



Observing heroic behavior and its influencing factors in immersive virtual environments

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Studying heroism in controlled settings presents challenges and ethical controversies due to its association with physical risk. Leveraging virtual reality (VR) technology, we conducted a three-study series with 397 participants from China to investigate heroic actions. Participants unexpectedly witnessed a criminal event in a simulated scenario, allowing observation of their tendency to physically intercept a thief. We examined situational factors (voluntariness, authority, and risk) and personal variables [gender, impulsivity, empathy, and social value orientation (SVO)] that may influence heroism. Also, the potential association between heroism and social conformity was explored. In terms of situational variables, voluntariness modulated participants' tendency to intercept the escaping thief, while perceived risk demonstrated its impact by interacting with gender. That is, in study 3 where the perceived risk was expected to be higher (as supported by an online study 5), males exhibited a greater inclination toward heroic behavior compared to females. Regarding other personal variables, the tendency to engage in heroic behavior decreased as empathy levels rose among males, whereas the opposite trend was observed for females. SVO influenced heroic behavior but without a gender interaction. Finally, an inverse relationship between heroism and social conformity was observed. The robustness of these findings was partly supported by the Chinese sample (but not the international sample) of an online study 4 that provided written descriptions of VR scenarios, indicating cultural variations. These results advance insights into motivational factors influencing heroism in the context of restoring order and highlight the power of VR technology in examining social psychological hypotheses beyond ethical constraints.

heroic behavior | virtual reality | risk perception | empathy | social conformity

Heroic behavior is widely regarded as an apex of human conduct (1–3). A concise definition of heroic behavior is to voluntarily act in a prosocial manner, particularly assisting others in need, despite personal risk (3). In the face of unprecedented risks and challenges in our global society, a nuanced understanding of heroic behavior becomes essential for formulating effective policies, interventions, and initiatives that cultivate compassion and responsibility. This paper explores how situational and personal variables modulate individual responses to situations requiring heroic actions. Despite the importance of this topic (4–9), progress has been limited, primarily due to the ethical challenges associated with manipulating risk levels in experimental settings to evoke heroic actions (3, 10). Instead, many studies rely on self-report measures and surveys to investigate heroism, potentially leading to discrepancies between reported attitudes and actual behavior (11–15). We suggest that this methodological limitation has contributed to inconsistent findings in previous studies (4–9).

To address the inherent challenges associated with investigating heroic behavior, we utilize virtual reality (VR) technology, which provides a unique way for designing experiments that may pose ethical concerns in real-world settings (16). By creating immersive and multisensory experiences, VR environments can elicit behavioral, emotional, and neural responses from participants that closely resemble those in real-life situations (17, 18). While some studies have investigated helping behavior in simulated life-threatening scenarios, they did not explicitly address the heroic nature of this behavior, did not consider personality variables, and did not manipulate social factors that may interact with heroism (2, 19–21). These limitations may restrict the comprehensive full utilization of the advantages offered by VR technology.

This paper delves into the potential modulation of various situational and personal factors on heroic behavior, aiming to illuminate its underlying conditions and motivational mechanisms (22, 23). In terms of situational variables, our primary focus was on the degree of physical risk, as heroism often entails the prospect of physical harm or even

Significance

The utilization of traditional methods for investigating heroism in controlled settings poses challenges and ethical concerns due to its association with physical risks. Leveraging virtual reality (VR), we constructed scenarios wherein Chinese participants witnessed crimes and had the opportunity to physically intervene. Our results showed significant effects of situational (voluntariness and risk) and personal factors (gender, empathy, and social value orientation) on heroism, as well as an inverse relationship between heroism and social conformity. The findings were partly supported by an online study providing written descriptions of VR scenarios. This use of VR technology not only offers insights into heroic behavior within immersive virtual environments but also paves the way for innovative applications of VR in social psychological research.

The authors declare no competing interest.

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death (1, 24). We also explored the potential effects of voluntariness and authority, roles suggested in heroism literature despite the lack of empirical evidence (25, 26). In terms of personal variables, we examined whether gender difference exists in the prevalence of physical heroism, in line with previous research (27, 28). Also, we investigated whether varying levels of empathy, social value orientation (SVO), and impulsivity contributed to individual difference in heroism. Empathy and SVO are recognized influencers of diverse forms of prosocial conduct (29, 30), while impulsivity was considered due to the impulsive and unplanned nature of heroic actions (28). Last but not least, we investigated the interplay between heroic behavior and social conformity. Franco, Blau, and Zimbardo underscored the heroic figure as a “rebel” making individualistic decisions, suggesting a connection between heroism and nonconformity (3). Remarkably, the tendency to resist conformity under group pressures interacts with gender (31–33).

Leveraging the capabilities of the VR technique, we designed an innovative paradigm employing a head-mounted display (HMD). Specifically, participants were instructed to engage in a seemingly routine task utilizing the VR headset but unexpectedly became witnesses to a brief criminal incident (i.e., thief). In reality, intervening in such an event could help restore order but has the potential to be physically risky, because the thief may violently resist or seek revenge. We aimed to investigate potential variations in people’s inclinations to engage in heroic behavior in this scenario. Further, we sought to explore whether situational or personal factors could elucidate the observed individual disparities in the likelihood of heroic intervention.

Results

Study 1, conducted as a pilot investigation with only one group (between-subject design), aimed to validate the feasibility of our VR setup and explore potential gender difference. In this study, participants immersed themselves in a VR scenario featuring a

female victim and a policeman chasing a thief. Both the victim and the policeman urgently called for assistance. Participants may respond to their requests by intercepting the thief, a potentially risky action in real life due to the possibility of physical conflict. The “escaping thief” event was intercepted by 91.2% of males (31 out of 34) and 90.3% of females (28 out of 31). The interception proportion ($\chi^2 = 0.014$, $df = 1$, $P = 0.905$; Fig. 1A), reaction time ($F(1, 55) = 1.086$, $P = 0.302$; Fig. 1D), and heart rate change ($F(1, 38) = 2.994$, $P = 0.482$) were insensitive to the gender factor. To address these findings, we suggest that some participants might have intervened due to prompts from the victim and the policeman. Notably, a crucial criterion of heroic actions is their voluntary nature (3), which could have been compromised in study 1. Additionally, both male and female participants could have been inclined to comply with an authority figure (i.e., the policeman) (33). Possibly for these two reasons, a “ceiling effect” was observed in study 1 where the likelihood of intercepting the thief exceeded 90% for both genders.

Study 2 examined the effects of voluntariness (by comparing with study 1), authority, and their potential interactions with gender. For these purposes, we made two modifications to the task in study 2 (between-subject design). First, we eliminated explicit requests to ensure the voluntary nature of participants’ actions. That is, shouts from the victim or policeman were directed at the thief with no specific guidance on what action to take. Second, we introduced a manipulation involving the authority factor, where the presence of the policeman varied between two groups. Results showed that the interception proportion was lower in study 2 than in study 1 (70.0% vs. 90.8%; $\chi^2 = 10.678$, $df = 1$, $P = 0.001$), indicating the influence of voluntariness. In the “authority” group, 83.8% of the males (31 out of 37) and 62.5% of the females (20 out of 32) intercepted the thief. In the “no authority” group, 71.1% of the males (27 out of 38) and 60.6% of the females (20 out of 33) intercepted the thief (Fig. 1B). A logistic regression analysis, which took gender and group as well as their interaction as the independent variables, showed no

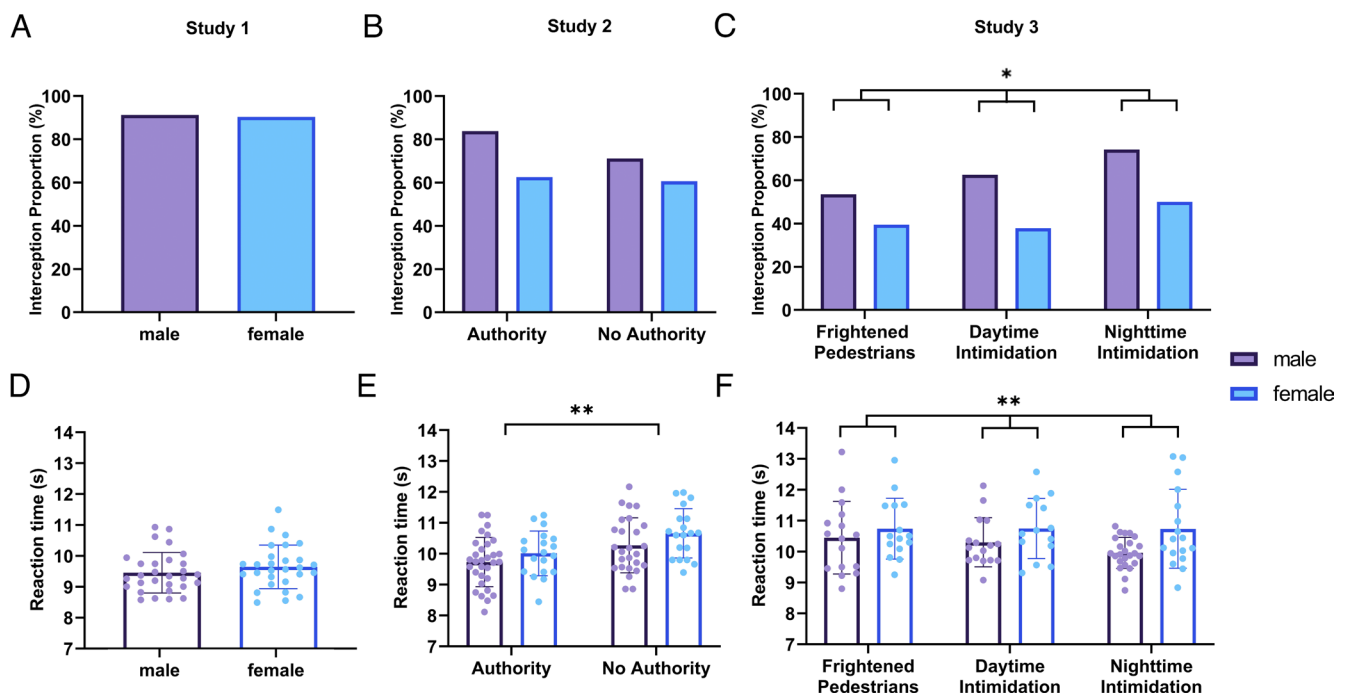


Fig. 1. The results of heroic acts (calculated as proportions) and reaction time in three VR studies. (Upper) the proportion of interception in (A) study 1, (B) study 2, and (C) study 3. (Lower) the reaction time in (D) study 1, (E) study 2, and (F) study 3. The error bars of reaction time indicate SD. * $P < 0.05$; ** $P < 0.01$.

significant main effect or interaction on interception proportion (SI Appendix). The gender gap in reaction time exhibited marginal significance, indicating that males acted more promptly in engaging in heroic actions ($F(1,91) = 3.958, P = 0.050, \eta_p^2 = 0.042$; Fig. 1E). This finding remained consistent regardless of the authority factor. Meanwhile, there was no significant main effect or interaction observed for heart rate change ($ps \geq 0.29$).

Moving forward, study 3 (between-subject design) explored whether gender difference in heroic behavior would emerge under a heightened level of perceived risk and investigated the potential relationship between heroic behavior and nonconformity. We also examined personal variables including SVO, impulsivity, and empathy, due to their potential relevance (see the Introduction). To achieve these goals, we set up three groups to elevate risk perception in different ways: the inclusion of pedestrians exhibiting fearful responses in the scene, aiming to evoke emotional contagion (“frightened pedestrians”); the thief’s intimidating shouts, implying a potential violent confrontation (“daytime intimidation”); and the nighttime setting, tapping into an innate fear of darkness (“nighttime intimidation”) (34, 35). Following the escaping thief event, participants continued their task and encountered a “red light” event at a crosswalk along their predetermined route: They witnessed pedestrians crossing on a red light and had to decide whether to follow them (i.e., conforming to the majority) or wait for the light to turn green within 10 s.

The interception proportion was lower in study 3 than in study 2 (51.6% vs. 70.0%; $\chi^2 = 11.407, df = 1, P = 0.001$). The results of study 3 showed that in the frightened pedestrians group, 53.6% of the males (15 out of 28) and 39.5% of the females (15 out of 38) intercepted the thief; in the daytime intimidation group, 62.5% of the males (15 out of 24) and 37.8% of the females (14 out of 37) intercepted the thief; in the nighttime intimidation group, 74.2% of the males (23 out of 31) and 50.0% of the females (17 out of 34) intercepted the thief (Fig. 1C). A logistic regression analysis, also using interception proportion as the dependent variable and gender, group, and gender by group interaction as the independent variables, revealed that the main effect of gender was significant ($P = 0.048$). That is, males were 2.875 times more likely to voluntarily intervene in the escaping thief event compared to females. Neither the main effect of group nor the interaction was significant (SI Appendix). Additionally, males needed shorter reaction times to intercept the thief than females ($F(2,91) = 9.068, P = 0.003, \eta_p^2 = 0.091$; Fig. 1F) and displayed lower heart rate changes compared to females ($F(2,177) = 4.167, P = 0.043$). A gender-specific interaction emerged in relation to empathy ($P = 0.006$): The tendency for heroic behavior decreased as empathy levels rose among males, yet the inverse was true for females (Fig. 2 and SI Appendix). Meanwhile, the main effect of SVO on heroic behavior was significant ($P = 0.002$) when combining the data of studies 1 to 3, indicating that prosocial individuals were more likely to intervene than proself ones (SI Appendix). Finally, a significant inverse relationship emerged between heroic behavior and social conformity ($P = 0.005$): Participants engaging in heroic behavior were 4.600 times more likely of not conforming with a majority’s decision to proceed through a red light (Fig. 3). This relationship was insensitive to gender ($P = 0.153$).

We then conducted two additional online studies 4 (preregistered with AsPredicted, #150931) and 5 (preregistered with AsPredicted, #150932) using a conventional approach widely utilized in heroism research, that is, written vignettes. Study 4 (between-subject design) aimed to compare the findings derived from traditional methods with those obtained through the VR

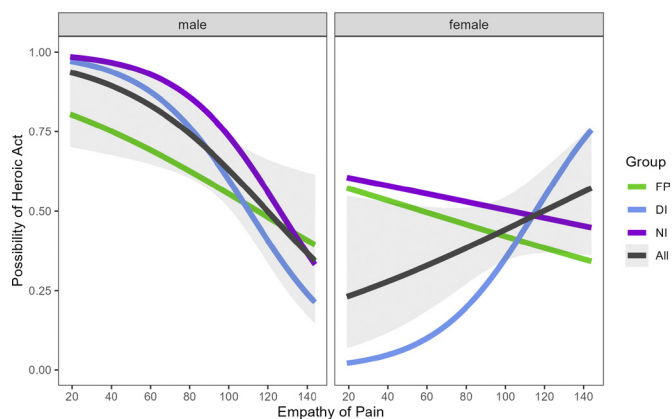


Fig. 2. The logistic fitting curve between empathy for pain and heroic behavior in study 3. The X axis represents an individual’s ability to empathize others’ pain. The Y axis represents the probability of a participant undertaking a heroic action. The Left and Right panels indicate the results for males and females, respectively. FP: the “frightened pedestrians group”; DI: the “daytime intimidation” group; NI: the “nighttime intimidation” group; All: all groups together. The light gray areas represent the 95% CI of the black lines.

technique, while study 5 (within-subject design) aimed to demonstrate the heroic nature of intercepting the thief in our VR experiments from a third-party perspective. Data collection in study 4 involved 528 Chinese participants and 541 international participants, whereas study 5 included 71 Chinese participants and 71 international participants. Chinese participants were recruited via the Credamo platform, while international participants were recruited via the Prolific Academic platform (36). In study 4, participants were presented with written descriptions of one of six scenarios (corresponding to the six conditions in studies 1 to 3). They were instructed to imagine themselves as the protagonist and provide a yes/no response indicating whether they would like to intercept the escaping thief. The results from the Chinese sample revealed noteworthy similarities to the findings of our VR studies, including the gender difference in heroic behavior in high-risk conditions ($ps \leq 0.080$), the gender \times empathy interaction on heroic behavior ($P = 0.061$), the main effect of SVO on heroic behavior ($P < 0.001$), and the inverse relationship between heroism and social conformity ($P = 0.071$). The same was not true for the international sample, but we found a significant main effect of gender on heroism (SI Appendix). In study 5, we asked participants who were not involved in study 4 to read written descriptions of all the six scenarios and rate the perceived heroism,

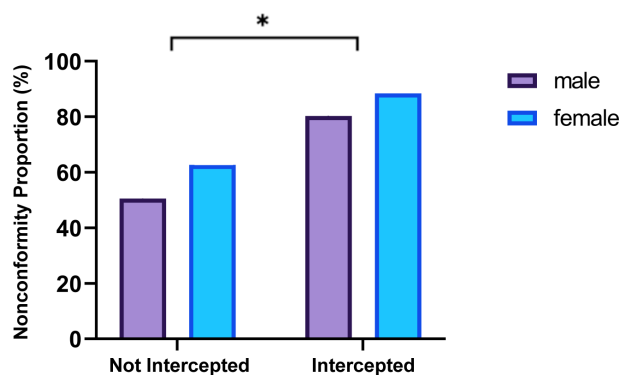


Fig. 3. The relationship between heroic acts and conformity in study 3. Intercepted: Participants who intercepted in the escaping thief event; Not Intercepted: Participants who did not intercept the thief. Nonconformity Proportion: the proportion of participants who did not conform to pedestrians jaywalking. * $P < 0.05$.

bravery, danger, and altruism of intercepting the thief from a third-party perspective using 7-point Likert scales. The results of one-sample *t* tests showed that all these indexes were significantly higher than the chance level (mid-point [4] on the 7-point scales) in both the Chinese and international samples. Further, a planned comparison revealed that the perceived level of danger was generally higher in study 3 than study 2 (*SI Appendix*).

Discussion

Using advanced VR technology, we set up an “escaping thief” event within an immersive virtual environment to investigate individual heroism in restoring order across a series of studies. The potential influence of various situational variables (voluntariness, authority, and perceived risk) and personal variables (gender, SVO, empathy, and impulsivity) was examined. The potential association between heroism and social conformity was also explored. We believe that the findings from these studies contribute to a better understanding of the complexity of heroism motivation, particularly in the context of restoring order, by elucidating the roles of different factors.

In general, we found that some factors directly modulated participants’ tendency to intercept the escaping thief (voluntariness between studies 1 and 2; SVO across studies 1 to 3), some factors manifested their influence by interacting with gender (perceived risk and empathy in study 3: see below for details), while others did not show observable effects (authority in study 2; impulsivity in study 3). Additionally, consistent with the idea that heroism involves resisting the influence of conformity pressures (37), there was an inverse correlation between heroic tendencies and social conformity in study 3, that is, participants who engaged in heroic behavior were more inclined to obey traffic regulations independently rather than yielding to the sway of the majority.

Regarding the gender factor, the difference in heroic tendencies between males and females was significant only when we induced heightened risk perception through various means in study 3. (The validity of these experimental manipulations was supported by the results of study 5.) Specifically, in study 3, males exhibited a greater willingness to engage in heroic behavior compared to females, required shorter decision-making times, and displayed lower heart rate changes. These findings potentially reflect societal influences on female heroism, more commonly observed in collective societies (24). Gender stereotypes, often internalized through socialization and education processes, serve as obstacles that hinder women from engaging in not only heroic acts (28) but also other risk-related activities (38, 39). Additionally, according to the costly signaling theory, mating motives are particularly likely to drive acts that highlight one’s heroic nature in males, as they are associated with masculine attributes (40). Finally, the focus of heroism in this research is specifically on the act of restoring order despite potential risks. This suggests that the observed gender difference may actually reflect differing levels of interest in restoring order among males and females. To explore this possibility, future studies should examine heroic behaviors that focus on life-saving or other purposes.

In addition, the only personal trait that interacted with the gender factor was empathy, such that the correlation between empathy and heroic behavior was negative in males but positive in females. One possible explanation is that men are more susceptible to antisocial motivations (such as a thirst for retaliatory action against the perpetrator) driving heroic behavior, while women show a stronger propensity for prosocial motives including empathy. In short, immersing participants in ecologically valid VR scenarios enriched with contextual details allow us to determine

that both perceived risk and empathy contribute to shape gender difference in heroism. These findings hold the potential to offer insights for developing innovative interventions aimed at fostering more equitable participation in acts of heroism across genders (27).

From a technical standpoint, this series of studies underscores the capacity of utilizing VR techniques to achieve nuanced experimental possibilities and reveal knowledge beyond conventional methods like written vignettes. In the Chinese sample of our study 4, where VR scenarios were presented through reading materials, we observed behavioral effects similar to the findings in our VR research, though some of them failed to reach statistical significance. It should be noted that self-reports derived from vignette studies and actual behavior may diverge, as self-reports primarily reflect individuals’ predictions of their actions rather than those actions per se (41, 42). In our opinion, the results from VR studies are likely to be more closely aligned with real-life performance than self-reports, given the immersive and vivid experiences provided by VR technology. This could help explain why some effects were significant in VR studies but not in vignette studies. Thus, we suggest that the VR approach not only overcomes previous challenges associated with ethical constraints in heroism studies but also opens promising avenues for the application of VR in the realm of social psychology. These avenues extend beyond heroism to encompass empirical research on various social phenomena with consequences too severe for conventional laboratory settings, such as aggressive behaviors. In practical terms, the current research also highlights the potential of VR technology in evaluating candidates for high-risk occupations, such as firefighters (43).

Looking ahead, researchers could consider analyzing not only whether participants intercept the target (i.e., a “hit” event) but also their moving trajectories before the interception. This additional information may prove valuable in interpreting the trade-off between heroic motives and perceived risk (44). Another challenge arises from the limited understanding of the brain mechanisms associated with heroic behavior (45). Future researchers may identify the neural correlates of our key findings by combining the VR technique. For instance, they could investigate whether gender-specific brain structures and functions underlie distinct heroic behaviors.

A few limitations of the current research warrant consideration. First, this series of studies concentrated on physical risk, given that individuals undertaking physical risks are often viewed as archetypal heroic figures in societies (24). Yet, the notion of heroism extends beyond physical risk to encompass forms of principle-driven courage, including those entailing social risks like ostracization (3, 13). Leveraging the VR technique, future investigations could explore whether females engage in social heroism with similar frequency to males (1, 27, 46). Second, given that our samples in studies 1 to 3 were exclusively drawn from China, it is crucial to acknowledge the limited generalizability of our findings beyond the Chinese context. That is, the gender difference in the willingness to undertake heroic acts under high-risk scenarios may be culture-sensitive (24). In our online study 4 which collected data from both Chinese and international participants, we found that the results from the Chinese sample exhibited more similarities with the findings from VR studies 1 to 3 compared to the international sample. Another phenomenon in study 4 indicating the importance of culture is that individual collectivism strongly predicted heroic tendencies, possibly because the heroic acts in our task were associated with restoring order (*SI Appendix*; see also ref. 47). Indeed, considering helping restore order as one kind of heroic behaviors might involve cultural and political sensitivities, although the majority of both Chinese and international participants in study 4 affirmed the heroic nature of intercepting a thief.

Table 1. Demographic information and descriptive statistics in studies 1 to 3

	Study 1		Study 2				Study 3					
	male	female	Group 1 (authority)		Group 2 (no authority)		Group 1 (frightened pedestrians)		Group 2 (daytime intimidation)		Group 3 (nighttime intimidation)	
			male	female	male	female	male	female	male	female	male	female
Mean age	22.44	21.32	22.78	21.75	22.79	21.91	22.54	22.05	21.38	21.22	22.94	21.94
SD	2.39	1.96	1.77	2.13	2.32	2.35	5.35	2.13	2.24	2.58	2.27	1.97
N	34	31	37	32	38	33	28	38	24	37	31	34
<i>P</i> value	0.044		0.031		0.117		0.615		0.806		0.063	

SD: standard deviation; N: number; *P* values indicate results of independent samples *t* tests for detecting significant age differences between males and females.

Materials and Methods

Participants. The sample size determination for VR studies 1 to 3 considered three factors: a) the number of participants required according to a prior power analysis; b) sample sizes utilized in previous VR studies within the realm of social psychology; and c) practical constraints related to time and resources. The power analysis, assuming an effect size of 0.4, an alpha value of 0.05, and a power of 0.8, yielded a sample size of 50 using a chi-square test (*G*Power* 3.1.7, RRID: SCR_013726). Meanwhile, previous VR studies in social psychology have employed sample sizes ranging from 43 to 96, to the best of our knowledge (19–21, 48, 49). Ultimately, we recruited as many participants as feasible to account for possible dropouts or errors during the experiments. The resultant sample sizes were 65 for study 1, 69 and 71 for the two conditions of study 2, and 66, 61, and 65 for the three conditions of study 3. Table 1 presents demographic details and descriptive statistics for all VR studies. All participants were healthy college students from Beijing Normal University, right-handed, and nonpsychology majors. Each participant was involved in only one condition across the three VR studies. The Institutional Review Boards of Beijing Normal University approved the experiment. Participants provided informed consent before the study and received 150 Chinese yuan as compensation upon completion.

Post hoc analysis revealed that the power value of the gender effect reached 0.88 in the entire sample of study 3. Considering this, the sample size for studies 4–5 was determined through a prior power analysis using *G*Power* 3.1.7, assuming a power of 0.8, an effect size of 0.3, and an alpha value of 0.05. According

to this calculation, the sample size should be no less than 88 for each condition of study 4 and 71 for study 5. Specifically, we recruited participants separately from a Chinese platform Credamo and an American platform Prolific Academic. On Credamo, the actual number of participants was 88 for each of the six conditions of study 4 (528 in total) and 71 for study 5. On Prolific Academic, the actual number of participants ranged between 88 and 98 across the six conditions of study 4 (541 in total) and was 71 for study 5 (*SI Appendix*).

VR Research Procedure. The experiment consisted of two parts: an online session and an in-laboratory VR experiment. In the online session, participants provided demographic details, including gender and age. Additionally, participants completed the SVO slider test (50) to categorize them into “prosocial” and “proself” orientations (51, 52). In light of recent findings about the importance of SVO orientations on social behaviors (29, 30, 53–55), we balanced the proportion of participants with these orientations (*SI Appendix*).

On the formal experiment day, participants wore an HMD and a heart rate monitor in the laboratory. They used a motion-sensing wireless controller to interact with the VR environment. Following instructions from an experimenter, participants had a 5-min adaptation period to the VR environment before independently completing the task (Fig. 4). The only difference in study 3 compared to studies 1 and 2 was that after the VR experiment, participants also finished the Balloon Analogue Risk Task (BART) to assess their impulsivity levels (56) and rate their empathy for pain (EP) with the picture assessment task (57, 58) on a personal computer (Fig. 5 and *SI Appendix*).

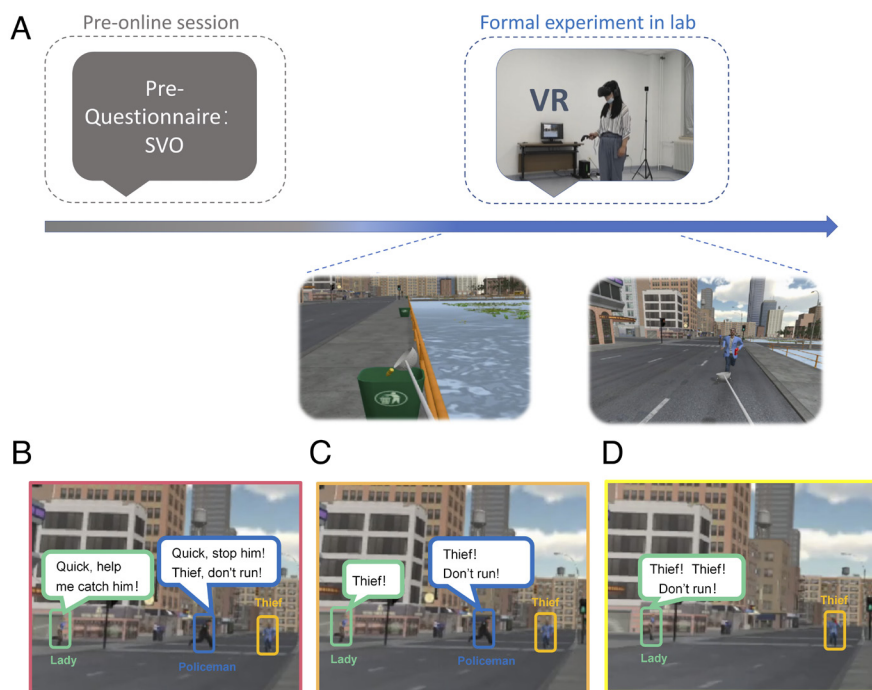


Fig. 4. (A) Experimental procedure of studies 1 and 2: participants completed the SVO slider test and then finished the VR task in which they picked up garbage from a river but unexpectedly encountered an escaping thief. (B–D) The design of the escaping thief event in (B) study 1, (C) the authority condition of study 2, and (D) the no authority condition of study 2.

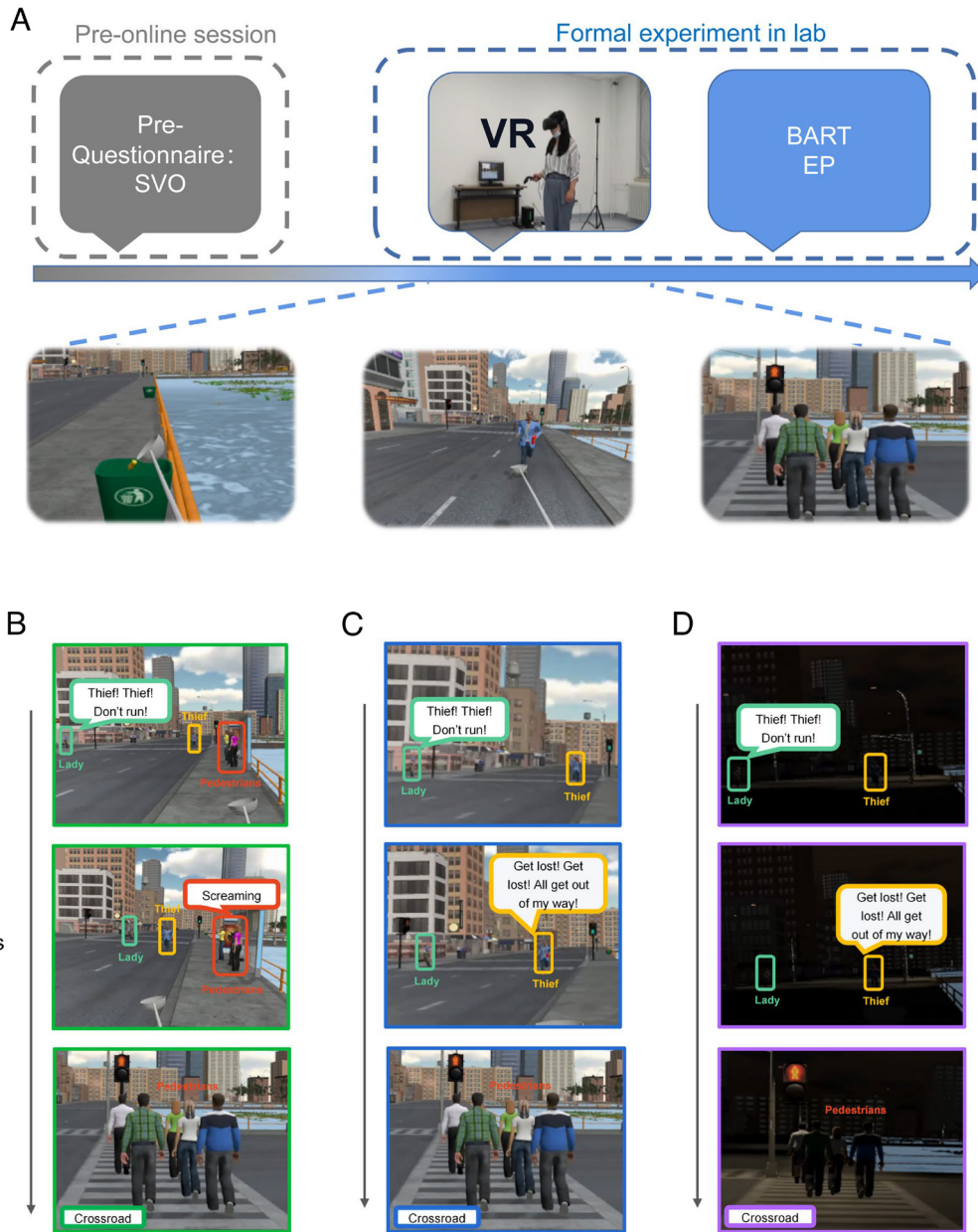


Fig. 5. (A) Experimental procedure of study 3: participants completed the SVO slider test, received the VR task, and finally finished the BART and the assessment of EP. (B–D) The design of the escaping thief event and the follow-up red light event in the (B) frightened pedestrians condition, (C) daytime intimidation condition, and (D) nighttime intimidation condition.

VR Research Task Design. The cover story positioned participants as environmental protection volunteers within a virtual city. Equipped with a long-handled iron spoon (controlled by the wireless controller in their dominant hand), participants strolled alongside a river, collecting litter and disposing of it in nearby trash bins. There was no time limit for this task. Unknown to participants, an escaping thief event would be triggered after they walked past the second garbage collection area. In study 1, participants heard a cry for help followed by police commands. They then witnessed a male thief pursued by a male policeman and a woman, aiming to stop the thief before he escaped. Participants could intervene by blocking the thief's path with their iron spoon or their body. Successful intervention resulted in the thief's capture, acknowledged by the policeman. Failure led to the thief and pursuers running past participants, concluding the event. The specifics of this event differed across studies for research purposes, detailed in *SI Appendix*. Each participant only witnessed one escaping thief event (i.e., one trial for each participant).

VR Research Data Acquisition and Analysis. The data collected in the experiment included a) the proportion of participants (represented as percentage) who intercepted the escaping thief; b) participants' reaction times for their heroic responses, calculated as the interval between the escaping thief initiation and their interception; c) participants' heart rate change between 5 s before the escaping thief event and that after the event, serving as an emotional response physiological marker; and d) pre- and post-task questionnaire data. Missing data were replaced with mean values in statistical analyses. Details of data acquisition methods and statistical analyses are available in *SI Appendix*.

Open Science Practice. The data of all studies and sample recording movies of the VR experiments are available on Science Data Bank (<https://doi.org/10.57760/sciencedb.14520>) (59).

Data, Materials, and Software Availability. Anonymized behavioral data and video recording data have been deposited in Science Data Bank (Science DB) (10.57760/sciencedb.14520) (59).

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