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ARTICLE

Environmental factors influencing target selection for residential burglary: experimental study using virtual reality

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Abstract

Data on the decision-making process of residential burglars at the micro-level are scarce. Furthermore, to the best of our knowledge, none of the related studies have investigated multiple relationships between the design features of a target, a burglar's assessment of effort and risk involved in the crime, and the final decision on target selection. This study aimed to test the hypothesis that a burglar's judgment of how difficult (ease of intrusion) and how risky (risk of detection) it would be to break into a certain target may mediate the relationship between the target's design features and target selection. The experiment using virtual reality was conducted to obtain more credible data by maximizing the immersion of participants, and the collected data were analyzed using path analysis. The results showed that the assessment of ease of intrusion and risk of detection for a burglary target served as mediators between the design features of the target and the decision on target selection. This study also found that the ease of intrusion and risk of detection were not evaluated independently but instead had influential relationships. These results suggest that when developing design strategies for burglary prevention, it is important to check the overall level of ease and risk of the possible intrusion routes of a target and their correlation by considering various environmental factors around the intrusion routes.

Keywords Virtual reality · Residential burglary · Target selection · Detached housing · Design strategy · Crime prevention

1 Introduction

According to the Federal Bureau of Investigation (FBI, 2018), burglary offenses accounted for 14.6% of the total number of violent and property crimes in the United States, meaning that burglary was the second most frequent crime after larceny-theft (62.1%). However, the

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burglary clearance rate (13.9%) was not as high as the rates of other crimes, such as murder and nonnegligent manslaughter (62.3%), aggravated assault (52.5%), rape (33.4%), robbery (30.4%), and larceny-theft (18.9%). Besides, burglary and break-ins are the most feared crimes by the public (Bullock et al., 2009; Ceccato, 2016; Warr, 2000). Victims of burglary experience financial damage, anxiety, and contraction in the spatial and temporal range of daily life. Numerous studies, especially in the field of social science, have attempted to determine the social and physical indicators influencing burglars' decision-making with the aim of presenting crime prevention strategies.

One dominant research framework for understanding residential burglars' behavior assumes that, when choosing a target, they go through a spatially structured, hierarchical, and sequential selection process (Brantingham & Brantingham, 1984). First, they select an area to commit a crime at the level of the neighborhood (macro-level); then, they determine a suitable street within the selected area, which is called the level of the block (meso-level); and finally, they identify the best house to break into and burglarize (micro-level).

Most empirical studies on residential burglary using crime records, community surveys, and census data have been predominantly conducted at the macro-level because most of the readily available data are macroscopic (e.g., Breetzke et al., 2014; Clare et al., 2009). Thus, physical and social indicators affecting burglary from a macroscopic perspective have been relatively well established. However, the studies at the house level are fairly limited. The smaller the area that burglars choose, the greater the number of detailed factors that influence their decisions (Bennett & Wright, 1984; Peeters, 2013). Since these house level factors can be directly controlled by residents and designers, it is important to understand how burglars make decisions at the micro-level in order to come up with useful design and management strategies for burglary prevention.

Studies on the house level tend to perform a questionnaire survey, interview, or experiment because crime records and environmental information at the micro-level are rarely available. Frequency, correlation, and/or regression analysis have been usually used to find the relationship between environmental features of a target (such as the location of an entrance door, the number of floors, the size of a house, the distance between a house and the nearest street corner or intersection, and the closeness of facilities) and the decisions of respondents.

The rational choice theory (Cornish & Clarke, 1986), which explains how offenders decide whether to commit a crime and how they select their targets, has provided an essential theoretical basis for the relevant research. This theory suggests that criminals select a target expected to produce the best outcome by comparing their decisions' costs and benefits (Bottoms, 2007; Elffers 2004). In order to maximize the expected profits while minimizing the anticipated costs (Pettiway, 1982; Van Koppen & Jansen, 1998), criminals make decisions based on contextual and situational cues that enable them to estimate the risk, effort, and benefits of a crime (Cornish & Clarke, 2006). This study focused on the "design features" of a house and its surroundings as contextual and situational cues for residential burglars to assess the crime costs and benefits. In addition, this study aimed to investigate how the risks, efforts, and benefits of the crime, that is, "assessment criteria",[1] would be

[1] The term "assessment criteria" employed in this study refers to the criteria that burglars would use to compare the costs and benefits of their decisions. More specifically, based on the rational choice theory, the "risk of detection (indicating risks)" and "ease of intrusion (indicating efforts)" were defined as elements of the assessment criteria. Other studies have adopted different terminology, such as "surveillability," "accessibility," "visibility," "occupancy," and "wealth," which seems to be partly based on the concept of Crime Prevention Through Environmental Design (e.g., Langton and Steenbeek 2017; Roth and Roberts 2017; Roth and Trecki 2017).

measured or calculated depending on the various combinations of the "design features" of a target.

There are a number of studies on how design features of a house and its surroundings directly affect burglars' decision-making based on the rational choice theory (Maguire and Bennett 1982; Bennett & Wright, 1984; Nee & Taylor, 1988; Taylor and Nee 1988; Wright & Logie, 1988; Cromwell, 1994; Wright and Decker 1994; Wright et al., 1995; Macintyre, 2001; Coupe and Blake 2011; Peeters, 2013; Townsley et al. 2015; Vandeviver et al., 2015; Langton & Steenbeek, 2017; Roth & Roberts, 2017). However, not much is known about how "assessment criteria" would be judged to make rational decisions through contextual and situational cues. Only a few studies suggested their own way of calculating each level of assessment criteria to explain the relationship between environmental cues and burglars' rational decisions.

Roth and Trecki (2017); Roth and Roberts (2017) introduced the formulas to compute the levels of assessment criteria (i.e., occupancy, occupancy proxies, accessibility, visibility, and empathetic deterrence) using a variety of house design features. For example, they computed the level of accessibility of a house using the following formula: (no. of doors + no. of doors containing glass panels + no. of doors with adjacent glass panels + sets of sliding glass doors + no. of windows) – (no. of glass block windows + no. of storm windows + no. of windows with window bars + no. of windows with visible locks). This formula utilizes various design characteristics of a house to quantitatively calculate the level of accessibility that can be used as one of the criteria for a burglar's target selection.

Similarly, Langton and Steenbeek (2017) used surveillability, accessibility, wealth, and ease of escape as property-level explanatory factors in their study. To obtain data for analysis, the authors calculated these factors using a variety of environmental features. The level of surveillability, for example, was calculated by considering the "no. of windows of neighboring houses with a direct view of the front ground floor," the "distance between the property and the building on the other side of the street," and the "visibility of the front door from the road." Even though they did not provide an exhaustive explanation for how they came up with these formulas, their approach gives a useful clue to think about the relationship between design features, assessment criteria, and target selection.

In contrast, Hwang et al. (2017) performed factor analysis to classify design features into assessment criteria (i.e., risk, ease, and reward). Through multiple regression analysis, they estimated the effects of assessment criteria on the rates of residential burglary and made suggestions about the structure of correlations between design features, assessment criteria, and the rate of residential burglary.

Although the research variables were defined differently, all these studies share the common assumption that burglars seek to calculate or compare the level of assessment criteria, which is a rather abstract concept, by recognizing relevant physical and tangible design features of a targeted house and its surroundings. Let us assume, for example, that a burglar considers the fence height and the presence of security spikes on a fence as essential factors when selecting a criminal target. It would be reasonable to interpret that the burglar tried to assess "the ease of breaching the fence" from the information contained in the fence design in order to decide whether to target the house or not. In other words, the burglar's assessment of "ease of intrusion" can be considered as a mediator of the relationship between the fence design and the target selection.

This example makes us consider multiple relationships between assessment criteria, design features, and criminal decision-making, which have not been well investigated yet. The main goal of this study is to elucidate these relationships, and, accordingly, our hypotheses are as follows:

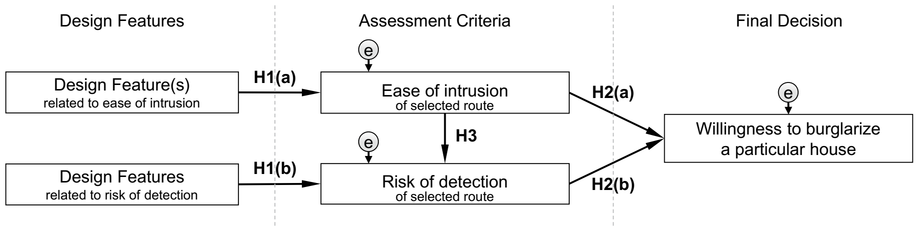

Fig. 1 The hypothesized model of this study

H1 The design features of a house affect a burglar's assessment of (a) ease of intrusion and (b) risk of detection[2] for a selected intrusion route.
H2 (a) Ease of intrusion and (b) risk of detection for a selected intrusion route have a positive impact on the willingness to burglarize a particular house.
H3 Ease of intrusion for a selected intrusion route has a direct positive effect on risk of detection and an indirect positive effect on the willingness to burglarize a particular house.

Figure 1 presents these hypothesized relationships. A more detailed explanation of the variables in this model is provided in Sect. 2.2. To test these hypotheses, path analysis was performed on the data obtained from the Virtual Reality (VR) simulation experiment.

2 Materials and methods

2.1 Experiment with VR simulation

Especially in the studies on criminals, it is inappropriate to directly observe criminals' behavior in action because of ethical and logistical issues (Nee et al., 2015; Van Gelder et al., 2017). Thus, many studies have relied on research methods such as interviews and surveys on criminals (e.g., Blevins et al., 2012; Taylor, 2018) or residents (e.g., Van Der Voordt and Cronje & Spocter, 2017; Van Wegen, 1990), which are relatively easy to conduct using a controlled investigation tool. However, these methods reveal a range of retrospective biases (Van Gelder et al., 2017) and do not guarantee data trustworthiness.

On the other hand, several studies have conducted experiments using simulation methods to determine significant factors in residential burglary at the house level (Wright and Logie 1988; Macintyre, 2001; Garcia-Retamero & Dhami, 2009; Snook et al., 2011; Homel et al., 2013; Roth & Roberts, 2017; Roth & Trecki, 2017). This simulation method has numerous advantages. Respondents do not need to depend on their memory, experience, or imagination to answer questions about their behavior but just respond to the given simulated situation like they do in the real world. They are also not directly questioned

[2] The values of all variables in this study were set in a direction favorable to burglary. Thus, in the case of the variable "Risk of detection," the higher the variable value, the lower the risk of detection. Intuitively speaking, the variable "Risk of detection" indicates the degree of "safety" from detection for burglars. The term "risk of detection" was adopted in consideration of continuity with the terminology of previous studies.

about their conscious thought process, but their revealed behaviors in a simulated situation can be analyzed to identify factors influencing their judgments.

However, simulation methods also have several limitations. First, if pictures or videos of actual houses are used as simulation materials, it is difficult to manipulate and combine variables according to the purpose of research, limiting the range of analysis (Lee & Lee, 2008). Second, the way participants obtain information in an experimental environment cannot be the same as in the real world. For example, for the method implemented in the simulation, participants passively receive the information provided by the simulation materials. However, in a real situation, motivated burglars are more likely to obtain information on the environmental conditions of a target more proactively. Finally, an artificial situation created for the simulation is unable to fully reflect an actual crime scene. It is always questionable whether the results of a simulation method are reliable enough to allow for generalization.

A number of recent studies on residential burglary have incorporated VR technology into the simulation method, attempting to overcome the limitations of simulation studies discussed above (Meenaghan et al., 2018; Nee et al., 2015, 2019; Van Gelder et al., 2017; Van Sintemaartensdijk et al., 2021). VR is regarded as one of the most useful techniques for maximizing users' immersion experiences by surrounding them perceptually and minimizing their awareness of the real world (Van Gelder et al., 2017). A virtually created environment can evoke users' cognitions, emotions, and behaviors similar to those in a real situation (Nee et al., 2019). Thus, the simulated environments resembling the real world allow researchers to study criminals' behavior during a simulated crime event and provide more reliable data (Van Gelder et al., 2017). It is also possible for researchers to use, manipulate, and combine research variables without many difficulties. In this study, we also used these VR advantages to create a hypothetical situation and the proper experimental environments in which participants search for a criminal target and carry out the target selection experiment.

2.2 Variables

2.2.1 Assessment criteria

Among the three well-known assessment criteria based on the rational choice theory (i.e., degrees of reward, effort, and risk), the variables associated with the degree of reward (e.g., visible expensive items, well-kept garden, house condition, and type of car parked outside) appeared to be somewhat limited in burglary-related studies at the house level. Also, the impact of target attractiveness (i.e., the prospective profitability of a burglary) on burglars' target selection tends to be debatable. Montoya et al., (2016: 539), who suggested using multilevel multinomial regression models for predicting day- and night-time burglaries, insisted that target attractiveness was not related to burglary. Vandeviver et al., (2015: 15) also revealed that burglars do not depend on the target's affluence assessment because they can expect to obtain expensive items anyway, such as smartphones, laptops, and tablets, from most houses in a general area. Wright et al., (1995: 49) mentioned that, especially at the house level, the attributes related to rewards tended not to influence burglars' target selection. Considering the uncertainty of reward-related variables, we only included the *effort* and *risk* of crime in the assessment criteria and excluded the *reward* from the scope of this study.

We defined the effort required to commit burglary as the ease of penetrating the barriers installed to protect the property and defend against intrusion. Depending on the selected intrusion route, the barriers a burglar should penetrate will vary. Therefore, it is assumed that a burglar focuses only on the design features of the selected intrusion route to assess the ease of intrusion, rather than comprehensively considering a variety of cues constituting the entire house. For example, when a burglar evaluates the ease of intruding a front door, he or she would be only concerned with the design features of the front door and would not care about a back door or side windows.

The risk of committing a residential burglary can be categorized according to the type of activity to be detected, such as invading, stealing, or escaping, and this study only focuses on intrusion detection. We classified intrusion detection according to three common intrusion stages for a typical detached house: crossing the *site boundary*, passing through the *garden*, or breaching the exterior wall of the *building*. Unlike the ease of intrusion, it can be assumed that a variety of design features simultaneously affect the judgment of risk because the risk of detection means a comprehensive awareness of the various possibilities that the crime scene can be detected. Thus, we supposed that the types of design features affecting the risk of detection would be determined depending on the intrusion stage (i.e., site boundary, garden, and building) instead of the intrusion route selected.

We also thought about the possible relationship between ease of intrusion and risk of detection and hypothesized that the ease would affect the risk since how easy it is to break in has a direct impact on the time it takes to break in, and this time is closely related to the likelihood of being detected.

We set up several possible routes for each intrusion stage. For the site boundary, a gate and a fence were presented as options. For the building, a front door, a front window, a side window, a back door, and a 2nd-floor window were set as possible intrusion routes. We assumed that burglars would take the shortest path through the garden, connecting the intrusion points of the site boundary and the building. During the VR experiment, the participants were asked to evaluate the ease of intrusion and the risk of detection of their chosen intrusion routes for each intrusion stage. As for the garden, they were asked to evaluate only the risk of detection because there were no barriers installed in the garden.

2.2.2 Design features

The type of residential facility used in this study was a detached house—the site where burglary occurs most frequently (Hope, 1999). Among the various design features of detached houses, we focus exclusively on built environmental elements that are possible to manipulate through architectural design. We reviewed a total of 24 previous studies[3] on residential burglary that investigated environmental factors at the micro-level and selected the design features that determine the ease of intrusion of each intrusion route and the risk of detection of each intrusion stage (Appendix 1). Table 1 represents the selected design features

[3] The list of 24 previous studies reviewed is as follows: Agarbati (2015); Amiri (2019); Bernasco (2011); Blevins et al. (2012); Buddhadasa (2021); Comeau and Klofas (2014); Garcia-Retamero and Dhami (2009); Homel et al. (2013); Hwang et al. (2017); Kim et al. (2017); Langton and Steenbeek (2017); Lee and Lee (2008); Macintyre (2001); Montoya et al. (2016); Nee (2015); Nee and Meenaghan (2006); Nee and Taylor (1988); Peeters (2013); Peeters et al. (2018); Roth and Roberts (2017); Sanders et al. (2017); Snook et al. (2011); Van Gelder et al. (2017); Wright and Logie (1988).

Table 1 Establishment of design features and their values

Design features	Design values		Ease (intrusion route)	Risk (intrusion stage)
	Facilitate burglary	Deter burglary		
Fence height	Low (1 m)	High (1.6 m)	Fence	
Fence spikes[a]	Not installed	Installed	Fence	
Fence transparency	Opaque	Transparent		S[b]
Gate height	Low (1 m)	High (1.6 m)	Gate	
Type of gate lock	Mechanical door lock	Electronic door lock	Gate	
Security alarm/camera	Not installed	Installed		S, G, B
Hiding place	Possible to hide	Impossible to hide		S, G, B
Distance from building to road	Far	Close		S, G, B
Direction of building[a]	Facing a neighbor's house	Facing road		S, G, B
Visibility from road	Invisible	Visible		G, B
Type of front door	Weak (wooden door with glass panel and mechanical door lock)	Strong (steel door without glass panel and digital door lock)	Front door	
Front door alcove	Installed	Not installed		B[c]
Type of front window	Sliding glass door	Sliders with security bars	Front win	
Type of side window	Sliders	Sliders with security bars	Side win	
Type of back door	Weak (wooden door and mechanical door lock)	Strong (steel door and digital door lock)	Back-door	
Extruding portions of façade	Installed	Not installed	2nd-FL win	

[a]Not mentioned in the 24 previous studies.

[b]Fence transparency is considered to influence the risk of fence intrusion only.

[c]The front door alcove is considered to influence the risk of front door intrusion only.

S site boundary; G garden; B building

and their values (i.e., facilitating burglaries and deterring burglaries) and how each design feature relates to the assessment criteria (i.e., ease of intrusion and risk of detection).

Among the design features, two (i.e., fence spikes and direction of building) were not mentioned in the previous studies but were added as variables. Considering that the most common way to cross a fence is by going over it (Park & Lee, 2021), we assumed that the presence of security fence spikes would affect the intrusion effort. The building's direction was added as a substitute for the "visibility from neighbors," which has been frequently mentioned in previous studies (Hwang et al., 2017; Nee, 2015; Nee & Taylor, 1988; Peeters et al., 2018; Roth & Roberts, 2017). The building facing a neighbor's house has more visibility from neighbors than the house facing the road. In addition, the variable "visibility from the road" was created by combining the values of two design features: fence height and fence transparency. For example, the house is assumed to be visible from the road when the fence is low *or* the fence is transparent, and the house is considered invisible from the road when the fence is high *and* the fence is opaque.

The combinations of the values of design features were carried out separately for the site boundary, the garden, and the building, and 25 combinations for each were constructed using the fractional factorial design method. We overlapped these combinations of the site boundary, garden, and building to obtain a total number of 32 combinations (i.e., differently designed houses). Because we used the factorial design, for all design features (except for visibility from the road that was added as a variable after the combination), one-half of the 32 houses had a facilitating burglary value, and the other half had a deterring burglary value.

The 32 houses were divided randomly into four experimental scenarios containing eight houses each. The distribution was slightly adjusted to ensure that the 16 design features of the eight houses in each scenario were not biased toward specific values of design features. To control the order-effect bias, three replicated scenarios with different orders of eight houses were constructed for each. Finally, a total of 16 experimental scenarios, including eight cases each, were prepared.

2.2.3 Willingness to burglarize a particular house

The methods of discovering the experimental participants' decisions vary. One type asks participants to select the right target in a block consisting of numerous differently designed houses (e.g., Lee & Lee, 2008). Other studies asked participants to decide whether to commit a crime for each target (e.g., Roth & Roberts, 2017) or choose one among two different targets (e.g., Garcia-Retamero & Dhami, 2009). These methods are likely to be similar to the actual decision-making process that burglars must experience in real life. However, from a research point of view, these methods may not be the ideal way to collect data, as participants' ratings of unselected houses cannot be investigated.

This study attempted to obtain more affluent information from one experiment. Hence, we requested the participants make a dichotomous choice for each house first (i.e., whether to burglarize this house as it is seen); then, we asked them to express their willingness numerically using an 11-point Likert scale. Zero points mean "I will never burglarize this house." Five points indicate "I will consider this house as a target," and 10 points mean "I will definitely burglarize this house." The participants were allowed to score their willingness from 0 to 10, with the first decimal place. We used their score as the dependent variable.

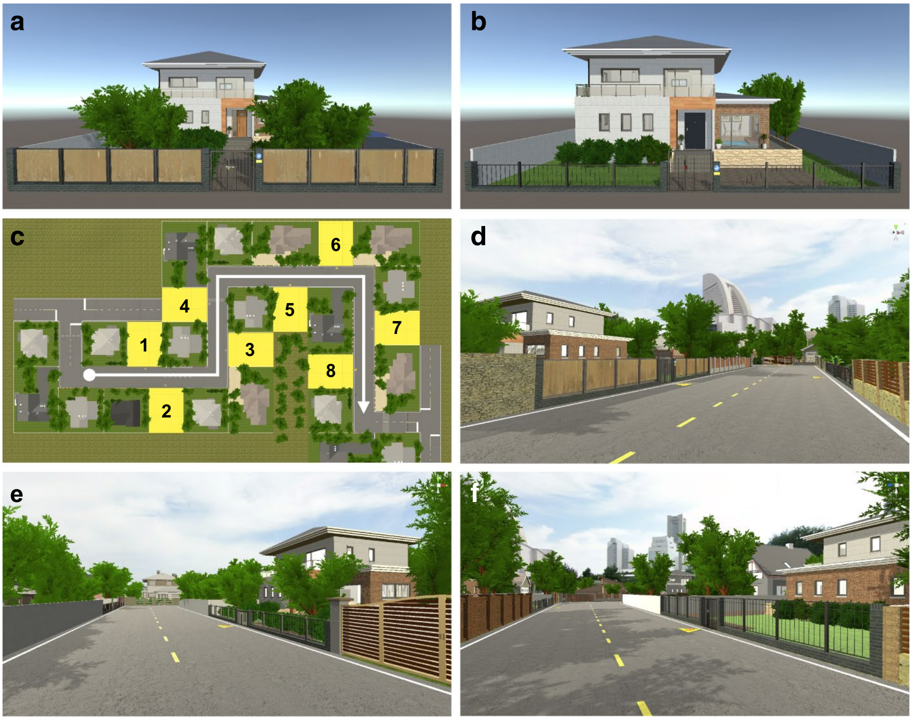

Fig. 2 Several scenes of a constructed virtual environment: **a** a scene from Case 1; **b** a scene from Case 20; **c** the layout of the block; and **d**–**f** scenes from the road passing through the block

2.3 Virtual environment for experimentation

First, we set up a three-dimensional (3D) model of a typical house as a default structure with two floors, a garden, a fence, a gate, a balcony on the 2nd-floor, front and back doors, and windows so that the design variables of this study could be applied to this house. Next, we made 3D models of both values of each design variable, considering whether participants would properly perceive the difference between both values. Then, we assembled the house structure and the design variables to complete 32 experimental cases. Figures 2a, b show examples of the assembled cases in SketchUp 2017.

To make the simulated environment replicate the actual target-searching process as much as possible, we set up a particular block that included one passing road and 27 lots where eight experimental houses and 19 neighboring houses could be located. Nineteen neighboring houses were designed to have similar characteristics (in terms of openness, visibility, richness, etc.) so that they do not act as indicators affecting participants' decisions. Figure 2c shows the top view of the constructed block and the path participants traveled while experimenting on eight experimental houses. By assembling the blocks and the corresponding eight houses, we built the 3D models of 16 experimental scenarios. The 16 scenarios were converted into VR through the game engine, Unity 2018.4.15f1, as shown in Figs. 2d–f.

2.4 Participants

Some studies have claimed that experienced burglars are specialized because of ongoing practice and differentiated from non-criminals (Nee & Ward, 2015; Nee et al., 2015, 2019). An investigation into what unique criteria experienced burglars have and how their expertise makes them more proficient is required to understand them as professionals. However, there is still a group of novices who have not yet had enough criminal experience and are even willing to commit their first crime. From the perspective of developing strategies to prevent crimes, it is necessary to investigate not only experienced burglars who professionally commit crimes with exceptional knowledge and skills, but also novices who do not differ much from ordinary people for the following reasons:

First, especially for burglary, the rate of juvenile offenders is relatively high (Cromwell, 1994). According to the FBI Criminal Records (2018), 19.68% of arrested burglars were teenagers, while the rate of arrested teenagers in all types of crimes was 12.80% (FBI, 2018). Soothill et al. (2004) mentioned that burglary is a popular principal criminal act when young new criminals initiate their official careers. In addition, Cromwell (1994) noted that because burglars mostly begin to build their careers at an early age, research on burglaries committed by teenagers can provide the basis for developing crime prevention strategies. Thus, not providing these first-time offenders with criminal opportunities to build their careers and acquire professional skills in the first place can be one effective way to prevent crime.

Second, professional burglars who would depend on their criminal jobs as a primary means of making a living tend to use special tools or techniques (rather than just giving up the job) even when they encounter a target designed to prevent break-ins. However, first-time offenders or beginners can easily give up on the crime itself rather than desperately seeking other means when the target is thoroughly protected, which means crime prevention efforts may be more effective for these novice burglars (Camel-Gilfilen, 2011; Maxwell et al., 2020).

Third, collecting data from experienced or incarcerated burglars can reveal the following problems: (1) Obtaining information about actual criminal activities can cause legal and ethical issues as well as researchers' own risks (Bennett & Wright, 1984). (2) Researchers cannot determine whether the data acquired from burglars in prison or from individuals with criminal records are reliable and representative. Cornish and Clark (1986) thus insisted that burglars who have been sentenced would not want to disclose their criminal experience precisely because of concern about the detection of additional crimes, and those who have experience in burglary would be likely to exaggerate their crimes.

In this regard, we carefully assumed that investigating non-criminals' decision-making can also be meaningful in crime prevention. Thus, 32 non-criminals were recruited for our experiment. Participants were limited to men in their 20 s and 40 s, considering the sex and age of burglars arrested in the United States in 2018. The average age of the participants was 34.44. College students and office workers accounted for 37.5% each, while the remaining 25% were researchers in various fields, including two participants from the field of architecture.

2.5 Experimental process

Each participant ($N = 32$) was involved with one randomly selected experimental scenario among 16 scenarios; thus, each scenario was evaluated by two participants. Before

Table 2 Composition of the questionnaire

Questions		Answers	Type
Intrusion route choice	Select an intrusion route for the site boundary.	Fence (1); Gate (2)	Categorical variable
	Select an intrusion route for the building.	Front door (1); Front window (2); Side window (3); Back door (4); 2nd-floor window (5)	
Perceived ease and risk	How easy is it to intrude into the site boundary?	Very difficult (1); Difficult (2); Easy (3); Very easy (4)	Continuous variable
	How safe is it to intrude into the site boundary?	Very risky (1); Risky (2); Safe (3); Very safe (4)	
	How safe is it to pass through the garden?	Very risky (1); Risky (2); Safe (3); Very safe (4)	
	How easy is it to intrude into the building?	Very difficult (1); Difficult (2); Easy (3); Very easy (4)	
	How safe is it to intrude into the building?	Very risky (1); Risky (2); Safe (3); Very safe (4)	
Final decision	How much are you willing to burglarize this house?	"I will never burglarize this house" (0); "I will consider this house as a target" (5); "I will surely burglarize this house" (10)	

the experiment, the participants were given a short description of the virtual situation (Appendix 2).

After reading the description, the researcher instructed the participants on operating the VR devices (Oculus Rift CV1 and Oculus Touch) because the VR environment was provided via a head-mounted display (HMD) system. The participants were allowed to take time to familiarize themselves with the process and were then asked to move to the designated location in the virtual environment to begin the experiment. The participants followed the road that passed through the block to evaluate the eight cases in sequential order. When they finished scrutinizing each case, the researcher asked them the questions shown in Table 2 aloud. The participants also responded orally to the questions while remaining in the virtual environment so that they could obtain visual information from the virtual houses whenever they wanted. They were allowed to ask any questions or comment on the experiment at any time. Figure 3 shows several photos of participants conducting the experiment.

2.6 Data analysis

The frequency of the intrusion route selection and the evaluations of the ease of intrusion and risk of detection of the selected intrusion route were analyzed using SPSS 21.0. In addition, our hypothesized models for each intrusion route were tested by a path analysis using a multi-mediation model since the model included the mediating effects of assessment criteria between design features and the burglar's target selection. The path analysis utilizing the bootstrapping technique was performed using AMOS 21.0.[4]

[4] In our previous study (Park and Lee 2021) that analyzed the same database, we conducted a logistic regression analysis to investigate how the design features of a detached house affect burglars' intrusion

Fig. 3 Photos of participants performing the experiment

3 Results and discussion

3.1 Evaluation of ease and risk of each selected intrusion route

We obtained 256 responses by conducting eight experiments per person. Among these 256 responses, 73.0% selected the fence as a route to breach the site boundary, whereas 27.0% selected the gate. The back door was the route chosen most frequently to enter the building (38.7%), and the percentage of participants who selected the 2nd-floor window was also high (29.7%). The selection rates for the side window, the front door, and the front window were 15.2%, 14.1%, and 2.3%, respectively. Figure 4 shows the selection rate of intrusion routes and the perceived ease of intrusion and risk of detection that were assessed by participants for each selected intrusion route.

3.1.1 Site boundary

Regarding the ease of intrusion at the site boundary, 77.5% and 91.3% of the participants who chose the fence and the gate, respectively, answered that it would be easy to break into the corresponding intrusion route. All participants who selected the fence answered that they would jump over it to breach the barrier. Similarly, most participants (N = 55) who selected the gate indicated a desire to jump over the gate instead of picking or smashing the door lock (Park & Lee, 2021). Since jumping over the fence or the gate does not require special skills or equipment, participants seemed to consider that jumping over the barrier of the site boundary is fairly doable and effortless, even when the barrier is 1.6 m high and has security spikes.

It was found that more than 60% of the participants perceived that it would be safe to intrude into the fence or gate. This is interesting in that the site boundary is possibly more visible to neighbors and pedestrians than the building. This result, like the one for ease of intrusion above, seems to reflect the participants' perception that the intrusion of the site boundary is not likely to be detected because the site boundary can be invaded quite effortlessly (by jumping over) in a very short time compared to the building.

Footnote 4 (continued)
route choice. In contrast, the present study aimed to test a hypothetical path model estimating the impact of design features on a burglar's target selection and to investigate the mediating effects of the assessment criteria between design features and burglar's target selection.

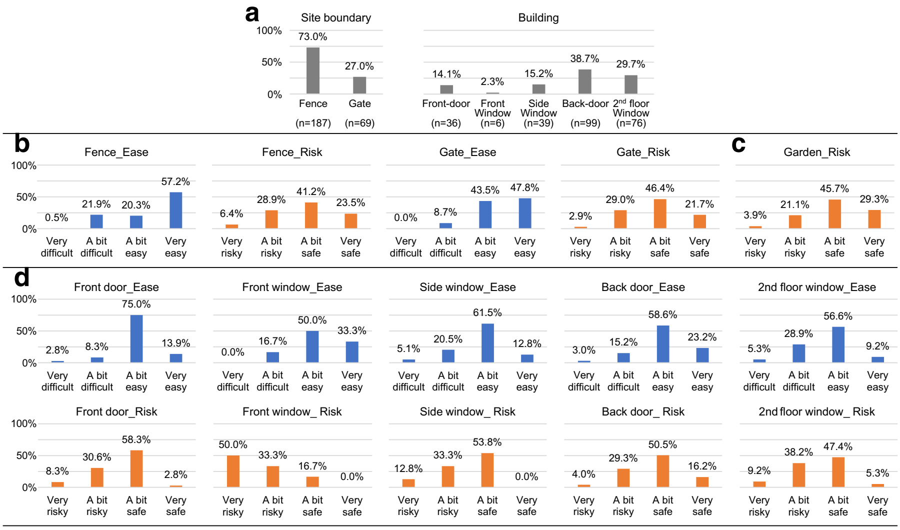

Fig. 4 Selection of intrusion route and ease and risk of selected intrusion route: **a** site boundary and building intrusion route selection; **b** ease and risk of site boundary; **c** risk of garden; and **d** ease and risk of building

3.1.2 Garden

75% of the participants considered passing through the garden to be a bit or very safe. The participants seemed to conclude that passing through the garden would not cause much suspicion for neighbors or pedestrians because it is perfectly normal behavior. Also, passing through the garden takes a very short time, even when the distance between the building and the road is set as "far." As such, the participants may have thought that there was not much chance of being detected while passing through the garden.

3.1.3 Building

Although 83.3% of the participants who chose the front window as a building intrusion route answered that breaking into the front window would be easy, their perceived risk of detection was very high. This strong concern about the risk of detection, which even those who chose the front window had, may explain why the front window selection rate was extremely low (2.3%).

In contrast, both the assessment of ease and risk of the back door that had the highest selection rate (38.7%) were favorable for intrusion. 23.2% and 16.2% of those who selected the back door answered that breaking into the back door would be very easy and very safe, respectively. However, the risk of the side window, which was installed on the same façade as the back door (i.e., the left side of the building), was evaluated somewhat differently. No one considered the side window as a very safe intrusion route, and 46.1% answered that entering through the side window would be risky. This result might be because breaching the side window is usually accompanied by the act of breaking the window glass, which causes significantly more noise than picking or damaging the door lock installed on the back door. The participants might have considered that breaking the side window is likely to draw more attention than breaching the back door.

Although the assessments of the ease of intrusion and the risk of detection for the 2nd-floor window were unfavorable compared to other routes, the selection rate (29.7%) was relatively high. Since it is quite common to leave most of the 2nd-floor windows open, whereas all windows and gates on the 1st floor are carefully locked, the participants may have thought that the 2nd-floor window is always a possible open route (even if climbing up to the 2nd-floor is not easy and safe). Thus, when it seems complicated to break in through other possible routes, the 2nd-floor window could be considered as the preferred alternative route.

On the other hand, despite the favorable evaluations for ease and risk of the front door, the selection rate of the front door (14.1%) was lower than that of the 2nd-floor window (29.7%) and the side window (15.2%), which indicates that, regardless of ease and safety, the participants did not prefer breaking in through the front door.

Interestingly, the intrusion routes that were not chosen at high rates, such as the front door, the side window, and the front window, had relatively high scores in the ease of intrusion. This might imply that these routes tend to be selected only if it is determined that intrusion via the corresponding route is easy. That is, those routes are chosen only when a certain variable associated with the ease of intrusion has a preferable value for burglary (e.g., the front door is deemed weak, the front window has no security bars, and the front window is a sliding glass door). Otherwise, the participants may determine that it is almost impossible or requires too much effort to break in through those routes and instead select other inherently preferred routes, such as the back door or the 2nd-floor window.

3.2 Path analysis for each intrusion route

Next, we conducted a path analysis to test the hypothesized model presented in Fig. 1. To perform the path analysis for each intrusion route, we divided the data according to the selected intrusion route for the site boundary and the building. Only design variables related to the assessment criteria of a specific intrusion route were included as independent variables in the corresponding route path model. In the path model of the fence, for example, fence height and fence spikes were included as predictors of the ease of intrusion, while fence transparency, security alarm/camera, hiding places, the distance from the building to the road, and the direction of the building were included as explanatory variables for the risk of detection.

Since only six responses selected the front window as a building intrusion route, we excluded them from the data set and also removed the type of front window from the collection of explanatory variables. The side window was selected only when no security bars were installed, which made it impossible to include the "type of side window" in the side window's path model. Therefore, we analyzed the side window without this variable.

To evaluate whether the tested path models fit the collected data, the goodness-of-fit indices, such as the Root Mean Square Error of Approximation (RMSEA), the Comparative Fit Index (CFI), and the Tucker-Lewis Index (TLI), were calculated. Models were considered to be acceptable if RMSEA < 0.08 (Browne & Cudeck, 1992), and CFI and TLI > 0.9 (Bentler, 1990; Bentler & Bonett, 1980).

3.2.1 Final path models

The final path models of all intrusion routes are illustrated in Fig. 5. Table 3 presents the results of the goodness-of-fit tests for each path model, which confirms that the path models, except for the gate and the back door, were well fitted to the collected data.[5]

According to the path analysis results, we could not find design features significantly affecting the risk of detection for both routes of the site boundary (i.e., fence and gate), whereas the ease of intrusion for these routes was affected by hypothesized design features. This might be because the risk of detection at the site boundary was predominantly determined by how easy it was to intrude into the barrier installed, rather than by other architectural planning factors. The path analysis also showed a significant effect of the ease of intrusion on the risk of detection for the fence and the gate. From this result, it can be suggested that to increase the risk of detection for the site boundary, it would be better to make the obstacle itself challenging to penetrate rather than rely too much on security devices for surveillance.

Similarly, no design features significantly affected the ease of intrusion at the front door or back door. Although it was highly expected that the types of door locks in both the front and back would significantly affect the ease of intrusion along the corresponding route, it was revealed that the preference of the participants for types of door locks varied. Some thought a key was easy to pick, while others found that opening a digital door lock was effortless, which seems to be a reason why we could not find any statistically significant relationship between the type of door and the ease of intrusion. A more in-depth investigation into burglars' preferences and perceptions of door lock types will supplement the results of this study.

As mentioned previously, the participants selected the side window only when there were no security bars on it, which implies that the type of side window decisively determines the assessment of ease of intrusion for the side window. Likewise, the path analysis showed that the ease of intrusion through the 2nd-floor window was also strongly affected by the installation of the extruded unit from the building façade.

The significant design features affecting the risk of detection for the garden and the building varied depending on the selected intrusion route. For example, it was found that the presence of a hiding place in the garden is considered significantly when passing through the garden and crossing the back door and 2nd-floor window. The direction of the building, on the other hand, significantly affected the garden, front door, and 2nd-floor window, while the presence of a security camera and alarm only influenced the detection risk at the front door.

As for the assessment criteria as explanatory variables for the willingness to burglarize, we were able to confirm that the detection risk had a significant effect on the willingness to burglarize in all intrusion routes. In contrast, with the exception of the gate and the front door, the ease of intrusion was mediated by the risk of detection and indirectly influenced the final decision. Since the ease of intrusion has already been shown to be an important

[5] Since this study aims to investigate the general relationships between the research variables, we did not include a discussion of why the path models of these two intrusion routes were not well-fitted to the collected data and, if so, how the variables would relate to each other, especially for these routes.

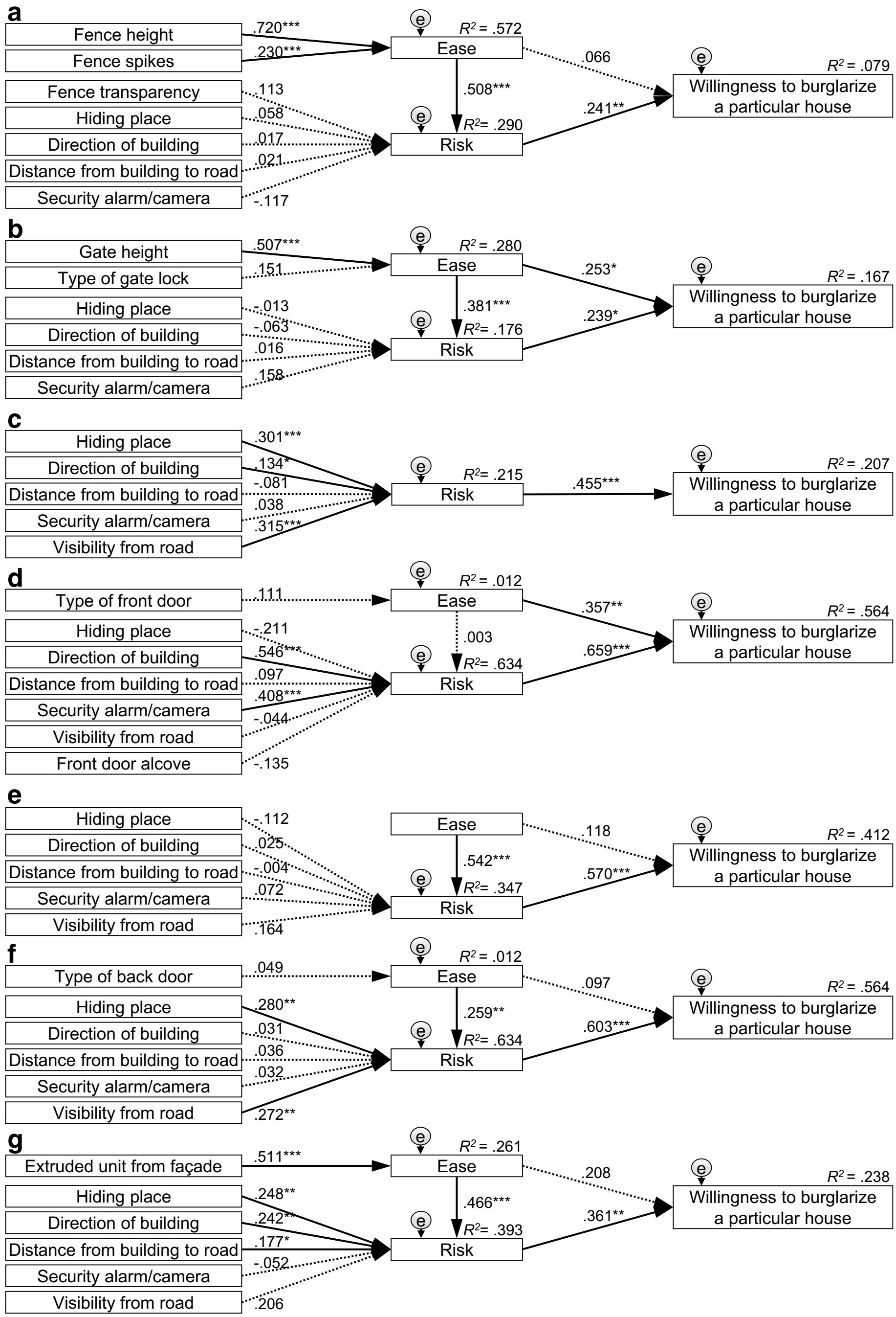

Fig. 5 Path analysis with standardized estimates and R^2: **a** fence; **b** gate; **c** garden; **d** front door; **e** side window; **f** back door; and **g** 2nd-floor window (*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$)

Table 3 Goodness of fit test for path models

Intrusion routes		N	χ^2 (*df*), *p*	CMIN/*df*	RMSEA	CFI	TLI
Site boundary	Fence	181	34.700 (33), 0.387	1.052	0.017	0.992	0.989
	Gate	69	31.968 (25), 0.159	1.279	0.064	0.883	0.831
Garden		250	17.894 (15), 0.268	1.193	0.028	0.974	0.963
Building	Front door	36	33.405 (33), 0.448	1.012	0.019	0.994	0.992
	Side window	39	18.763 (19), 0.472	0.988	0.000	1.000	1.010
	Back door	99	34.160 (27), 0.161	1.265	0.052	0.901	0.868
	2nd-floor window	76	32.002 (25), 0.158	1.280	0.061	0.937	0.909

CMIN minimum chi-square

criterion for selecting an intrusion route (Park & Lee, 2021), it seems that the selected intrusion route already entails the possibility of penetrating the route, which may weaken the direct influence of the ease of intrusion on the final decision.

We also found a significant impact of the ease of intrusion on the risk of detection for all final path models. This finding confirms our assumption that making intrusion difficult indirectly affects burglars' willingness to commit a crime by increasing the likelihood of being detected.

The path analysis results showed that significant relationships between research variables depended on the intrusion route they selected. Even though most of the prior studies regarded a house as the smallest unit to be analyzed, the findings of this study indicate that it may be reasonable to consider the various possible intrusion routes that comprise a house as the spatial unit of analysis. Also, the results of this study suggest that when measuring the safety level of an existing house against burglary, it might be better to identify the possible intrusion routes of the house and check the environmental features of each route rather than comprehensively evaluating the entire house.

3.2.2 Mediation analysis

As shown in Table 4, the total estimated effects of the ease and risk on the willingness in the final path models were investigated using the bias-corrected bootstrap confidence intervals with 1,000 bootstrap iterations and 95% confidence intervals. This bootstrapping method provides credible inferences for indirect effects (MacKinnon et al., 2004; Shrout & Bolger, 2002) and tends to be powerful, especially for smaller samples (Hayes & Scharkow, 2013). Except for the gate and the 2nd-floor window, the impact of the risk of detection on the willingness turned out to be larger than the ease of intrusion. However, even though the ease of intrusion only indirectly affected the final decision, the degree of influence seemed to be unneglectable. These results emphasize that both assessment criteria, ease and risk, should be considered important in establishing strategies to prevent residential burglary.

Table 4 Total effects of the ease of intrusion and the risk of detection on the willingness to burglarize a particular house

Path models	Ease Willingness		Risk Willingness	
	Total effects	*p*-value	Total effects	*p*-value
Fence	0.189**	0.009	0.241**	0.003
Gate	0.344**	0.004	0.239*	0.038
Front door	0.359*	0.020	0.659**	0.009
Side window	0.427	0.060	0.570**	0.007
Back door	0.253**	0.008	0.603**	0.006
2nd-floor window	0.376*	0.015	0.361**	0.009

*$p<0.05$, **$p<0.01$, ***$p<0.001$

4 Conclusions

This study aimed to expand the understanding of burglars' target selection and their decision-making process. We have found that in the process of investigating design features to evaluate whether a certain house is suitable for a burglary, the assessments regarding the ease of intrusion and the risk of detection serve as mediators. In other words, environmental cues are used to assess the ease of intrusion and the risk of detection for a specific house, and the final decision to attempt the burglary is made based on the assessment of both ease and risk. This finding suggests that when we develop crime prevention strategies, it is necessary to check the overall level of ease and risk of possible intrusion routes of a building by comprehensively considering various environmental factors, rather than just focusing on only one or two environmental features of the target.

It was also revealed that the types of design features affecting participants' decision-making were determined by the intrusion routes they selected. Since previous studies conducted at the house level have not considered intrusion routes as a spatial analysis unit, this finding is meaningful for expanding the understanding of residential burglary and crime prevention. When developing design strategies to prevent residential burglary, it would be desirable to present the frequently used intrusion routes and to show how to make these routes challenging and risky to penetrate.

This study also showed that an assessment of the ease with which one might be able to trespass directly affects the assessment related to the risk of detection. In other words, the ease of intrusion and the risk of detection are not evaluated independently but instead have influential relationships. This finding could have an important implication for researchers conducting further studies on this topic in establishing a research framework.

In terms of the experimental method, this study utilized VR techniques to collect more reliable data. VR has many advantages in that it provides researchers with a great deal of freedom in conducting an experimental design and allows variables to be controlled as desired. It can also serve as an excellent experimental tool because the participants can be immersed in the virtual experiment situation and feel a high sense of reality. The potential for VR, especially in the study of crimes, is highly anticipated since it helps to overcome the difficulties of collecting appropriate criminal data or observing real crime scenes. However, despite a massive development in graphics and computing ability for VR, there are still limitations and pitfalls that can cause dissimilarities between users' behaviors in a virtual environment and a real environment. As Pan and Hamilton (2018) made a suggestion on how to deal with challenges that research using VR should solve, if we figure out essential factors that should be considered when creating virtual experimental environments to make users feel a similar way to reality, more credible data can be obtained and analyzed.

This study also reveals several limitations. The most important limitation lies in the fact that the experiment included non-criminals only. We could not cover the experienced burglars' professional skills and specialized knowledge. Due to a lack of experience, participants might have tried to figure out the researcher's intention or what the researcher was asking of them, rather than making prompt and automated decisions. Further experimental research on a disparate group of participants using the same experimental material could compare groups with different backgrounds and more reasonably generalize the research results. Secondly, even though we collected 256 data by conducting eight experiments per person, generalizing the research results is quite inappropriate since there were only 32 participants. Also, a relatively large number of researchers and students were included in the sample because we recruited participants by asking people around us who fit their profile to participate in the experiment (i.e., males in their 20–40 s). Although we did not find significant differences between the researcher group and the rest of the sample in terms of assessment of ease of intrusion and risk of detection as well as the final decision, the skewed occupational composition of the sample may hinder the generalization of the research results. Thirdly, although we took advantage of the benefits provided by VR technology, we were not able to adopt dynamic elements, such as walking pedestrians, moving cars, and barking dogs, in the virtual environment, which might have made the atmosphere of the experimental environment different from that of the real residential area. This issue is expected to be resolved soon, considering the rapid development of VR technology. Finally, we focused exclusively on the design features at the micro-level and property-level selection. However, since it is well known that burglars go through a spatially structured, hierarchical, and sequential process to choose their targets, future experimental investigations could include a selection of neighborhoods or blocks with differing characteristics (e.g., street network, house density, symbol of wealth, type of houses).

Appendix 1

See Table 5.

Table 5 Previous studies related to our variables

Previous Studies on Burglar's target selection	Variables (design features) of this study													
	Fence height	Fence transparency	Gate height	Gate-lock type	Security alarm/camera	Hiding place	Distance from building to road	Front door type	Alcove of front door	Front window type	Side-window type	Back door type	Extruded unit from façade	Visibility from road
Agarbati (2015)		O				O				O	O		O	
Amiri et al. (2019)							O							O
Bernasco (2011)					O	O	O							
Blevins et al. (2012)					O	O	O	O		O	O	O		
Buddhadasa et al. (2021)		O				O		O			O	O		O
Comeau and Klofas (2014)				O	O	O		O		O	O	O		
Garcia-Retamero and Dhami (2009)					O	O				O	O			

Table 5 (continued)

Previous Studies on Burglar's target selection	Variables (design features) of this study													
	Fence height	Fence transparency	Gate height	Gate-lock type	Security alarm/ camera	Hiding place	Distance from building to road	Front door type	Alcove of front door	Front window type	Side-window type	Back door type	Extruded unit from façade	Visibility from road
Homel et al. (2013)	O		O		O	O		O		O	O	O		
Hwang et al. (2017)	O	O	O			O				O	O		O	
Kim et al. (2017)	O		O							O	O			
Langton and Steenbeek (2017)					O		O		O	O	O			
Lee and Lee (2008)	O	O				O				O	O		O	
Macintyre (2001)	O		O	O	O	O		O		O	O	O		
Montoya et al. (2016)	O	O	O		O	O			O	O	O			O

Table 5 (continued)

Previous Studies on Burglar's target selection	Variables (design features) of this study													
	Fence height	Fence transparency	Gate height	Gate-lock type	Security alarm/ camera	Hiding place	Distance from building to road	Front door type	Alcove of front door	Front window type	Side-window type	Back door type	Extruded unit from façade	Visibility from road
Nee (2015)	O		O	O	O	O		O				O		
Nee and Meenaghan (2006)					O	O								
Nee and Taylor (1988)		O			O	O		O						O
Peeters (2013)	O	O	O		O		O	O	O					
Peeters et al. (2018)	O	O	O			O								
Roth and Roberts (2017)	O		O		O	O	O	O	O	O	O	O		O
Sanders et al. (2017)					O	O		O		O	O	O		

Table 5 (continued)

Previous Studies on Burglar's target selection	Variables (design features) of this study													
	Fence height	Fence transparency	Gate height	Gate-lock type	Security alarm/camera	Hiding place	Distance from building to road	Front door type	Alcove of front door	Front window type	Side-window type	Back door type	Extruded unit from façade	Visibility from road
Snook et al. (2011)				O	O	O		O						
Vandeviver et al. (2015)													O	
Wright and Logie (1988)				O	O	O		O				O		

Appendix 2

A short description explaining the virtual situation presented to the participants.

> "You are currently unemployed. You have committed several crimes (breaking into houses and stealing goods) to cover living and entertainment expenses. Fortunately, you have never been arrested by the police. For the past few months, you have been suffering from a lack of money and thus have decided to commit burglary to make some money. Based on past criminal experiences, you have selected a certain residential area, in which detached houses are concentrated, in the suburbs. The chosen area is known to be predominantly populated by the middle class. At 3 pm on weekdays, you visited the selected area and picked one block. Now you are standing at the entry of the block, wanting to find the right target to commit a crime."

Author's contributions Conceptualization: SY.P., KH.L.; Methodology: SY.P., KH.L.; Formal analysis and investigation: SY.P.; Writing—original draft preparation: SY.P.; Writing—review and editing: SY.P., KH.L.; Funding acquisition: KH.L.; Resources: SY.P.; Supervision: KH.L.

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Declarations

Conflict of interest The authors have no conflicts of interest to declare that are relevant to the content of this article.

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