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RISK PERCEPTION AND PRODUCT SAFETY IN USER-CENTERED DESIGN

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ABSTRACT

When customers decide which product to buy, the perceived risks associated with the purchase are typically part of consideration. The customer's purchase decision is directly related to the perceived risk about finance, safety, reputation, or others. It is important to incorporate the customer's perception of risks in user-centered product design. Existing research of risk perception in product development focuses on the warning label design to ensure that consumers are aware of product safety and potential hazards. There is limited work on how to design the product itself with the consideration of risk factors. In this research, the effects of risk perception from consumers on design are studied. The results show that the perceived product safety by customers can be independent from objective measurements of risks. The perceptions are influenced by individual experiences, information obtained from government regulations and standards, as well as personal characteristics. Design variables related to the levels of comfort, aesthetics, and performance for automobile could affect the customers' perception about vehicle safety.

Keywords: risk perception, probability, consequence, product safety, user-centered design

1. INTRODUCTION

Although there is no unique and universally accepted definition of risk [3], risk is usually regarded as the combination of probabilities of adverse events and the corresponding consequences. In engineering applications, the major risk of a product is closely associated with reliability and safety, which have been extensively studied. Reliability emphasizes a product or system's ability to function under uncertain conditions for a specified time period. The probabilistic description of the states of the product under uncertainty is the main approach that we use to model and analyze reliability. Safety engineering also considers the consequence of failure in addition to the probability. Significant studies have been given in reliability and safety engineering. Recently research efforts were also given to risk management for product development process [40]. Risk management methods such as iterative review [41], characteristics identification [42], and management maturity level identification [43,44] were developed. Quantitative methods such as Bayesian networks [45] and graphical evaluation and review technique (GERT) [46] have also been applied in assessing and managing different risks in the development process.

Risk can be analyzed from two perspectives, objective and subjective. Objective risk is typically quantified with the combination of probability and consequence, whereas subjective risk is an individual's feeling about the importance of an amount at stake and subjective certainty that a person will gain or lose all or some of the stake. That is, the subjective risk is the individual's perceived risk. When customers decide what to purchase, the perceived risks associated with the products are typically considered in their decision-making process [3,6]. There is also another distinction between the perceived risk in product category and the product-specific one. Product category or inherent risk is the latent risk associated with an entire class of products perceived by the consumer, whereas product-specific or handled risk is the risk associated with a specific model of a product [9,19]. When a consumer is making the decision of whether to buy a product or not, he/she usually first evaluates the inherent risk associated with the product as a whole category. If purchasing this type of products is desirable, the handled risk for a specific brand or model will be evaluated [6]. Given that customer's decisions of purchase are heavily involved with the risks associated with products, it is important to incorporate the customer's perception of risks in a user-centered product design paradigm.

Although the importance of risk in product engineering has been well recognized, there is limited research work to study how to incorporate perceived risk of customers in user-centered product design. Existing research of risk perception in product development focuses only on the warning label design [35-37] to ensure that consumers are aware of product safety and potential hazards, such as the ones in Figure 1. There is limited work on how to design the product itself with the consideration of risk factors. In this research, the potential effects of risk perception from consumers on product design are studied. We focus on the characteristics of products that influences customers' risk perception. A survey study is conducted to identify the major factors that have impacts on customer's risk perception. The research question is to identify what the influential factors are for risk perception related to product safety.

Figure 1. Examples of safety risk warning labels for product and equipment

2. BACKGROUND

2.1 Risk Perception

In customer decision-making process, perceived risk is a function of the amount at stake in the decision and the individual's feeling of subjective certainty that he/she will "win" or "lose" all or some of the amount at stake [6]. The amount at stake for a purchase is proportional to the importance of his/her goal.

While risk and uncertainty are certainly related, they are different concepts. Risk has a known probability, but uncertainty exists only when a precise probability is unknown. However, the knowledge of a precise probability is not especially important to consumer decision making. In risk perception, both consequences and their probabilities could be not precisely known and vary between individuals. There is also a distinction between risk attitude and risk perception in decision making. Risk attitude is decision maker's preference for risky actions such as design [5, 15, 28] and quantified by the difference between his/her certainty equivalence and expected utility, whereas risk perception is how risky an action is perceived as being. For instance, entrepreneurs do not actually have the risk attitude that people may believe they do, but they instead have an overly optimistic perception of the risks involved in their ventures.

Risk perception has been extensively studied by researchers of risk analysis. Various approaches have been developed to model the risk perception differences among individuals, including mental models [20], social amplification theory [21], risk information processing model [10], psychometric paradigm [12,24], attitude-behavior model [30], and cultural risk theory [8]. Risk perception is influenced by many factors, such as cultural differences [23], political and ideological biases [32], genders [13], risk targets [25], affect and emotion [26,29], communicator's characteristics [27], controllability [18], etc. Table 1 lists three main approaches that model the differences between individuals' risk perceptions.

Table 1. Summary of major risk perception models

Models	Summary
Mental models[20]	The main steps are as follows: Step 1. create an expert model. Step 2. conduct mental model interviews. Step 3. conduct structured initial interviews.
Social amplification theory[21]	The main thesis is that hazards interact with psychological, social, institutional, and cultural processes in ways that may amplify or attenuate public responses to the risk or risk event.
Risk information processing model[10]	This method articulates a model that focuses on characteristics of individuals that might predispose them to seek and process information about health in different ways.

2.2 Objective Risk

Different from perceived or subjective risk, objective risk can be quantitatively measured by the frequencies of adverse events and identified with risk factors. Objective risks can affect the risk perceptions, and the two are usually positively correlated [38,39]. Objective risks can be quantified according to the contributing factors and components. These factors usually are directly measureable and statistics are typically available. Here, we use automobile safety risk to illustrate.

A vehicle's safety depends on several factors, including its make, model, year and size [16]. Newer cars tend to be equipped with advanced safety features such as more airbags, electronic stability, crash avoidance technology, and bodies engineered to prevent rollover. The Insurance Institute for Highway Safety (IIHS) found that collision fatalities in the latest models of vehicles dropped by more than a third in the past three years. The IIHS and the National Highway Traffic Safety Administration (NHTSA) evaluate crashworthiness, which is how well a vehicle protects its occupants during a crash. They emphasize different factors that could be important to customers. The bottom line is that new technologies lower the chances of collision, injury, and death. Table 2 lists six major risk factors to analyze the objective risk of vehicle safety, including size, body build, tire pressure monitoring system, airbag, electronic stability control, and crash avoidance technology.

Table 2. Objective risk factors of automobile safety [16]

Factors	Example Statistics
Size	Regular size cars have a death rate of 56 per million, while mini-cars have an average of 82 deaths per million.
Body Build	Older vehicles do not redirect the energy of impacts as well as newer models because of the steel used to construct the body and reinforce the vehicle's frame.
Tire Pressure Monitoring System	Tire Pressure Monitoring System (TPMS) became mandated in 2007. NHTSA estimates that this safety feature can prevent upwards of 79 deaths and 10,365 injuries each year in the United States.
Airbag	IIHS research shows that front airbags reduce driver fatality in frontal crashes by 29 percent, and additional airbags reduce driver death by 37 percent in cars and 52 percent in SUVs
Electronic Stability Control	Electronic stability control (ESC) uses speed sensors to allow each wheel of the vehicle to brake individually, which is the foundation of anti-lock brakes. Rotation and steering sensors detect the vehicle's position and auto-adjust the brakes on the wheel, giving the driver more control.
Crash Avoidance Technology	Crash avoidance technology includes several systems that can greatly reduce the risk and severity of collisions, including adaptive cruise control, adaptive headlines, back-up cameras, blind spot monitors, and front crash prevention systems, which can ultimately lower the chances of collisions and injury.

2.3 Factors to Affect Risk Perception

Risk perception is affected by the information that an individual receives as well as how information is received. Public and private information channels have different influences (e.g., government report vs. news media and social media). How much information to communicate and when to communicate specifically to the target individual have major impacts on this individual's risk perception. The influential factors also come as the culture in the society and groups, peer pressure, the education levels of individuals, levels of scientific knowledge, prior experiences, personal beliefs, and political orientation [34].

An individual's risk perception does not rely equally on the consequence of hazard and possibility. Instead, it appears to rely more on the consequence of hazard than on the probability. The actual value of probability of event occurrence has much less influence on the consumer's perception of risk. Cunningham [7] found that the consumer cannot differentiate between the concept that there is 80 percent of chance he or she would make a bad purchase and the one that he or she just might make a bad purchase. Therefore, ambiguity and partial ignorance are the inherent characteristics of the perceived risk. Some researchers [27] even argued that the actual objective risk does not exist. For example, a piece of manufacturing machinery such as a power press is likely to be perceived as having very high risk because it could cause a great deal of harm, even though there are a variety of safety precautions built into both the machine and its operating procedure that greatly reduce the risk of injury. On the other hand, the risk perception of a box cutter is very low because it typically causes only minor injuries, even though these injuries are much more common than those due to heavy machinery. This effect results in overestimation of risk for products with the potential for causing great injury and underestimation of risk for products likely to cause more minor injuries. Engineers need to be mindful of the perceived risk of products when making design decisions so that perceived risk and objective risk are as closely aligned as possible.

It is common for lay persons to form the perception of risk that is different from experts. Young et al. [33] conducted a survey study about risk perception related to product safety. It was found that subjective ratings given by participants about safety risks are independent from the objective measures of severity and frequencies of injuries according to the National Electronic Injury Surveillance System (NEISS) data, such as frequency of hospital visits. Furthermore, the effectiveness of product safety warning labels is dependent on other factors of individuals, such as the cautious intent. Cautious people are likely to read the warning labels. Through a series of surveys, it was seen that there is no connotational difference between 'risk' and 'hazard' for lay persons. There are strong correlations among the perceived overall danger, injury severity, likelihood of injury, cautious intent, and willingness to read warnings. It was shown that likelihood and consequence are not clearly differentiated in lay persons' risk perception. The overall danger and severity of potential injury predict cautious intent much better than the likelihood of injury. In other words, the severity of the potential consequences motivates caution much more significantly than the probability of incurring an injury. The results imply that the subjects were unable to capably estimate the probability of injury. The study reaffirmed that there is a difference between subjective risk perception and objective measures, and lay persons interpret risks differently from experts.

2.4 Risk Perception for User-Centered Design

Garrett [14] studied the elements of user experience and presented that there are differences between designing a product and designing a user experience. In some simple cases, the requirements to deliver a safe and pleasant user experience are built into the definition of the product itself. With more complex products though, the requirements to deliver a successful user experience are dependent on more than the definition of the product. It was found that the more complex a product is, the more difficult it becomes to identify exactly how to deliver a safe and pleasant experience.

To increase the safety index of customers in user-centered design, Martin and Wogalter [17] performed a user study to determine if accident scenario analysis reduces accident frequency mis-estimation and leads to a heightened precautionary intent. It was found that hurried subjects reported lower precautionary intent than unhurried subjects, though their frequency estimates were equally accurate. Subjects with injury experience (either themselves or someone they knew) reported higher precautionary intent than subjects without this experience. There was no relationship found between precautionary intent and frequency estimates, though it appears that accident frequency estimates were influenced to some extent by perceptions of severe injury. Being provided with accident scenarios does not appear to correct risk perception errors or increase precautionary intent, therefore it is not a viable solution to preventing product injuries. This study suggests that increased perception of more severe injuries increases precautionary intent.

Polinsky and Shavell [22] proposed to use liability to adjust the risk perception of consumer on product. If a product's risk is being consistently underestimated, which could lead to low levels of precaution and potential injury. The product could be designed to appear more dangerous to increase the perception of risk (without, of course, increasing the actual risk). In other words, a product could be made safer through the increase of precautionary intent by making the product appear to have the potential for greater injury. However, this would likely conflict with a product development team's desire to increase marketability of the product because safer products are generally preferred by consumers. Therefore, an appropriate perception of risk benefits customers and designers through facilitating the safety of users.

Weegels and Kanis [31] examined the significance of risk perception and awareness in understanding and clarifying how and why accidents (specifically those involving consumer products) occur. Participants (who were involved in accidents with consumer products) were asked to demonstrate what happened so the accident could be reconstructed. They were also interviewed to determine their awareness of the risks involved. Based on this information, it was found that many subjects had no idea that they had any significant risk of injuring themselves while operating the product. From this, it can be concluded that the product was either being used in a way that was not anticipated in its design or the design did not accurately portray the risk involved with the product's use.

Given that injuries caused by regular consumer products have often been reported, it is suspected that consumer products usually appear safer than they are because the product design does not accurately project its true risk. This is likely because it is easier to market a product that appears safer. The important issues associated with designing for risk perception are how to prevent users from using the product in a potentially risky way other than its intended use and how to accurately portray risk such that users are constantly aware of it, without becoming accustomed and unresponsive to it.

3. REGULATION, STANDARDIZATION, AND PERCEPTION OF PRODUCT SAFETY RISK

The consideration of risk perception is important in designing consumer products in industries. A carefully designed product can lead to a desired level of risk perceived by customers, if the influential factors can be identified. For instance, in automobile industry, the models of family minivans and sports cars are targeting at different customers. The perceived safety risk of minivans from the vehicles' behavior, performance, appearance, reputation, and others needs to be low enough to attract customers. The targeted levels of risk perception for sports cars however may be different with a different group of potential customers. In contrast to automobile, the design of roller coasters in theme parks is different. The customers of theme parks are seeking thrilling experiences and risky activities. Therefore, the perceived risk should be high enough to be attractive. In this case, the roller coasters need to be designed with a high level of perceived risk but the objective risk should be very low.

Government regulations and standards play an important role in the formation of risk perception for customers. In various industries such as automobile, there are restrictive government regulations for safety. Industry-wide standards also often exist for manufacturers to follow. As the major stakeholder, insurance companies usually require designers and manufacturers to practice according to certain guidelines. Here we use examples of automobile, amusement park, and bicycle helmet to illustrate the effect of regulations and standards in risk perception.

3.1 Automobile

The U.S. government sets regulations for cars at a federal level, which influences engineering design to the extent that the products need to satisfy these requirements. These cars are also rated for safety by the IIHS. The crash test protocols involved in this formulaic rating are published publicly online for both consumers and manufacturers. Manufacturers are able to design for performance on these tests, which is ideally the same as designing for safety, if the tests and ratings are truly good measures of safety. These safety ratings in combination with the compliance to government regulations significantly influence consumers' risk perception of various automobiles. The government regulations help reduce the safety risks perceived by automobile users in general. The IIHS ratings on individual car models help users refine their perception on the individual cars. Manufacturers are aware that these ratings influence consumers' perception of the car safety, which in turn affects the marketability of their products.

In the IIHS ratings, there are different size classes, including mini-cars, small cars, midsize cars, midsize luxury cars, small SUVs, large SUVs, minivans, small pickups, etc. Even in the same size class, it provides specific safety ratings for different kinds of automobiles, such as 4-seat sedan and 4-seat wagon both of which are in the small car category. Customers usually pay more attentions on the factors such as size and car type because of the influence by government regulations and insurance company standards.

3.2 Amusement Park

Similarly, amusement parks and their rides are regulated through local and state governments as well as insurance companies. However, unlike the automotive industry, the theme park industry voluntarily united to form a set of standards and regulations to govern themselves with the help of ASTM. Again, the existence of and adherence to these standards reduce the risk perceived by customers.

This standard has specific provisions on the structure and specific components of roller coasters. ASTM F2960-16 standard [2] is applicable to the design, manufacture, installation, operation, maintenance, and inspection of permanent amusement railway vehicles with a track gauge greater than or equal to 12 inches (305 mm), and its associated installations and facilities, such as bridges, tunnels and signal support structures other than vehicles.

This industry is rather unique in that, while these parks want to have very low actual or objective safety risks, they want to make their rides seemly thrilling enough to attract risk seekers. To accomplish this, roller coasters and other thrill rides are built to go higher and faster such that the potential consequences of failure are catastrophic, while at the same time all of the systems are highly regulated and tested so that the probability of the failure is very small and nearly negligible. Based on the studies of risk perception, this is the optimal way to increase risk perception while maintaining a low level of objective risk, as a combination of likelihood and severity of consequences.

3.3 Bicycle Helmet

Helmet safety is regulated by the U.S. Consumer Product Safety Commission (CPSC) standard, which is mandatory for all helmets manufactured for sale in the U.S. after 1999. It was based on the ASTM and Snell standards, and it requires dropping the helmet 2 meters in the flat anvil test.

The ASTM F1447-18 standard [1] pays special attention to the helmet mass and the quality of important components. This specification recognizes the desirability of lightweight construction and ventilation. For example, helmets shall be impacted with anvils centered on or above the prescribed test line. Each hot, cold, wet, and ambient helmet should be tested with flat and domed anvil shocks individually. The peak acceleration is measured during the impact. Position stability (roll) test also is carried out for ambient helmets. The movement strength maintenance test is conducted for hot, cold, and wet helmets.

A helmet functions as an external prevention of accident injuries during bicycling. Even though the wearing of a helmet is not mandatory, the safer a helmet can make consumers feel, the more likely that they will make the purchase. Therefore, the risk perception plays an important role in the sale of bicycle helmets.

4. METHODOLOGY PROPOSITION FOR IDENTIFICATION OF INFLUENTIAL FACTORS FOR RISK PERCEPTION

In this study, we conducted an online survey to test users' risk perceptions about automobile safety. The collected data were analyzed and some influential factors of risk perception about product safety are identified.

From the study of the published regulations and standards, it is seen that size, shape, color, mass, structure, quality of specific components are important safety factors to be regulated. From the literature review, we summarized some major influential factors of risk perception that design engineers need to consider for product design. The proposed risk perception factors are listed in Table 3. For vehicles, open space is also a design factor.

The survey questions were designed based on the identified major risk perception factors and focus on automobile design. The survey questions are both graphical and textual so as to facilitate the imagination of the subjects. Some example questions are listed in Table 4.

A controlled study was conducted with 104 participants including both genders, marriage status, and different personal characters, ages and driving experience. Participants were given brief information regarding the purpose and procedure of the study, but no specific details about the design task, the purpose of risk and personality measures. Once informed consent was obtained, participants were asked to complete an online survey to assess individually perceived risk and ambiguity perception using a set of 36 questions including ranking, rating, and short answers.

Since risk is simultaneously quantified by two aspects, probability and consequence, the survey is designed to collect information by asking "what the probability of getting injured (high, medium, low) is" and "how serious the injury (high, medium, low) could be" separately.

5. RESULT AND DISCUSSIONS

After data are collected, factor analysis is first applied to summarize users' most concerned product features related to risk perception so that relationships and patterns can be identified. Then the perceived risk levels are assorted separately according to five personal factors, which are personality, gender, driving experience, age, and marriage status. Because the factor of personality or personal character is not easy to collect directly, we design a small questionnaire for respondents and quantify their personal characters based on the answers.

5.1. Factor Analysis of Product Features

We applied factor analysis to regroup the influential factors for risk perception rated by customers into a limited set of clusters based on the shared variance. First, to test whether there are correlations between influential factors of risk perception, we tested the correlations between 9 variables (size, shape, color, mass, structure, quality of specific components, inherent cognition about product types, car speed, and open space of car) through Kaiser-Meyer-Olkin (KMO) measure and Bartlett sphere test, where KMO measure is 0.752 and the significance probability of Bartlett sphere test is 0.000. The test results showed that there are strong correlations between the 9 variables in users' risk perception, which means that the variables are suitable for factor analysis. When selecting how many factors to include in the model, we applied the Cattell's scree test according to the variance, which is accessible in the SPSS statistics software, and finally decided to include three major factors as principal components.

Table 3. Assumed influential factors of risk perception for automobile safety

Factors	Interpretation
Size of product	Size of product is important in designing a safe product. For vehicles, larger cars can leave an impression of more comfortable, sturdy, stable, and consequently safer.
Shape of product	Much attention is also drawn to the geometry or shape of a product when it is first seen by customers. Different shapes can lead to different impressions about a vehicle's performance therefore the chance or severity of injury when accidents are involved.
Color of product	Color influences the appearance of a product to a large extent. Bright colors make products more distinguishable and recognizable such as cars to avoid accidents. Bright colors are also adopted intentionally in bicycle helmets to be more recognizable in a low light environment.
Mass of product	Larger mass always implies higher stability. Sometimes designers increase the mass of automobile and roller coaster vehicles to improve the stability of products.
Structure of product	Structures affect physical properties of products. For example, the center of gravity for cars affect the stability and dynamics of vehicles. The sturdiness of the shell and body decide how much impact absorption the vehicles have. As another example, bionic helmet gets inspirations from human skull structure, which makes the structure of the helmet stronger, and at the same time, the external form of design also makes helmet more fit for the actual head type of human body, thereby providing more safety support.
Quality of specific components	In vehicle design, the design of tires and comfortable level of seats can affect customers' evaluation of the product as a whole, thereby influencing the risk perception.
Open space of automobiles	Car buyers usually perceive more open space as unsafe. When comparing the convertible and other conventional cars, customers who emphasize more about safety may choose the latter.

A. Communality of factors and factor loading

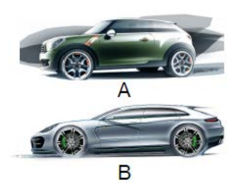
First, we obtained the communalities of the three major latent variables or factors from SPSS, but the unrotated component matrix can hardly tell us which latent factor the variance of an observable variable should be explained by, and how much each factor contributes to the variable's variance if the variance is contributed by multiple factors. In order to reduce the possibility of a variable belonging to several factors, the orthogonal rotation is applied to the factor loading matrix to ensure that the variables with higher loadings are aligned together, as shown in Table 5. After the rotation, a variable can be attributed to one latent factor to a large extent. That is, a variable is strongly associated with only one latent factor, whereas the association to other factors is very small. For example, the variable "car speed" is attributed to factor 1 with a correlation coefficient of 0.821, while for factor 2 it is only 0.075. The larger the factor loading value is, the higher the reliability of explaining the variable variance with this factor is, and the more important the variable is for this factor. From the factor loading matrix in Table 5, the correlation relationship between the variables and factors can be obtained as follows.

The shades in the table highlight how each of the three factors is correlated with or support the variables. Factor 1 has higher loadings in the variables "color", "quality of specific components", "inherent cognition about product types", "car speed", and "open space of car" than the other. These five measurable variables are related to the comfort level of vehicles. Therefore, we name factor 1 as "comfort level" factor for risk perception.

Table 4: Example of survey questions

1a. Which car do you think is safer?

- A
- B



1b. For the car perceived as riskier, please evaluate:

	High	*Medium*	*Low*
• ***what the probability of getting injured is***	○	○	○
• ***how serious the injury could be***	○	○	○

1c. Please rate the following influential factors that help you choose the safer car (from the most important factor to the less important ones.)

- Size
- Shape
- Color
- Mass
- Structure
- Quality of specific components
- Inherent cognition about car types
- Car speed
- Open space of car
- Other

Table 5. Communality of factors and factor loading

Variable	Factor loading			Communality
	Factor 1	Factor 2	Factor 3	
Color	.622	.590	.331	.844
Quality of specific components	.619	.233	.517	.704
Inherent cognition about product types	.761	.242	.329	.745
Car speed	.821	.075	.259	.747
Open space of car	.791	.334	.128	.753
Size	.458	.733	.211	.791
Shape	.079	.851	.289	.813
Mass	.426	.415	.615	.732
Structure	.252	.289	.867	.899

Factor 2 has higher loadings in the variables "size" and "shape", and these two factors are related to the aesthetics of products. Therefore, we name factor 2 as "aesthetic level" factor for risk perception.

Factor 3 has higher loadings in the variable "mass" and "structure", which are related to functioning or performance of vehicles. Therefore, we name factor 3 as "performance level" factor for risk perception.

B. Total variance

In Table 6, the variance contributions (% of variance under the initial eigenvalues) by each of the 9 factors before rotation are listed. It is seen that the most significant factor contributes over 62% of the total variance. The cumulative variances are also shown in the table. It is seen that the first three major factors account for 78.1% of the total variance.

Table 6. SPSS output for total variance

Factor	Initial Eigenvalues		
	Total	% of Variance	Cumulative% of Variance
1	5.597	62.192	62.192
2	0.873	9.702	71.894
3	0.559	6.206	78.1
4	0.495	5.503	83.603
5	0.446	4.952	88.555
6	0.338	3.76	92.314
7	0.301	3.344	95.658
8	0.252	2.803	98.461
9	0.139	1.539	100

The rotation sums of squared loadings are listed in Table 7. Among the extracted three major factors, "comfort level" (factor 1) is in the dominant position, whose variance contribution rate is 34.514%, followed by "aesthetic level" (factor 2) accounting for 23.268%, and the last factor is "performance level" (factor 3) accounting for 20.291%.

Table 7. Rotation sums of squared loadings

Factor	Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative% of Variance
1	3.109	34.541	34.541
2	2.094	23.268	57.809
3	1.826	20.291	78.1

5.2. Result Assorted by Personal Characteristics

A. Risk perception categorized by personal character

The personal characters are collected from a specially designed questionnaire. 104 participants are categorized according to three main personal characters: rational, passionate, and serious. For each group of car pictures, the participants were given questions similar to Example 1b in Table 4. Figure 2 shows the participants' choices for injury probability levels, from high to low, for each of the three personal character types. The values listed above the chart show both the number and percentage of subjects in each category. Similarly, Figure 3 shows their anticipated severity of injury if the accidents had happened.

People with the rational personality show a positive correlation between the estimated level of probability for injury and the estimated severity of injury, while the results from people with the passionate and serious personalities display differences between the probability of injury and the estimated severity of injury. In particular, people with serious personality pay more attention to the color of product.

Probability	High	Medium	Low
Rational	19(30.16%)	34(53.97%)	10(15.87%)
Passionate	7(21.88%)	20(62.5%)	5(15.63%)
Serious	4(44.44%)	4(44.44%)	1(11.11%)

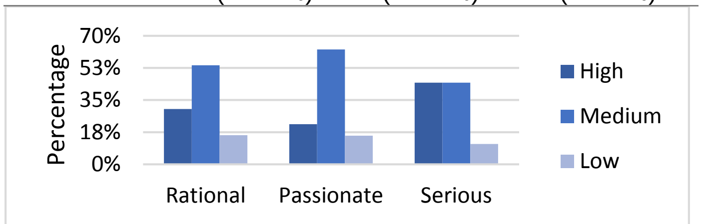


Figure 2. The probability of getting injured categorized by personal character

Anticipated severity	High	Medium	Low
Rational	22(34.92%)	29(46.03%)	12(19.05%)
Passionate	9(28.13%)	14(43.75%)	9(28.13%)
Serious	2(22.22%)	6(66.67%)	1(11.11%)

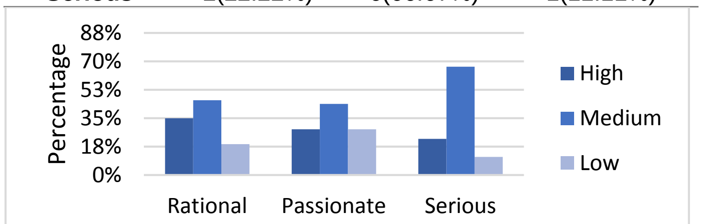


Figure 3. The severity of anticipated injury categorized by personal character

B. Risk perception categorized by marriage status

People's perception of risk may change as they get married. We want to see whether the risk perception behavior shows some pattern with their marriage status. Both married and single respondents pay much attention to the shape and structure of vehicles. Unmarried subjects have higher risk estimations than married ones, and they are more susceptible to the size of vehicles. In general, the relationship between marital status and risk perception is similar to the tendency between age and risk perception. The probabilities and severities of injury with respect to marriage status are shown in Figure 4 and Figure 5 respectively.

Probability	High	Medium	Low
Married	16(27.12%)	36(61.02%))	7(11.86%)
Single	14(31.11%)	22(48.89%)	9(20%)

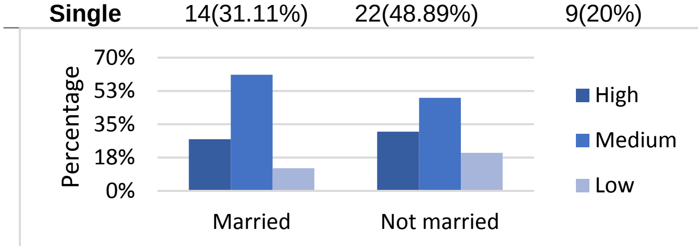


Figure 4. The probability of getting injured categorized by marriage status

Anticipated severity	High	Medium	Low
Married	27(45.76%)	28(47.46%)	4(6.78%)
Single	17(37.78%)	22(48.89%)	6(13.33%)

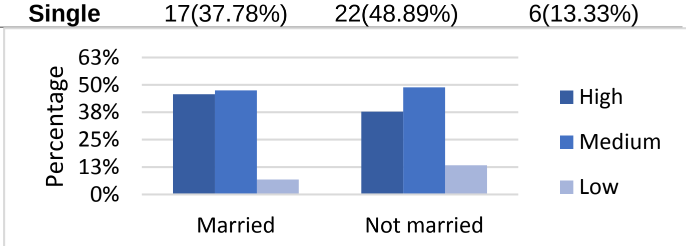


Figure 5. The severity of anticipated injury categorized by marriage status

C. Risk perception categorized by gender

The results of the survey show that women are more likely to feel at risk than men. Both men and women are more concerned with shape than other factors. Interestingly, women are more inclined to judge risks by simulating the scene (such as imagining the speed of a car). Men are more concerned about the quality of certain parts than women. Figure 6 shows the subjects' choices for injury probability level, from high to low, in gender categories. Similarly, the anticipated severities of injury if the accidents had happened are shown in Figure 7.

Probability	High	Medium	Low
Male	13(27.66%)	25(53.1%)	9(19.15%)
Female	12(21.05%)	36(63.1%)	9(15.79%)

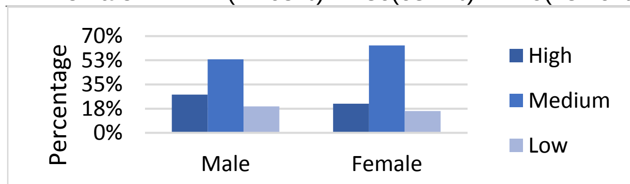


Figure 6. The probability of getting injured categorized by gender.

Anticipated severity	High	Medium	Low
Male	17(36.17)	20(42.55%)	10(21.28%)
Female	16(28.07)	29(50.88%)	12(21.05%)

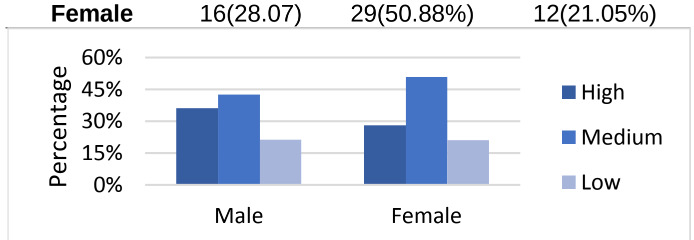


Figure 7. The severity of anticipated injury categorized by gender.

D. Risk perception categorized by age

Risk perception is directly related to experiences as well as cognitive capabilities. In our study, four age groups are considered. The results are shown in Figure 8 and Figure 9. It is seen that teens are likely to have the estimation of the high injury likelihood, and young adults with ages between 26 and 30 are more likely to estimate a higher level of the injury severity than other age groups. The survey results also show that while most people focus on the shape of products in judging the risk level, young adults also pay attentions to other aesthetic factors including size. The subjects who are older than 30 years are more concerned about the quality of the parts involved.

Probability	High	Medium	Low
18-20 yrs	5(41.67%)	6(50%)	1(8.33%)
21-25 yrs	7(28%)	13(52%)	5(20%)
26-30 yrs	6(24%)	14(56%)	5(20%)
>30 yrs	12(28.57)	25(59.52%)	5(11.9%)

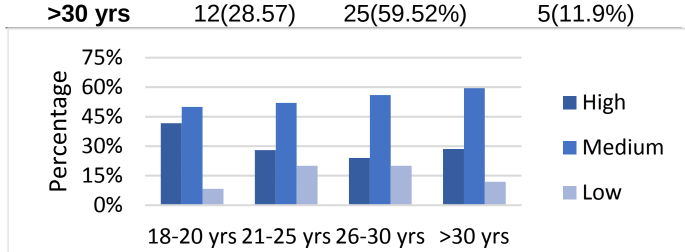


Figure 8. The probability of getting injured categorized by age.

Anticipated severity	High	Medium	Low
18-20 yrs	4(33.33%)	7(58.33%)	1(8.33%)
21-25 yrs	9(36%)	12(48%)	4(16%)
26-30 yrs	12(48%)	11(44%)	2(8%)
>30 yrs	19(45.24)	20(47.62%)	3(7.42%)

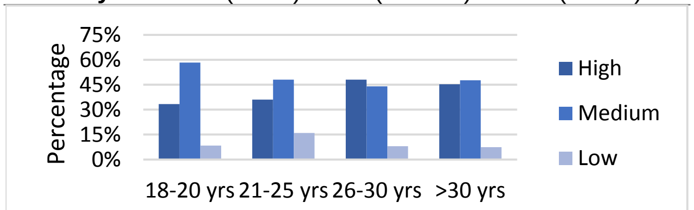


Figure 9. The severity of anticipated injury categorized by age.

E. Risk perception categorized by driving experience

Prior driving experiences, especially the involvement of accidents, naturally affect the formation of the perceived vehicle safety risk. It is found in the survey that the estimated probability of injury from people without driving experience is significantly higher than that from people with driving experience, and the estimated probability of injury was inversely proportional to the driving experience. Those who have been driving for a long time tend to use the speed to judge the risk instead of shape and structure. The perceived probabilities and consequences by subjects with no, short (1-2 years), and long (>2 years) driving experiences are shown in Figure 10 and Figure 11 respectively.

Probability	High	Medium	Low
0 yr	7(46.67%)	6(40%)	2(13.33%)
1-2 yrs	9(25%)	24(66.67%)	3(8.33%)
>2 yrs	14(26.4)	28(52.83%)	11(20.75%)

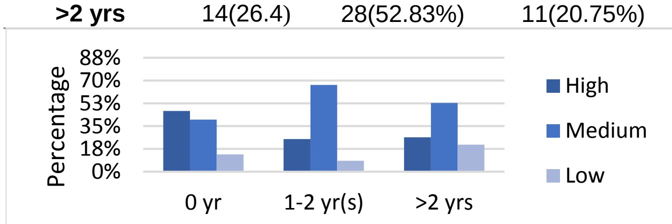


Figure 10. The probability of getting injured categorized by driving experience.

Anticipated severity	High	Medium	Low
0 yr	4(26.67%)	8(53.33%)	3(20%)
1-2 yrs	16(44.44)	17(47.22%)	3(8.33%)
>2 yrs	24(45.28)	25(47.17%)	4(7.55%)

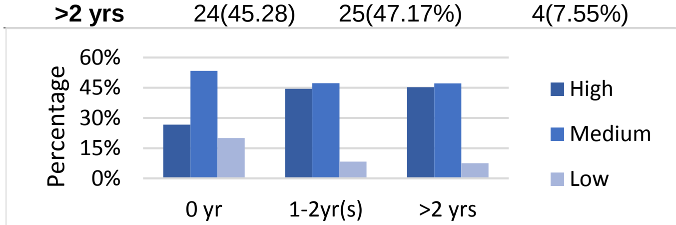


Figure 11. The severity of anticipated injury categorized by driving experience.

5.3. Summary

The participants were chosen to be as representative as possible for risk perception. In the participants of the survey, male accounts for 41.59% and 54.81% are female. Among the participants, 35.58% have experiences of car related accidents, and 44.23% experienced bicycle related accidents.

By analyzing customers' influential factor ratings related to risk perception, it is found that the most sensitive factor for subjects with respect to personal characters is shape. In addition, rational users of cars pay more attention to size, whereas passionate users are more concerned about structure, and the participants with serious personality care more about the color of vehicles.

Ages are related to experiences. The influential factors also vary in different age groups. Younger users in the age groups of 18-20 years and 21-25 years list shape, size, and structure as the most influential factors. However, elder customers regard structure as a more important factor and pay much attention to the quality of specific components.

In analyzing gender differences, we find that male customers rank the three most important factors for safety concern as shape, structure, and quality of specific components. For female customers, the three most influential factors are shape, vehicle speed, and size. For both married and single participants, shape and structure are listed as the two most important factors. Following these two, the married care more about vehicle speed, whereas the singles view size as the third most important risk factor.

The survey result shows that customers with different driving experiences give different rankings of factor importance. Respondents with no driving experience rate shape, structure, and mass as the most important ones. Similarly, respondents with short driving experiences of 1 to 2 years select shape, structure, and size as the most influential factors. More experienced drivers emphasize more on the vehicle speed but less on the structure.

The survey study suggests that it is important for vehicle designers and manufacturers to have a better understanding of their target customers' background so that the perceived risks can be better calibrated. The customers' perception tendency is that the more experienced customers with more in-depth knowledge of products pay more attentions to the specifics of design and also the prominent components, whereas the beginners or less experienced customers tend to judge the risk from a more general scale.

6. CONCLUSION AND FUTURE WORK

This paper presents a study of risk perception about product safety and its potential influential factors that are directly related to product design. Design engineers need to incorporate risk perception in product conceptualization. Multiple factors such as shape, size, and structure of vehicles affect customers' risk perception about vehicle safety. At the same time, reliability and quality of components also have influences to the customers' perception.

In the context of user-centered design, perception based design is still an under-studied research area. Our study shows that design decisions should be carefully made in order to achieve a target level of risk perception, depending on the nature of products and target customers. It is seen that perceived risk can be different from objective risk. Therefore risk perception should not be simply treated as existing objective metrics in reliability engineering. Understanding the influential factors about perceptions will allow designers to optimize the designs and control the perceived risk levels.

The current study focuses on automobile safety risk. The methodology of risk perception factor identification however is generic and can be generalized to other product design. The process of identifying major sources of risks and the influential risk factors of the product, as well as analyzing the customers' responses to the factors, is generally applicable to any product.

In future work, we will perform more quantitative analysis of the survey data and study how sensitive the risk perception can be related to the influential factors and personal characteristics. A quantitative model will be further developed, with additional data collection, to capture the relationship between influential factors and safety risk so that the perception can be predicted. The model can be used to support design decision making. The model can also be applied for quantitative risk assessment on product safety on existing products. The current study focuses on the conceptual design stage. Future work will need to include embodiment and detailed design stages, since safety related risks are also associated with detailed structures, which more complex risk factors can be associated with.

7. ACKNOWLEDGMENTS

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