participant were much more detailed: "*There are several things I pay attention to. Windows that are*

*open, gardens. It is difficult here because I can't look over the fences. I would do that to check if the residents were home. This neighborhood is difficult because everyone can monitor each other, you are in the line of sight from all the houses. You have to stay in the dark and avoid the lights. A lot to pay attention to.*" Participant 72 responded to the same question in the interview: "*When I receive tips or it's holiday time.*" But in the RTA, the same participant said: "*This dark alley is ideal for scouting, very attractive—easy hiding, limited police access, multiple escape routes. Good targets here. If there would be dogs and a lot of lights, those are a no-go*" The interview answer of Participant 94 to the same question was equally short: "*Wealth.*" However, the RTA from the same participant revealed valuable insights: "*This neighborhood offers abundant hiding places, making it attractive for cover. Limited social activity means fewer people outside, with families as you can see from the toys lying around. Easy balcony access for break-ins; a small, long alley provides good cover. The quiet, boring atmosphere stands out; I prefer busy neighborhoods like in Amsterdam for blending in.*"

In a similar vein, interview responses regarding deterrent factors in neighborhoods also tended to be brief. Conversely, during their RTA participants emphasized the importance of several facets determining surveillance, social control, and deterrence. Contrasted with the interview answer "*Nothing deters me*" from Participant 53, the RTA from the same participant revealed a more nuanced attitude: "*In a community where people watch and monitor each other, good neighbors are vigilant about suspicious activities, so you have to be careful about the residents.*" Compared to the interview answer "*Nothing deters me, couldn't care less*" Participant 70 revealed different insights during the RTA: "*Vigilance and surveillance are problematic in this neighborhood. Close-knit neighbors oversee everything, making breaking in too risky. No, I wouldn't break into this neighborhood, having too many eyes is dangerous.*" Similarly, the interview answer "*Nothing deters me, I can avoid everything*" from Participant 129 was nowhere near as insightful as the RTA from the same participant: "*Avoiding being visible is crucial. This neighborhood's lack of attractiveness stems from houses being too close to each other, which enables residents to monitor each other closely.*" In the same way, the interview answer "*Nothing deters me, if it is worth it there is no fear*" from Participant 182 was complemented by insightful details during the RTA: "*Child-friendly neighborhoods pose risks. Vigilant parents, more people at home, and neighbors actively watching out make it too risky.*"

These examples demonstrate the importance of community dynamics in burglars' decision-making processes, something which was not fully reflected in the interview responses. Furthermore, they demonstrate how the use of VR-RTA can provide valuable and detailed insights into the decision-making process of offenders. By allowing burglars to reflect on their actions using the RTA method, we tap into their cognitive process, making it easier for them to talk about their methods and resulting in rich and detailed information.

## Discussion

We introduced a novel multi-method approach, VR-RTA, that integrates retrospective think-aloud protocols with virtual reality methodology with integrated eye tracking to gain insight into offender decision-making processes. We illustrated the method among a sample of incarcerated burglars, who reflected on their actions from a first-person perspective after scouting a virtual neighborhood for opportunities to commit a burglary. Allowing burglars to reflect on their actions whilst observing their own experience makes it easier for them to elaborate on their choices and to verbalize cognitive processes while on the job. That is, it captures "in-the-moment" considerations underlying decision-making during the crime commission process. The results demonstrate how the application of VR-RTA to the study of criminal behavior can provide relevant insights into the decision-making processes of offenders and complement findings from other data sources.

The VR-RTA method overcomes several challenges facing conventional approaches to studying criminal decision-making. First, by letting participants think out loud, it assists in the verbalization of decision-making processes that have become automated and are therefore not subject to deliberate retrieval through interviews or surveys. Second, as the screen recording is played back immediately following the action, the time lag between the (virtual) crime and the subsequent data collection is reduced from what is commonly a period of months or even years to a mere few minutes, thus overcoming problems related to retrospection and memory degradation. Beyond its ability to reduce bias due to participants' limited recall when reconstructing events, this also reduces possibilities for intentional fabrication while describing an event. Third, this approach also adds to virtual reality research and observational research as it allows for discussing specific participant behavior with them, rather than having to rely solely on behavioral or observational data. Lastly, VR-RTA turned out to be an effective way to build rapport between the researchers and the participants.

The first research question regarded the extent to which the results in this study align with established findings from prior research into the cues that guide the decision-making of burglars. The four different categories of

burglary cues (i.e., layout, security, occupancy, affluence) that had been established in earlier research also emerged in the current study. In line with prior work, layout cues were most frequently mentioned with an emphasis on surveillance. Other frequently mentioned subcategories, such as social control, target hardening, and presence of residents, also aligned with prior work (Nee et al., 2019; Peeters, 2013). These findings can be interpreted as supporting the validity of the VR-RTA method. Regarding the second research question, the VR-RTA method was shown to extend and complement interview and VR eye tracking data in several meaningful ways. First, the RTA task contributed to understanding the "why" behind gaze direction and spatial data. Second, the VR-RTA method elicited more detailed information, not only pertaining to the exploration of the virtual neighborhoods but also about the modus operandi of the research participants when "on the job" in the real world.

### Limitations and future directions

Inevitably, this study was also characterized by limitations that merit discussion. First, we were not able to quantify the extent to which our method enhanced participants' motivation to disclose information. Future studies should seek to quantify the degree of the incremental value of the VR-RTA method, for example by adding a control condition consisting of an interview but without a think-aloud protocol. Second, and related to the former, future research could subject the VR-RTA to a more formal analysis of discriminant and convergent validity. Third, it is important to acknowledge that committing a "virtual burglary" is not the same as committing an actual burglary. Despite the realism of the virtual neighborhoods in this study, and one of them being a virtual copy of an existing neighborhood, and despite prior research showing that burglars in virtual environments operate in similar ways as in real life (Nee et al., 2015, 2019; van Sintemaartensdijk et al., 2022), general transferability of (criminal) behavior in VR to behavior in the real world is not a given. Finally, participants did not physically walk through the virtual environment, but used a game controller to navigate it instead. Future studies could consider using treadmills so that participants actually engage in walking to render the experience even more realistic and immersive.

## Conclusion

The VR-RTA method has potential as a tool to complement existing approaches to studying crine. It can help unveil cognitive process underlying criminal decision-making and allows researchers to access motivations behind specific behaviors that would otherwise remain undisclosed. In this way, the method provides a firsthand offender perspective and allows for examining crime in action. The present study serves as a first illustration of how think-aloud protocols can be integrated with VR in research designs. It is our hope that VR-RTA will be implemented across the field and become an important instrument in the criminological toolkit.

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The data used in this study can be made available upon reasonable request.

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