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Understanding risk perceptions of e-scooter use: E-scooter users and non-users

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ABSTRACT

E-scooters share the roads with other users, making it crucial to understand how these different road users perceive the risky behaviors of e-scooter riders. While perceptions of risk situations caused by the e-scooter rider are likely complex and multifaceted, previous research has not adequately clarified these perspectives. Additionally, the specific roles of assessment tools in describing each distinct risk scenario have yet to be thoroughly examined. This study analyzed the validity of existing risk assessments by examining e-scooter risk perceptions among both users and non-users, grouped according to riding experience (non-users: fewer than five rides; users: five or more rides). The assessment included three primary analyses: (1) a comparison of perceived risk and perceived control across two descriptive assessment tools (text-based and video-based); (2) an examination of the relationships among perceived risk, perceived control, and willingness to share the road; and (3) an analysis of differences in how e-scooter users and non-users prioritize evaluation criteria when assessing specific risky situations. Participants (20 escooter users and 20 non-users) evaluated 14 risky scenarios. Data on perceived risk and willingness to share were collected for each scenario, while perceived control was assessed once after viewing all 14 scenarios. Analyses were conducted using SPSS, with paired t-tests to assess differences across assessment tools, 2-tailed correlation tests to examine relationships among variables, and Kruskal-Wallis tests to rank the importance of different evaluation criteria by group. The results of the study confirmed that participants' risk perceptions varied depending on the assessment tool used to describe risk. Additionally, it demonstrated that road user experience influences various perceptions of risk. The results underscore the importance of selecting appropriate assessment tools for effective risk communication and assessment strategies and emphasize the need to complementarily use various descriptive assessment tools as necessary.

1. Introduction

E-scooters have gained attention as sustainable modes of transportation. They are recognized for their potential to reduce congestion in modern urban traffic and minimal environmental impact in terms of carbon emissions [1]. Since the outbreak of the pandemic, e-scooters have become crucial transportation alternatives in many cities and universities [2]. The use of e-scooters and social concerns regarding their safety are increasing [3]. Particularly, e-scooters operate on the same roads with various road users,

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such as pedestrians, cyclists, and vehicles in diverse road conditions. Therefore, it is important to discuss the negative impact of e-scooters on other road users [4,5]. Ongoing research focuses on understanding the safety of e-scooters, and behavior and attitude of riders [6,7]. According to the Anti-Corruption and Civil Rights Commission report (2020), the majority (71.5%) of complaints related to e-scooters concerned where they are used, inexperienced riding, and reckless behavior (14.9%) [8]. Similarly, White et al. (2023) identified rider behavior (14.9%), infrastructure issues (67%), and the presence of other users (19%) as the primary factors contributing to crashes [9].

Owing to the negative aspects highlighted in media, e-scooters have not been objectively evaluated [10]. Safety issues and serious concerns regarding e-scooters have counteracted these [11,12]. To establish e-scooters as sustainable modes of transportation, various road users must have a balanced understanding of their positive and negative aspects. It is essential to reflect the voices of various road users when exploring user experiences on shared roads [13].

Existing studies on e-scooter crash and safety have primarily focused on analyzing crash frequency and contributing factors, as well as legal and regulatory approaches. However, insufficient empirical research has been conducted on the psychology and attitude of road users in unsafe relationships [7]. Some studies on the relationship between e-scooters and other road users have been conducted from the perspective of e-scooter riders; however, research from the perspective of pedestrians and other road users is scarce [14].

Describing and understanding hazardous situations can significantly influence risk assessment [15]. Some studies have indicated that individuals' perceptions and attitudes toward such situations are shaped by their personal characteristics and experiences, which aligns with findings in research on the risks of e-scooters [16,17]. Text-based assessments may be limited in evaluating these hazards due to the lack of a comprehensive frame of reference [18]. Consequently, people without firsthand experience of e-scooter riders' risky behavior may struggle to fully comprehend and assess the associated hazardous situations. Alternatively, video-based assessments can be utilized, as videos provide adequate perceptual information, such as temporal and spatial cues and sound [19], allowing participants to better understand behaviors unfamiliar to them. The enhanced authenticity and intensity of sensory properties and experiences facilitated by a comprehensive frame of reference can significantly influence individuals' judgments [20,21].

This study aimed to investigate the risk perception of road users regarding the risky behavior of e-scooter riders frequently encountered in universities. Specifically, we examined the differences in risk perception among road users depending on the assessment tool used to describe the risk. Two assessments were conducted using text- and video-based information to investigate participants' risk perceptions for the same scenarios. The measurement of risk perception included risk perception level (perceived risk), willingness to use the same road (willingness to share), and perceived degree of control (perceived control). Specifically, this study aimed to address the following research questions. **RQ1** provided the framework for this study. **RQ1-1** and **RQ1-2** explore **RQ1** by analyzing the tendencies of the e-scooter user and non-users and independently comparing their similarities and differences.

RQ1: Do e-scooter users and non-users have similar perceptions of e-scooter users' risky behaviors or do they vary?

RQ1-1: Do participants assess the risky behaviors of e-scooter users similarly in text- and video-based assessments or do they vary depending on the assessment tool?

RQ1-2: What factors account for the diverse nature of e-scooter users' perception of risky behaviors?

2. Literature review

2.1. Features of risk studies

Risk perceptions are diverse. Previous research has suggested that various factors influence an individual's risk assessment [22]. For instance, Slovic (2000) argued that risk is assessed based on two psychological factors: dread and knowledge. Dread is influenced by the severity of potential harm, controllability, and voluntariness of risk exposure, whereas knowledge varies according to an individual's familiarity with risk [23]. Lazarus and Folkman (1984) classified the process of cognitive appraisal of demands into two categories: primary appraisal relates to "how relevant the situation is to oneself" and secondary appraisal involves evaluating "what one can do to change the situation" [24]. Tomas (2004) delineated processes from risk perception to acceptance. It comprises risk perception, attitude, acceptance, and avoidance [25]. According to this framework, risk perception precedes the formation of risk attitude. Risk attitude is a subjective response in which an individual willingly accepts a potential risk [26]. Subsequently, adaptive behaviors of risk acceptance or avoidance manifest based on the perceived benefits of risks and extent of controllability [27]. In summary, individuals' evaluations of "risk" depend on how they perceive risk stimuli; it does not depend solely on risk but on how they define risk based on their experiences and perceptions. Therefore, it is necessary to understand risk assessment in the dual context of risk stimuli and individuals' subjective risk perceptions.

Additionally, differences in the assessment tools used to convey risky behaviors should be considered. There is no consensus on an appropriate assessment tool for describing circumstances when investigating perceptions of risky behavior. However, assessment tools that realistically depict circumstances typically provide adequate insight into behavior [28,29]. Surveys provide the foundation for evaluating specific objects. Therefore, the explanatory tools used should be carefully considered. However, all explanatory tools have the potential to convey objects that are different from reality. When conveying similar risk circumstances, individuals' evaluations and interpretations of the circumstances may vary depending on the quantity and characteristics of the information provided through the explanatory tool [30].

2.2. Difference in risk perception based on e-scooter riding experience

The subjective evaluations of certain entities can vary based on individual experiences. Individuals who reflect on their experiences when evaluating objects tend to perceive and process information [31–33]. Several studies have highlighted differences in risk perception levels and attitude toward e-scooters among road users with varying levels of e-scooter experience and proficiency [34–36]. For example, Sanders et al. (2020) reported that 65 % of e-scooter users rated riding e-scooters as safe or very safe [37]. However, James et al. (2019) found that 56 % of non-users perceived maneuvering with e-scooter riders as unsafe or very unsafe [38]. Comer et al. (2020) directly compared the opinions of two groups of road users. They found that novice e-scooter users rated the threat posed by e-scooters to other road users higher than experienced users [39]. This may be due to the differences in the experiential risk perceptions of e-scooters between the two types of road users.

2.3. Road users' perception of risky behaviors

Previous empirical studies on the risky behaviors of road users have used behavioral questionnaires (BQs) [40]. These studies used survey assessment methods that provided detailed descriptions of circumstances in the text and requested responses regarding perceptions [41–43]. In this case, it is considered a first-person evaluation because it reflects the participant's personal experiences [30]. The text has high fidelity to the message it aims to convey from a situational perspective and does not require much imagination from the recipient [44]. Thus, text-based assessments are assumed to promote consistent understanding of the questions among all participants [45]. However, text-based assessments have several limitations regarding survey assessments of traffic safety. First-person perspective written surveys lack contextual understanding of circumstances [46] and can cause reliability issues, such as response bias [47]. Particularly, circumstances in which relevant experience is inconsistent or lacking, the absence of a comprehensive frame of reference for assessment can be problematic. This limits the applicability of this type of assessment [18].

To address these flaws, external evaluators can be used in BQ surveys [48], or approaches involving the provision of photos/videos from the perspective of external observers can be used [49,50]. Particularly, the effectiveness of video-based assessments in estimating risk in traffic scenarios has been demonstrated. Videos emulate real situations [51] and deliver higher levels of insight by providing temporal movement information [19]. As all observers can view the same road and event, they can compensate for variations in experiential differences among the participants [29]. Observers gain third-person visual experience from a video and adopt an outsider's perspective [52,53]. As such, they tend to perceive contextual information from observed objects rather than from individual empirical factors [54]. Videos simultaneously provide substantial visual and auditory information. Thus, it is up to the participants to acquire information from the video. Therefore, videos are limited by the substantial room available for participants to reconstruct the message [55,56]. For example, participants may partially understand the information provided in the video content, which could influence their assessment [19].

2.4. Hypothesis development

This study comprehensively reviewed previous studies to explore the differences in risk perception between e-scooter users and non-users. Section 2.1 presents an analysis of the characteristics of risk research, demonstrating that individuals' risk assessments are influenced by a range of psychological factors. Notably, Slovic (2000) argued that risk is evaluated based on "dread" and "knowledge" [23], and a study by Lazarus and Folkman (1984) suggested that risk assessments are measured using two key factors: the relationship with the evaluator themselves and the capacity to create change in the situation [24]. This theoretical background underscores the notion that risk is not evaluated in isolation but rather varies based on individuals' experiential characteristics. This, in turn, gives rise to differences in how they perceive and understand risk. Section 2.2 examines the impact of e-scooter experience on risk perception. Several studies have demonstrated that individuals with experience of using e-scooters tend to perceive risks as being lower than those without such experience. This indicates that experience with e-scooters has a significant impact on risk perception. Finally, Section 2.3 addresses the potential for variation in risk perception based on the tool utilized to explain risk behaviors.

The study specifically notes that the amount of information conveyed by text and video may lead to differences in how road users perceive and interpret risky behaviors, with evaluation outcomes being influenced by the level of recipients' involvement in understanding and interpreting these explanatory tools. Additionally, examining perceived risk, perceived control, and willingness to share provides a deeper understanding of the factors shaping risk-related decision-making. Perceived risk shows how an individual evaluates the severity and likelihood of harm, while perceived control reflects individuals' confidence in managing risks, influencing their adaptive responses. Willingness to share, as a behavioral dimension of risk perception, measures acceptance of risks and offers valuable insights into how individuals assess and respond to risky situations. Based on the previous studies, this research establishes the following hypotheses.

H0-1: There is no difference in the perceived risk assessment of risky behavior depending on the assessment tool.

- H0-2: There is no significant correlation between perceived risk and perceived control regarding risky behavior.
- H0-3: There is no significant correlation between perceived risk and willingness to share regarding risky behavior.

H0-4: There is no difference in the prioritization of risk assessment criteria between users and non-users.

3. Methods

3.1. Study design

This study used a within-subjects design to explore how different assessment tools influence perceptions of risky behaviors related to e-scooter use. Participants were divided into two groups: the e-scooter user group (N = 20) and non-user group (N = 20). This classification aimed to capture potential differences in risk perception between experienced e-scooter riders and individuals without e-scooter experience. The within-subjects design allowed each participant to complete both text-based and video-based assessments, enabling comparisons within individuals regarding the impact of assessment type on risk perception. The study focused on three main factors across all scenarios: perceived risk, perceived control, and willingness to share. Each factor was assessed under two different conditions (text-based and video-based) to examine how the presentation format affects risk perception. The main objectives of the study were threefold: to compare perceived risk and perceived control across text-based and video-based assessment tools; to examine the relationships among perceived risk, perceived control, and willingness to share; and to explore differences in the prioritization of assessment criteria for specific hazardous situations between user and non-user groups. This design facilitated a comprehensive examination of how assessment format and e-scooter experience shape risk perceptions. The summary overview of this study design is presented in Fig. 1.

3.2. Participants

Forty university students participated in this study. The participants were divided into two groups. Twenty individuals who had ridden e-scooters at least five times were classified as the e-scooter user group. The remaining twenty individuals, with fewer than five e-scooter riding experiences and without consideration of other mobility experiences, were placed in the non-user group. The minimum sample size was calculated using G*Power software version 3.1.9.7. In a previous study that examined the impact of video instructions on the perception of traffic-related risks, the effect size was reported as 1.44 (Cohen's d) [57]. Based on this finding, the effect size for the current study was set at 0.8, which is regarded as a high effect size. Assuming this effect size, along with a significance level of 0.05 and a statistical power of 0.9 for a paired *t*-test, the required sample size was determined to be 19. Consequently, 20 e-scooter users and 20 non-users were selected. The average age of all participants was 23.3 years (standard deviation [SD] = 3.67), with 15 males and 25 females. Nine e-scooter users and three non-users reported having experienced at least one e-scooter crash. The



tools(text-based and video-based), (2) investigating the relationships among perceived risk, perceived control, and willingness to share the road, and (3) examining how e-scooter users and non-users differ in prioritizing assessment criteria for specific hazardous situations.

Fig. 1. Study design.

descriptions of the participants are presented in Table 1. This study was approved by the Institutional Review Board of Pukyong National University (No. 1041386-202310-HR-116-02) in accordance with the ethics and guidance for experiments involving human subjects.

3.3. Risky behaviors

"Deviation from designated lanes or disregard for traffic regulations" is one of the peculiarities of riding in universities [58]. Nevertheless, roads in local universities are considered non-road areas, which limits the enforcement of traffic laws. Consequently, it is difficult to regulate riders who violate e-scooter safety [59]. This study focused on scenarios commonly encountered on campuses, rather than general e-scooter crash incidents. Fourteen risky riding behaviors were identified as situational factors based on previous research [6,7,35,40,60–62] and references to road traffic laws. Prior to establishing the survey items, factors related to risky situations from previous studies were reviewed, and redundant factors were eliminated. Subsequently, the items were revised in accordance with the Korean Road Traffic Act punitive clauses. The Korean Road Traffic Act classifies e-scooters as single-person transportation equipment with a speed limit of less than 25 km/h. Using helmets is mandatory, and e-scooters are not allowed on sidewalks. Additionally, risky behaviors frequently observed among e-scooter users in universities, such as carrying belongings and wearing audio devices, were considered. Five illegal and nine non-illegal behaviors were included in the risky behavior scenarios (Tables 2 and 3).

Risk perceptions were rated using a 7-point Likert scale based on the descriptions of risky behaviors presented above, whereas the video-based assessment was conducted using footage that appropriately duplicated the events and was filmed specifically for this purpose. All visual materials were filmed in universities and consisted of videos lasting approximately 10–15 s each. The video clips were recorded using a GoPro camera mounted on a 1.35 m tripod. This height was preferred to simulate the perspective of a pedestrian, based on the average shoulder height of an adult Korean. Except for zigzag riding, e-scooter rider was instructed to ride in a straight line. If the movement or speed did not match the specified conditions, the video was retaken. The videos were presented twice consecutively and average speed of the e-scooters in the videos was maintained at 15 km/h, except in scenarios involving inconsistent speeds (ranging from a minimum of 5–18 km/h) and speeding (exceeding 18 km/h). An overview of this video is shown in Fig. 2 and Table 4.

3.4. Measurements

Risk perception was measured using three items: perceived risk, willingness to share, and perceived control. The scores were measured with a 7-point Likert scale. A questionnaire was developed, as shown in Table 5.

To investigate the differences in risk assessment criteria between the e-scooter user and non-user groups, the participants were asked to rank the six assessment criteria variables listed in Table 6 in order of priority. Subsequently, qualitative interviews were conducted to determine which evaluation criteria were applied to situations rated as higher risk.

3.5. Procedure

The procedure for this study included a pre-experiment demographic survey, two main assessments using text-based and videobased tools, and a follow-up session consisting of ranking and discussing assessment criteria. Fig. 3 provides an overview of the entire procedure. Before beginning the main experiment, participants completed a demographic questionnaire and consent form. Based on their e-scooter riding experience, they were classified into either the e-scooter user group or the non-user group. The first assessment involved a text-based questionnaire. In this phase, participants were asked to evaluate perceived risk for each of the 14 scenarios and perceived control for the entire set of scenarios. After completing the text-based survey, participants moved on to the video-based assessment. In this phase, they watched video clips corresponding to the same 14 scenarios. Following each video, they provided ratings for perceived risk, willingness to share, and perceived control for the entire set of scenarios. To minimize order effects, the video clips were presented in a random sequence. After completing both assessments, participants took part in an interview where they ranked the importance of six predefined risk assessment criteria and discussed the scenarios they considered particularly risky, explaining which assessment criteria they applied when evaluating those scenarios. This interview aimed to equally capture the participants' prioritization of different criteria and their reasoning and approach in applying these criteria to specific scenarios.

Table 1	
Demographic characteristics	of participants.

Index	Response	Frequency
Sex	Male	15
	Female	25
Age (years)	20–29	38
	>30	2
E-scooter experience	E-scooter user	20
	on-user	20
E-scooter crash	Yes	12
	No	28

Risky behaviors prohibited by law.

Risky Behavior	Description
Sidewalk riding	Riding on a sidewalk without pedestrians
Sidewalk riding face to face	Riding on a sidewalk facing pedestrians
Sidewalk overtaking	Overtaking pedestrians on a sidewalk
Not wearing a helmet	Riding without wearing a helmet
Excess passengers	Riding with more than the designated number of riders

Table 3

Risky behaviors not prohibited by law.

Risky Behavior	Description
Inconsistent speed	Riding at an inconsistent speed
Speeding	Riding at high speeds below 25 km/h
Zigzag driving	Maneuvering the e-scooter by moving it left and right
Sudden braking	Abruptly stopping, leading to an unstable state
Insufficient distance from vehicles	Riding without maintaining a sufficiently safe distance from surrounding vehicles
Using mobile phone	Checking or manipulating a mobile phone while riding
Carrying belongings	Riding with belongings placed on the handle of the e-scooter
Wearing audio devices	Wearing earphones or headsets while riding
Unprepared braking action	Not taking braking action in preparation for sudden stops



Fig. 2. Video descriptions. (a) Lateral spacing between pedestrian center and e-scooter rider center, (b) Lateral spacing between stopped vehicle's side edge and e-scooter rider center, and (c) An example of risky behavior scenarios presented in the video.

3.6. Data analysis

The data for this study were processed using SPSS software version 27.0 (IBM Corp., Armonk, NY, USA). Data curation involved collecting and pre-processing responses related to willingness to share, perceived risk, and perceived control, which were evaluated as key indicators of risk perception. Descriptive statistics, including means and standard deviations, were calculated to summarize the data for each group and assessment method. Assumption analyses were conducted to confirm the normality of the data using the Shapiro-Wilk test and Q-Q plots, ensuring no violations of the normality assumption. These checks validated the use of parametric tests for further analysis. Inferential analyses included paired t-tests to compare perceived risk between participants surveyed using text-and video-based methods. Participants were categorized into e-scooter users and non-users, and separate paired t-tests were performed for each group. Cohen's d was employed to quantify the effect size of differences between the two assessment methods. According to Cohen's guidelines [69], an absolute value of d = 0.20 indicates a small effect, d = 0.50 a medium effect, and d = 0.80 or above a large effect. Larger Cohen's d values reflect stronger differences between the two assessment methods, providing insights into how risk perception varied depending on the method of assessment. To examine relationships among the key indicators of risk perception, correlation analyses were conducted using Pearson's 2-tailed correlation test. Positive correlations indicated direct relationships, while negative correlations suggested inverse relationships. Correlation coefficients closer to ± 1 represented stronger relationships, whereas values near zero indicated weaker correlations [70]. Finally, the differences in priority rankings of risk assessment criteria between

Description of the video stimuli.

Risky Behavior	Description
Sidewalk riding	Riding on a sidewalk with no pedestrians
Sidewalk riding face to face	Approaching in the opposite direction in front of a pedestrian on the sidewalk
Sidewalk overtaking	Approaching from behind the pedestrian, moving in the same direction on the sidewalk
Not wearing a helmet	Riding without wearing a helmet
Excess passengers	Riding a single e-scooter with two people
Inconsistent speed	Riding at an inconsistent speed, ranging from a minimum of 5 km/h to a maximum of 18 km/h, with a total of four speed
	changes
Speeding	Riding at a fast speed within the regulated range, exceeding 18 km/h but remaining below 20 km/h
Zigzag driving	Moving irregularly, zigzagging left and right across the lane, with a total of eight direction changes
Sudden braking	Abruptly stopped and nearly caused an accident
Insufficient distance from	Maintaining a lateral distance of approximately 1m from the stationary vehicles
vehicles	
Using mobile phone	Checking a mobile phone while riding
Carrying belongings	Riding with a big bag placed on the handle of the e-scooter
Wearing audio devices	Wearing a headset while riding
Unprepared braking action	Incorrect hand positioning on the e-scooter prevents taking a proper braking posture

Table 5

Structure of questionnaire.

Question Item	Description	References
Perceived risk	"How dangerous do you think a given situation is?": response options ranged from "not at all dangerous" (1) to "extremely	[7]
Derestrad	angerous" (/). "Dedoctions (a seaster users can avoid graphes or near graphes with other read users based on their intentions", response	[62 64]
control	options ranged from "Strongly Disagree" (1) to "Strongly Agree" (7).	[03,04]
Willingness to	"As a pedestrian, how much can you accept sharing the road with e-scooters in the given situation?": response options ranged	[65]
share	from "Not at all acceptable" (1) to "Very acceptable" (7).	

Table 6

Factors influencing the risk of e-scooter riding.

Factor	References
Physical riding environments	[9]
Human and physical obstacles in complex riding environments	[9]
Lack of consideration for other road users by e-scooter riders	[9]
Insufficient skill or proficiency in e-scooter operation by riders	[66]
Negligence of attention obligations by e-scooter riders	[67]
Insufficient safety awareness of e-scooter riders	[68]





e-scooter users and non-users were analyzed using the Kruskal-Wallis test. Since rank data were used, a non-parametric method was deemed appropriate. This approach allowed for the evaluation of group differences without assuming a normal distribution.

4. Results

4.1. Differences in risk assessment tools

The results indicated that participants' perceived risk varied depending on the assessment tool used to convey the scenario. Significant differences were observed between text and video assessments in 12 of 14 scenarios, except "sidewalk riding" and "carrying belongings" (Tables 7 and 8). In most scenarios, such as "not wearing a helmet," "speeding," and "zigzag riding," had a lower perceived risk in video-based than in text-based assessments. However, in some scenarios, video assessments had a higher perceived risk. For instance, behaviors such as "sidewalk riding face to face" and "sidewalk overtaking" led all participants to perceive a higher level of risk in video-based assessments.

Furthermore, these differences varied between e-scooter user and non-user groups. For scenarios involving "excess passengers," "using a mobile phone," and "wearing audio devices" the e-scooter user group rated perceived risk as significantly lower in video-based assessments than in text-based assessments whereas risk was rated significantly higher in "sudden braking." In contrast, the non-user group perceived a lower risk in video-based assessments than in text-based assessments for the "inconsistent speed" scenario.

The mean score for perceived risk in the text-based assessments was 5.71 (SD = 0.80) for the e-scooter user group and 5.61 (SD = 0.67) for the non-user group. In the video-based assessments, the mean score was 5.09 (SD = 0.92) for the e-scooter user group and 4.96 (SD = 0.69) for the non-user group. These results suggest that e-scooter users perceived a slightly higher risk than non-users in both assessments. However, the difference was not statistically significant.

In terms of perceived control, significant differences were observed based on the assessment tools. Responses from the e-scooter user group indicated significantly higher perceived control in the text-based assessments, with a mean score of 4.15 (SD = 1.84), compared to 3.05 (SD = 1.67) in the video-based assessments. This shows a significant decrease in perceived control after viewing the video clips (t = 2.820, p = 0.011). The effect size for the e-scooter user group was calculated as d = 0.631, indicating a medium effect size. The non-user group showed a similar trend, with a mean score of 3.90 (SD = 1.25) in the text-based assessments and 2.70 (SD = 1.49) in the video-based assessments (t = 2.662, p = 0.015). The effect size for the non-user group was d = 0.595, also indicating a medium effect size. Both groups demonstrated medium effect sizes (Cohen's d > 0.5), reflecting meaningful differences between the text- and video-based assessments in terms of perceived control.

4.2. Multifaceted risk perception

The concept of risk is complex and includes several interrelated factors. Consequently, a diverse approach is required that encompasses the intensity of the risk, willingness to accept potential risks, and extent of personal control over those risks. Considering that personal experience has a significant impact on risk perception, this study compared individuals with and without e-scooter riding experience to examine the correlation between the three risk perception indicators: willingness to share, perceived risk, and control. The correlation between perceived risk and willingness to share showed significantly negative correlations in all risky riding scenarios, regardless of the e-scooter riding experience. However, the correlations between perceived risk and perceived control), between willingness to share and perceived control, varied with prior experience.

4.2.1. Perceived risk and control

Table 7

The negative correlation between perceived risk and perceived control indicates that participants' perceived sense of control may vary depending on the perceived magnitude of a particular risk. As perceived risk increases, individuals are more likely to feel a loss of control in the given situation. This reflects a lack of confidence in their ability to effectively manage or avoid the risk. Out of the 14 risky behaviors, five showed strong correlations within the e-scooter user group, whereas only one was identified in the non-user group. Both groups showed a significantly negative correlation regarding "zigzag driving" (r = -0.691, p = 0.000 and r = -0.493, p = 0.014). The e-scooter user group showed additional significantly negative correlations for illegal behaviors, such as "sidewalk riding" (r = -0.403, p = 0.039), "sidewalk riding face to face" (r = -0.445, p = 0.025), and "sidewalk overtaking" (r = -0.432, p = 0.029) and so on (Tables 9 and 10), whereas the non-user group did not.

Results of the paired t-tests for the perceived risk of e-scooter user group.

Risky behaviors	Perceived risks for the e-scooter user group			
	Text-based	Video-based	p value	Effect size
Sidewalk riding	4.45(2.04)	4.85(1.63)	0.418	-0.185
Sidewalk riding face to face	5.35(1.53)	6.35(0.88)	0.023	-0.554
Sidewalk overtaking	5.20(1.36)	6.25(0.97)	0.008	-0.668
Not wearing a helmet	5.15(1.73)	3.75(2.20)	0.006	0.696
Excess passengers	6.65(0.67)	5.85(1.46)	0.028	0.531
Inconsistent speed	4.95(1.57)	4.50(1.99)	0.427	0.181
Speeding	5.95(1.39)	3.90(2.22)	0.001	0.872
Zigzag driving	6.30(0.80)	5.15(1.79)	0.014	0.605
Sudden braking	6.10(1.29)	6.75(0.64)	0.015	-0.597
Insufficient distance from vehicles	6.15(0.99)	5.10(2.02)	0.047	0.475
Using mobile phone	6.70(0.57)	5.90(1.45)	0.009	0.645
Carrying belongings	4.75(1.65)	3.95(1.73)	0.096	0.392
Wearing audio devices	5.90(1.52)	4.70(2.25)	0.045	0.479
Unprepared braking action	6.30(0.80)	4.30(2.08)	0.000	0.963

Note: Mean values and standard deviations for each risky behavior (with standard deviations in parentheses). Significant differences between the groups are indicated in bold, and the effect size was calculated using Cohen's d.

Results of the paired t-tests for the perceived risk of non-user group.

Risky behaviors	Perceived risks for the non-user group			
	Text-based	Video-based	p value	Effect size
Sidewalk riding	4.65(1.76)	5.30(1.22)	0.108	-0.377
Sidewalk riding face to face	4.90(1.29)	5.80(1.20)	0.022	-0.556
Sidewalk overtaking	4.60(1.60)	5.80(0.89)	0.008	-0.658
Not wearing a helmet	5.55(1.39)	3.80(1.99)	0.002	0.788
Excess passengers	6.10(1.45)	5.85(1.35)	0.577	0.127
Inconsistent speed	5.45(1.28)	3.95(1.88)	0.001	0.866
Speeding	6.05(0.94)	3.25(1.68)	0.000	1.489
Zigzag driving	6.40(0.75)	5.15(1.23)	0.000	1.226
Sudden braking	6.05(1.23)	6.40(0.94)	0.349	-0.215
Insufficient distance from vehicles	5.80(1.58)	4.70(1.72)	0.037	0.500
Using mobile phone	6.75(0.44)	6.40(0.88)	0.149	0.337
Carrying belongings	5.00(1.65)	4.45(1.82)	0.313	0.232
Wearing audio devices	5.40(1.43)	5.15(1.31)	0.460	0.169
Unprepared braking action	5.85(0.93)	3.50(1.57)	0.000	1.650

Note: Mean values and standard deviation for each risky behavior (with standard deviations in parentheses). Significant differences between the groups are indicated in bold, and the effect size was calculated using Cohen's d.

Table 9

Pearson's correlation between perceived risk for each risky behavior and perceived control in the e-scooter user group.

Perceived risk for risky behavior	Perceived control for the e-scooter user group		
	r	p-value	
Sidewalk riding	-0.403	0.039	
Sidewalk riding face to face	-0.445	0.025	
Sidewalk overtaking	-0.432	0.029	
Not wearing a helmet	-0.556	0.005	
Excess passengers	-0.277	0.118	
Inconsistent speed	0.008	0.487	
Speeding	-0.211	0.185	
Zigzag driving	-0.691	0.000	
Sudden braking	-0.234	0.160	
Insufficient distance from vehicles	-0.189	0.213	
Using mobile phone	-0.194	0.206	
Carrying belongings	0.110	0.322	
Wearing audio devices	-0.136	0.284	
Unprepared braking action	0.011	0.482	

Note: Two-tailed Pearson correlation coefficient (r) and p-value. The significance of correlation was tested at 0.05 level. Statistically significant correlations are highlighted in bold.

Table 10

Pearson's correlation between perceived risk for each risky behavior and perceived control in the non-user group.

Perceived risk for risky behavior	Perceived control for the non-user group		
	r	p-value	
Sidewalk riding	-0.006	0.490	
Sidewalk riding face to face	0.230	0.164	
Sidewalk overtaking	-0.245	0.149	
Not wearing a helmet	-0.128	0.296	
Excess passengers	-0.102	0.334	
Inconsistent speed	0.032	0.447	
Speeding	0.178	0.226	
Zigzag driving	-0.493	0.014	
Sudden braking	-0.023	0.462	
Insufficient distance from vehicles	-0.222	0.174	
Using mobile phone	0.336	0.074	
Carrying belongings	0.014	0.477	
Wearing audio devices	-0.030	0.451	
Unprepared braking action	-0.337	0.073	

Note: Two-tailed Pearson correlation coefficient (r) and p-value. The significance of correlation was tested at 0.05 level. Statistically significant correlations are highlighted in bold.

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4.2.2. Willingness to share and perceived control

The positive correlation between willingness to share and perceived control suggests that participants who rated their ability to manage or avoid risks arising from risky riding behaviors by e-scooter users more highly were also more willing to share the road with e-scooter users. Among the 14 risky behaviors, the e-scooter user group exhibited strong correlations in six cases, whereas two strong correlations were identified in the non-user group. Both groups were positively correlated with willingness to share and perceived control of "zigzag driving" behavior, as shown in Tables 12 and 13 (r = 0.437, p = 0.027 and r = 0.446, p = 0.024). Additionally, the e-scooter user group was positively correlated for illegal riding behaviors such as "sidewalk riding" (r = 0.552, p = 0.006), "sidewalk riding face to face" (r = -0.586, p = 0.003), "sidewalk overtaking" (r = -0.451, p = 0.023), "not wearing a helmet" (r = 0.580, p = 0.004), and "speeding" (r = 0.479, p = 0.016), whereas the non-user group did not.

Table 11 provides descriptive statistics showing the willingness of the two participant groups to use the same road in 14 risk scenarios.

4.3. Different risk assessment priorities based on e-scooter experience

To examine the differences in priority considerations for evaluating the risk of e-scooters based on e-scooter experience, a Kruskal–Wallis test was conducted on the priority scores for the six risk assessment criteria: A) physical riding conditions, B) manmade and physical obstacles in complex riding conditions, C) lack of consideration for other road users by e-scooter riders, D) insufficient skills or proficiency in e-scooter operation by riders, E) violation of attention obligations by e-scooter riders, and F) insufficient safety awareness of e-scooter riders. Differences in priority were observed between users and non-users for criteria A (H = 5.486, p = 0.019) and criteria E (H = 4.293, p = 0.038). The non-user group prioritized factors related to Criterion A when assessing risk more than the escooter user group, whereas the e-scooter user group prioritized factors related to Criterion E more than the non-user group. Overall, when considering the priority of each evaluation criterion, e-scooter users and non-users prioritized criteria E > F > B > C > D > A and B > E > A = F > C > D, respectively (Fig. 4).

5. Discussion

5.1. Differences in risk assessment tools

The results demonstrated that both user groups showed differences in their risk perceptions between textual and video assessments in specific risky riding scenarios. Participants generally rated the risk levels lower in video-based assessments than in text-based assessments in most scenarios. However, in scenarios deemed especially risky, such as "sidewalk riding face to face" and "sidewalk overtaking," participants rated the risk higher after watching the video than the text-based assessments. Moreover, perceived control significantly decreased in video-based assessments, regardless of e-scooter riding experience. This suggested that the descriptive tool used for risk assessment influences the perception and understanding of the risk being evaluated. Based on these findings, H0-1 is partially rejected, indicating that participants assessed the risks of e-scooter use differently in text- and video-based assessments. Among the 14 scenarios, the hypothesis was rejected in 11 scenarios for the e-scooter user group and eight scenarios for the non-user group.

This is consistent with the results of Lee and Park (2022) [7], which appeared to be due to differences in referencing risks between text- and video-based assessments [71,72]. Participants may have relied on their own experiences in text-based assessments [30]. Owing to the significant psychological impact of negative experiences [73], participants might have shown a tendency to rate their perceived risk relatively higher for most scenarios in the text-based assessments than in the video-based assessments.

Differences in perceived risk were also observed between the two groups across assessment tools. Specifically, while the perceived risk of the non-user group was unchanged in the "sudden braking" scenario, that of the e-scooter user group changed significantly after

Table 11

Descriptive statistic	s of the willingnes	ss to share for	each risky	v behavior.
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Risky behaviors	Willingness to share for the e-scooter user group	Willingness to share for the non-user group	
Sidewalk riding	3.20(1.47)	3.10(1.48)	
Sidewalk riding face to face	2.00(1.08)	2.75(2.05)	
Sidewalk overtaking	1.95(1.19)	2.35(1.14)	
Not wearing a helmet	4.65(2.30)	5.00(1.59)	
Excess passengers	2.40(1.47)	2.95(1.76)	
Inconsistent speed	3.55(1.96)	4.00(2.03)	
Speeding	4.25(2.22)	4.60(1.70)	
Zigzag driving	2.40(1.85)	3.10(1.55)	
Sudden braking	1.65(1.42)	2.50(1.99)	
Insufficient distance from vehicles	3.25(1.94)	3.80(1.77)	
Using mobile phone	2.00(1.26)	2.10(1.52)	
Carrying belongings	4.20(1.77)	3.90(1.80)	
Wearing audio devices	3.65(2.03)	3.95(1.73)	
Unprepared braking action	3.85(2.11)	5.10(1.65)	

Note: Mean values and standard deviation for each risky behavior (with standard deviations in parentheses).

Pearson's correlation between willingness to share as a pedestrian for each risky behavior and perceived control in the e-scooter user group.

Willingness to share for risky behavior	Perceived control for the e-scooter user group		
	r	p-value	
Sidewalk riding	0.552	0.006	
Sidewalk riding face to face	0.586	0.003	
Sidewalk overtaking	0.451	0.023	
Not wearing a helmet	0.580	0.004	
Excess passengers	-0.224	0.171	
Inconsistent speed	-0.025	0.458	
Speeding	0.479	0.016	
Zigzag driving	0.437	0.027	
Sudden braking	-0.147	0.268	
Insufficient distance from vehicles	0.077	0.373	
Using mobile phone	-0.025	0.458	
Carrying belongings	0.050	0.417	
Wearing audio devices	0.083	0.364	
Unprepared braking action	-0.117	0.311	

Note: Two-tailed Pearson correlation coefficient (r) and p-value. The significance of correlation was tested at 0.05 level. Statistically significant correlations are highlighted in bold.

Table 13

Pearson's correlation between willingness to share as a pedestrian for each risky behavior and perceived control in non-user group.

Willingness to share for risky behavior	Perceived control for the non-user group		
	r	p-value	
Sidewalk riding	0.348	0.067	
Sidewalk riding face to face	0.181	0.223	
Sidewalk overtaking	0.376	0.051	
Not wearing a helmet	0.244	0.150	
Excess passengers	0.375	0.052	
Inconsistent speed	0.349	0.066	
Speeding	-0.279	0.117	
Zigzag driving	0.446	0.024	
Sudden braking	0.089	0.355	
Insufficient distance from vehicles	0.476	0.017	
Using mobile phone	-0.009	0.484	
Carrying belongings	0.321	0.084	
Wearing audio devices	0.279	0.116	
Unprepared braking action	0.013	0.479	

Note: Two-tailed Pearson correlation coefficient (r) and p-value. The significance of correlation was tested at 0.05 level. Statistically significant correlations are highlighted in bold.

viewing the video instructional material. Perceived control was slightly higher for the assessment methods in the e-scooter user group than that in the non-user group. This suggests that evaluations of the perceived magnitude of risk and extent of control may vary depending on the tools used to describe e-scooter risks and evaluators' experiential characteristics. Previous research on risk perception explained these findings partially. E-scooter users may explore risk-related cues more efficiently than non-users [74–76]. These results support the finding that the e-scooter user group had a higher risk perception in both assessments than the non-user group. However, repeated exposure to risk can cause adaptation to danger, resulting in lower attention and vigilance toward risky circumstances [77,78]. E-scooter users may have a higher sense of perceived control as they become accustomed to such risks. Previous studies on road users' traffic safety behaviors, have indicated that perceived control significantly influences behavioral intentions [63, 79]. Despite the higher perceived risk in both assessments, the e-scooter user group exhibited higher perceived control than the non-user group. This suggested that to reduce risky behaviors among e-scooter users, it may be more effective to focus on changing their perception of their ability to avoid such risky behaviors, rather than emphasizing the dangers associated with those behaviors. Future research should further investigate factors that influence risky behavior. In relation to this, there are cases in which various intrinsic factors have been analyzed to explain the risky behavior of cyclists, such as attitude toward risky behavior, subjective norms, perceived behavioral control (the difficulty of controlling the behavior), risk determination (the likelihood of being involved in an accident), and perceived self-efficacy [80].

5.2. Multifaceted risk perception

The results showed that individual risk perceptions and attitude were multifaceted. The risk assessment of e-scooters was based on

Rank of the risk assessment criteria 0 1 5 9 1 1 2 9	3.50(1.88) 4.90(1.02)	2.80(1.70) 3.10(1.80)	3.55(2.04) 3.40(1.93)	4.20(1.54) 4.00(1.69)	3,40(1.35) 2.55(1.19)	3.50(1.79) 3.05(1.57)
	A	В	С	D	E	F
H-value	5.486	0.160	0.085	0.119	4.293	0.553
p-value	0.019	0.689	0.771	0.730	0.038	0.457

Six risk assessment criteria: A) physical riding environments, B) human and physical obstacles in complex riding environments, C) lack of consideration for other road users by e-scooter riders, D) insufficient skill or proficiency in e-scooter operation by riders, E) neglect of attention obligations by e-scooter riders, and F) insufficient safety awareness of e-scooter riders.

e-scooter user group

non-user group

Fig. 4. Priority considerations provided by the e-scooter user and non-user groups assessing the risk of e-scooters.

three factors: perceived risk, willingness to share, and perceived control. Significantly negative correlations were observed between perceived risk and willingness to share in all risky riding conditions for both participant groups. This finding supports previous research suggesting that perceived risk influences risk acceptance [26,81].

However, the correlations between willingness to share, perceived risk, and control varied based on e-scooter riding experience. These findings partially support the rejection of H0-2 and H0-3, as significant correlations were observed among the user group across various scenarios, while non-users showed similar correlations only under specific conditions. For H0-2, the hypothesis was rejected in five scenarios for the e-scooter user group and one scenario for the non-user group. For H0-3, the hypothesis was rejected in six scenarios for the e-scooter user group and two scenarios for the non-user group. Significant correlations were observed between perceived control and willingness to share in scenarios such as "sidewalk riding," "sidewalk riding face to face," "sidewalk overtaking," "not wearing a helmet," and "zigzag driving" in the e-scooter user group. This suggests that the more e-scooter users feel they can control the situation, the more likely they are to tolerate the risky behaviors of other e-scooter users and share the road when they are pedestrians. Additionally, a significant correlation was observed between the perceived risk and control in the same scenario. Notably, users' perceptions of their ability to control the situation may vary depending on their level of perceived risk, indicating that perceived risk influences their sense of control. In the non-user group, significant correlations were similarly observed between willingness to share, perceived risk and control, in the "zigzag driving" scenario. However, in the "insufficient distance from vehicles" scenario, significant correlations were observed between perceived risk and willingness to share, as well as perceived control and willingness to share. No significant correlation was observed between the perceived risk and control in this scenario. These results provided a partial answer to RO1, as significant differences in risk perception were observed between e-scooter users and non-users in certain scenarios. This suggested that, when non-users perceive risk in certain situations, the relationship between their sense of control and risk perception may be weak. Notably, their perceptions of their ability to control the circumstance may not necessarily be reinforced by their perceptions of risk. This is likely because the assessment focused on external risks posed by e-scooter users, rather than pedestrian behaviors.

This suggested that while perceived risk is an important factor in explaining risk attitude and acceptance, risk perceptions are multifaceted determinations that involve various factors. Therefore, when assessing risk, it is desirable to use various factors to explain it. This is consistent with studies by Berge (2019) [34] and Che et al. (2021) [35], which indicated that experience plays a role in shaping e-scooter risk perception. Compared to the non-user group, the e-scooter user group demonstrated a more consistent and stronger influence of perceived risk and control on risk acceptance (willingness to share). Particularly in the e-scooter user group, negative correlations were observed between perceived risk and control for illegal behaviors, such as "not wearing a helmet" and "sidewalk riding," whereas positive correlations were observed between willingness to share and perceived control. This suggested that participants with e-scooter experience may have a comprehensive understanding and increased awareness of illegal riding behaviors than those without such experience.

5.3. Different risk assessment priorities based on e-scooter experience

The main theme of this study was the effect of e-scooter riding experience on the perception of risks. Consistent with previous

research, e-scooter experience is a significant predictive variable in risk estimation for identical risk situations [16,38,82]. For instance, the perceived risk of the e-scooter user group was generally higher than that of the non-user group, and the correlations between the perceived risk indicators in each situation showed different trends between the two user groups.

The participants' responses regarding the conditions they prioritized when evaluating the risks of e-scooters showed that the evaluation criteria for risk situations varied based on experience. Particularly, the e-scooter user group prioritized personal factors of e-scooter riders, such as "lack of attention of the e-scooter riders" and "lack of safety awareness of e-scooter riders," whereas the non-user group did not. The observed differences in risk assessment prioritizes between user and non-user groups provide support for rejecting H0-4, as e-scooter experience influences the prioritization of risk factors. Considering the additional interview statements, it seems that multiple criteria were considered rather than a single criterion when assessing risky situations:

"Situations in which pedestrians and e-scooters riders are face to face on the sidewalk, the risk of a crash is higher if the rider is unskilled, and there are manmade obstacles."

"The risk is highest in situations such as speeding, riding with excess passengers, using a mobile phone, and wearing audio devices, due to both the rider's lack of safety awareness and lack of consideration for other road users."

5.4. Practical implications

This study emphasized the influence of e-scooter riding experience on risk perception and provided valuable insights for developing safety education materials and promotion campaigns in universities. Contrary to typical urban roads, universities vary significantly in terms of their traffic systems and pedestrian density. Vehicles on campuses travel at lower speeds, and the absence of formal traffic signals increases the likelihood that road users navigate without explicit lane separation. This leads to frequent and complex interactions with pedestrians [83,84]. Therefore, it is crucial to develop educational and campaign materials that reflect these unique environmental characteristics. Particularly, e-scooter users should be provided with clear riding rules and strategies to avoid risky behaviors, especially those involving interactions with pedestrians. Furthermore, based on the finding that e-scooter users perceive higher risks and exhibit higher perceived control, it is important to develop materials that mitigate the influence of this perceived control on risk behaviors. Emphasizing the limitations of control or consequences of risky behavior may effectively encourage cautious behavior.

5.5. Limitations

This study had several limitations. First, fourteen scenarios were examined, which may not have captured the diverse risk contexts. Additionally, the small sample size may have limited the generalizability of the findings. Another limitation of this study is that the analysis of correlations among key indicators of risk perception, such as perceived risk, willingness to share, and perceived control, does not allow for the determination of causal relationships. While correlations provide valuable insights into the relationships between these indicators, they do not establish whether changes in one variable directly influence changes in another. Future research should explore more behaviors related to e-scooter usage, use a larger sample size to enhance the robustness of the results, and investigate potential causal pathways among these key indicators. Moreover, urban conditions, contrary to universities, are characterized by high speeds, more complex traffic signals, and a variety of transportation modes. In these conditions, it is essential to investigate how e-scooter users' compliance with traffic regulations varies and their relationship with pedestrians. Despite these limitations, this study remains significant as it examines how road users perceive and understand e-scooter-related risks using various.

6. Conclusions

This study addressed the risk scenarios caused by the behavior of e-scooter riders in universities. Specifically, the validity of the risk assessment tools was analyzed by comparing the perceptions of e-scooter risks between e-scooter user and non-user groups based on two risk descriptive tools and various risk factors. The results showed that participants' risk perceptions varied depending on the assessment tool used to describe the risk in a particular scenario and their experience. These findings highlighted the importance of appropriate assessment tools for effective risk communication and assessment strategies. This research is expected to contribute to the establishment of traffic safety policies for e-scooters and could be extended to other modes of transportation.

CRediT authorship contribution statement

Yu Gyeong Son: Writing – review & editing, Writing – original draft, Investigation, Formal analysis, Conceptualization. Min Joo Kim: Writing – review & editing, Investigation, Data curation. Yushin Lee: Writing – review & editing, Supervision, Methodology. Donggun Park: Supervision, Project administration, Funding acquisition, Conceptualization.

Ethical statement

All participants were informed about the purpose and procedure of this study and signed the written informed consent. This study was approved by the Institutional Review Board of Pukyong National University (No. 1041386-202310-HR-116-02) in accordance of

ethics and guidance for the experiment involving human subjects.

Data availability statement

Data will be made available on request.

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Declaration of competing interest

The authors declare no conflict of interest.

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