Heliyon 9 (2023) e13524

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Design and psychometric analysis of the safety harness usability and comfort assessment tool (SH UCAT)

Parvin Sepehr [a], Mousa Jabbari [a,b,*], Hassan Sadeghi Naeini [c], Ali Salehi Sahl Abadi [a], Mansour Ziaei [d,e], Asma Zare [f], Amin Kazemi [g]

[a] *Department of Occupational Health and Safety Engineering, School of Public Health and Safety, Shahid Beheshti University of Medical Sciences, Tehran, Iran*
[b] *Workplace Health Promotion Research Center, Shahid Beheshti University of Medical Sciences, Tehran, Iran*
[c] *Industrial Design Department, School of Architecture & Environmental Design, Iran University of Science & Technology, Tehran, Iran*
[d] *Department of Health, Safety and Environment, School of Health, Bushehr University of Medical Sciences, Bushehr, Iran*
[e] *Systems Environmental Health and Energy Research Center, The Persian Gulf Biomedical Sciences Research Institute, Bushehr University of Medical Sciences, Bushehr, Iran*
[f] *Department of Occupational Health Engineering, Sirjan School of Medical Sciences, Sirjan, Iran*
[g] *School of Mechanical Engineering, College of Engineering, University of Tehran, Tehran, Iran*

A R T I C L E I N F O

Keywords:
Safety harness
Assessment tool
Ergonomics
Fall from height

A B S T R A C T

Purpose: The present study aimed to design a quantitative tool to evaluate the comfort and usability of working at height safety harnesses.
Methods: This cross-sectional study was conducted in both qualitative and quantitative sections in 2022. The research steps included field interviews, an expert panel, and compiling the questionnaires for assessing the comfort and usability of the harness. The items of tools were designed based on the qualitative part of the research and review of the literature. The face and content validity of the instrument were assessed. Its reliability was also evaluated using the test-retest method.
Results: Two tools were developed including a comfort questionnaire with 13 questions and a usability questionnaire with 10 questions. The Cronbach's alpha coefficients of these instruments were 0.83 and 0.79, respectively. Additionally, the content and face validity indices were 0.97 and 3.89 for the comfort questionnaire and 0.991 and 4 for the usability questionnaire, respectively.
Conclusions: The designed tools showed appropriate validity and reliability and could be used to evaluate the comfort and usability of safety harnesses. On the other hand, the criteria used in the designed tools could be employed in user-centered harness designs.

1. Introduction

Falling from a height is one of the major hazards to human health and one of the most important causes of serious and fatal injuries to construction workers) [1](. Falling from a height is one of the occupational accidents in various industries [2](. According to the

* Corresponding author. Department of Occupational Health and Safety Engineering, School of Public Health and Safety, Shahid Beheshti University of Medical Sciences, Tehran, Iran.
E-mail address: jabbarim@sbmu.ac.ir (M. Jabbari).

https://doi.org/10.1016/j.heliyon.2023.e13524
Received 4 October 2022; Received in revised form 31 January 2023; Accepted 2 February 2023
Available online 8 February 2023

report provided by the World Health Organization (WHO) in 2018, 646,000 people die due to falls every year) [3]. The Occupational Safety and Health Administration (OSHA) reported that the main cause of death in the construction industry is “falling from a height”) [4]. Among construction accidents, falling from a height has the highest risk) [1]. Lack of safety equipment and its non-use is one of the main causes of accidents in the construction industry [5]. The use of Personal Protective Equipment (PPE) such as harnesses can sometimes save lives in the accidents caused by falling from heights [6]. Thus, it has been considered as one of the most important ways to protect people against falls. Although harnesses cannot eliminate the risk of falling from a height, they are used as the last resort to save lives [5]. Even though using safety harnesses is a legal requirement for the workers who work at heights, some construction workers may be reluctant to use them due to various reasons such as discomfort, lack of awareness of dangers, inadequate training, and lack of regular inspections) 7, 8. One of the reasons why people don’t feel comfortable in a harnesses is because they are not asked for their opinions regarding the harness design. Since workers may be suspended from harnesses for a long time, they may feel pain, discomfort, and anxiety) [9]. Additionally, the designs of harnesses are generally weak, causing discomfort among users [10]. The fit of the harness to body dimensions can bring better satisfaction and comfort to end-users) [11]. Some studies have referred to users’ dissatisfaction and discomfort with the existing harnesses) [12,13]. For instance, Shamsuddin et al. mentioned discomfort as a reason for not using safety harnesses by workers [14]. To minimize the workers’ perceptions of difficulty and discomfort associated with using a safety harness when working at heights, the safety harness design should be strengthened. People who work at heights have to endure the harness on their bodies for a long time. Therefore, the harness design should help them feel comfortable and satisfied. However, commercially available harnesses cause discomfort as well as severe and persistent pain for end-users [15]. In addition, users should be mentally evaluated to determine their willingness or unwillingness for wearing harnesses [16], because harnesses may be present in the workplace but may not be used properly due to dissatisfaction and discomfort) [17].

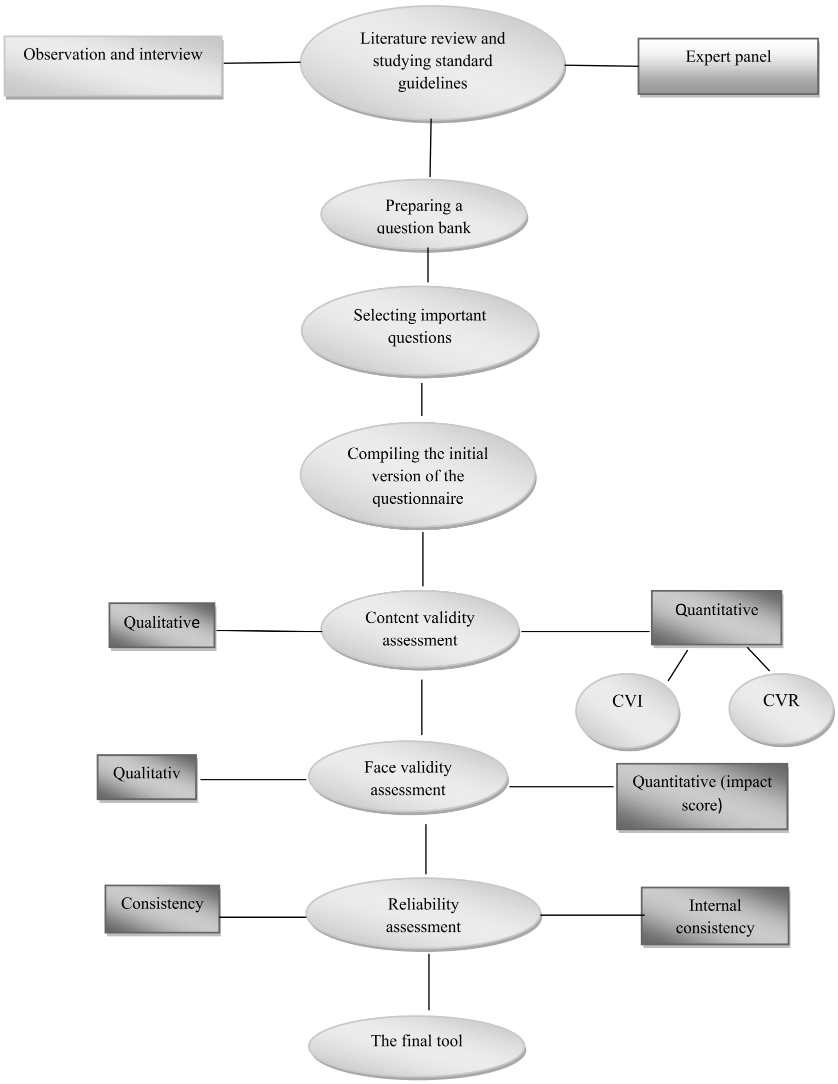

Fig. 1. Flowchart of the questionnaire design steps and evaluation of its validity and reliability.

Up to now, numerous studies have assessed safety parameters in harnesses, but few studies have been done in terms of evaluation of the comfort, satisfaction, and usability of harnesses. Despite the safety of most harnesses, users are reluctant to use them due to the lack of satisfaction and comfort. In general, people use PPE when they feel comfortable and satisfied. Thus, the designs must be user-centered. According to ISO 13407, in user-centered designs, usability requirements have to be incorporated into the development process. In this standard, there are five essential processes that should be used in the development process: (1) user-centered design planning, (2) understanding and defining the field of use, (3) defining the user and organizational needs, (4) production of designs and prototypes, and (5) evaluation by the user) [18]. Studies have indicated that user-centered designs can lead to a reduction in the development time and costs, production of high-quality products, and an increase in end-user satisfaction) [19].

Generally, there are various standards for harnesses, some of which refer to the ergonomics of the harnesses and people's comfort. Despite the existing standards for producing harnesses, workers still feel dissatisfied. Therefore, more comfortable and useable harnesses have to be designed. In this context, a tool is needed to identify the related indices and help produce a user-centered design. The review of the literature revealed no standard tools to assess the comfort and usability of harnesses. Previous studies examined harness comfort and satisfaction through interviews or very few questions. Chae et al. used semi-structured interviews to evaluate comfort and satisfaction harnesses [20]. Angles' study used three questions with a scale of 1–10 in order to observe the discomfort of people using the harness. He also used three open questions about the problems of harnesses, their design and improvement (Angle, 2013). So far, no study has been conducted on assessing the validity and reliability of a questionnaire to determine the satisfaction and comfort as well as the usability of harness. The purpose of this study was to design a quantitative instrument for evaluating the comfort and usability of safety harnesses.

2. Materials and methods

2.1. Study design

This methodological research was conducted in two qualitative and quantitative parts, aiming at designing a tool to assess the comfort and usability of safety harnesses in 2022. In this research, in addition to obtaining an ethical approval certificate from the "Research Ethics Committees of the School of Public Health & Neuroscience Research Center - Shahid Beheshti University of Medical Sciences, Tehran. Iran" with the Approval ID: IR. SBMU.PHNS.REC.1401.083, informed consent was obtained from all participants in the research, and professional and legal requirements were met. A qualitative study was conducted in order to identify the factors related to the non-use of safety harnesses by searching resources, reviewing studies, field observations, and interviewing experts and specialists in the fields of safety and ergonomics. In addition, a quantitative study was performed to evaluate the psychometric properties of the instrument. The flowchart of the study stages has been depicted in (Fig. 1).

Semi-structured interviews were conducted with the participants (eight Iranian and five Afghan construction workers) in a quiet and secluded place at the construction site so that the interviewees could express their real opinions. Additionally, both face-to-face and virtual interviews were performed with university professors and Civil engineers.

2.2. Determining the parameters of comfort and usability of safety harness

.

2.3. Searching for sources and reviewing studies

The available sources and inventions were reviewed in various sources and scientific sites. Searches were also conducted in databases, related journals, and library resources. Science Direct, Web of Science, Wily, Scopus, Google Scholar, PubMed, and Springer databases were searched using the following keywords: full body harness, the usability of harness, the standard for harness, satisfaction, and comfort of harness, industrial harness, and ergonomic harness. Then, the articles related to the topic were selected and studied.

2.4. Field observations

At this stage, accessible construction workers who had at least one year of experience working with harnesses were selected from the construction industry workers in Tehran. At first, they were requested to complete a written informed consent form to participate in the interview. During the semi-structured interviews, they were asked to explain their problems and concerns about using harnesses, what made it difficult for them to use harnesses, and the reasons they were not willing to use harnesses. Since the study was qualitative, the interviews were continued until reaching the data saturation point. At this stage, according to the interviewees' responses, the related issues were raised and the provided answers were recorded. The interviews lasted for an average of 30 min, ranging from 20 to 45 min.

2.5. Standard guidelines for harnesses

Generally, there are several standards for safety harnesses. These standards include ISO 10333-1: 2000 for full-body harnesses and the installation of comfort pads in the harness, EN 361: 2002 on PPE against falls from heights with full-body harnesses, BS EN 813:

2008 standard for sitting harnesses and people's satisfaction and comfort when using harnesses, and EN358 standard for work harnesses and lanyards. These standards were thoroughly analyzed by the research team and the important factors on the comfort and usability of safety harnesses were extracted.

2.6. Survey of experts

The findings of the previous steps were discussed during four sessions with a panel of experts in safety, ergonomics, occupational health, and civil engineering.

2.7. Compilation of a questionnaire regarding the comfort of the harness

After defining the concept and determining the dimensions and items of the tool, the collected data during the meetings was reviewed by the researchers. Some items were merged or deleted and some were changed. In this way, the initial assessment tool included 15 questions with a five-option Likert scale. After designing the initial tool, its psychometric properties were evaluated. The final version contained eight demographic questions (height, weight, history of harness use, work experience in the construction industry, age, level of education, job position, and nationality) and 13 main questions designed by the researchers. The questions could be responded to via a five-option Likert scale ranging from five (strongly agree) to one (strongly disagree).

2.8. Psychometric properties of the instrument

2.8.1. Face validity

Step 1. To determine the qualitative face validity, three occupational health and safety specialists, one ergonomics specialist, one civil engineer, one safety engineer, two foremen, and two workers were interviewed in a face-to-face manner about the formulated questions. According to these individuals' comments on the level of difficulty, degree of inconsistency, the ambiguity of the phrases, and the existence of inadequacies in the word meanings, minor changes were applied in the questionnaire. At this stage, the number of questions was reduced from 15 to 13.

Step 2. For quantitative face validity, the impact score was calculated for each question separately. The questionnaire was given to ten construction workers who used harnesses. After completion of the questionnaire by the target group, face validity was calculated using the equation of the item effect method. In this way, the participants were asked to rate the importance of each item on a five-option Likert scale ranging from one (not important at all) to five (absolutely important). Then, the impact scores were calculated using Equation (1):

$$\text{Impact score} = \text{Frequency } (\%) \times \text{Importance} \qquad \text{Equation (1)}$$

Where frequency referred to the number of people selecting items 4 and 5 and importance represented the average score of importance based on the five-option Likert scale. It is worth mentioning that only questions with face validity scores >1.5 were acceptable (Waltz et al., 2010).

2.8.2. Content validity

Step 1: To assess the qualitative content validity of the instrument, eight occupational health, ergonomics, and safety experts were asked to submit their corrective views after carefully studying the tool. After collecting the experts' opinions, the necessary changes were made in terms of grammar, use of appropriate words, the importance of questions, and order of questions.

Step 2: The content validity index was assessed using the method proposed by Waltz et al. Based on this method, the tool was sent to 15 specialists in the field of occupational health, four ergonomics experts, five safety specialists, and two civil engineers who were asked to rate each item according to a three-option Likert scale (it is necessary, it is useful but not necessary, and it is not necessary). Then, the Content Validity Ratio (CVR) equation was employed [21] and Lawshe's table was examined using the Bayesian approach [22]. Accordingly, considering 15 specialists, the CVR had to be greater than 0.49 [21]. In other words, in case the resulting number was larger than the table number, the existence of the relevant item with an acceptable level of statistical significance ($p < 0.05$) was both necessary and important.

To ensure that the questions were best designed to measure content, the Content Validity Index (CVI) was used which has been proposed by Waltz et al. For this purpose, the questionnaire was given to 15 experts for calculating the CVI by using the three criteria of relevance, simplicity, and clarity based on a five-option Likert scale (1: completely irrelevant, 2: irrelevant, 3: somewhat relevant 4: relevant, and 5: completely relevant). The CVI score was calculated by summing up the number of experts giving a ranking of 'agreed' for each item divided by the total number of experts. The items with scores >0.79 were considered acceptable [24]. Afterward, based on the mean CVIs, the Average Content Validity Index (S-CVI/Ave) of the questionnaire was computed. According to Polite and Beck, CVIs ≥0.9 were considered acceptable [23].

2.9. Reliability

Internal consistency and test-retest methods were used to determine the reliability of the questionnaire. To do so, 20 construction workers were asked to complete the questionnaire. Then, the reliability of the instrument was estimated by calculating its internal consistency using Cronbach's alpha coefficient. Accordingly, alpha values between 0.6 and 0.7 were considered acceptable) [21]. After two weeks, the same construction workers were asked to complete the questionnaire. If there was no significant difference between the obtained Cronbach's alpha values, the stability of the questionnaire was approved. Stability means obtaining the same scores in a group of people at two different time points. The correlation between the results of the two tests indicates reliability or repeatability. If this index is higher than 0.74, the stability is confirmed. Finally, the Intra-class Correlation Coefficient (ICC) between the results of the two tests was 0.78, which indicated an acceptable correlation (Waltz et al., 2010).

2.10. Developing a questionnaire for the usability of harnesses

System Usability Scale (SUS) is a usability method to measure the quality of human-centered designs [22]. One of the most common tools for assessing the usability of the SUS Brooke Questionnaire was presented in 1996 [24]. In the present study, based on this scale, the questions were changed to harness usability and were validated. All the steps followed to compile the questionnaire for the harness comfort were used for the usability questionnaire.

3. Results

3.1. Determining the dimensions and design of the tool

3.1.1. Field observations

This study was conducted on the construction workers with a mean age of 29.5 ± 8.2 years and a mean work experience of 25.78 ± 4.2 years. The mean duration of the interviews was 30 min, ranging from 20 to 45 min. The results of the interviews revealed various problems such as discomfort in the harness, pressure from the harness straps to the waist, shoulders, thighs, and genital areas, incompatibility of the dimensions of the harness with body dimensions, and limitations associated with the harness. The number of participants at different stages of the study has been presented in (Table 1).

3.2. Overview of the research background

Literature review showed that the most important reasons for not using the existing harnesses were the discomfort of the harnesses, the pressures caused by the harnesses on the body, limited mobility, and inappropriate dimensions and size. Although most participants' complaints about harnesses were related to discomfort and lack of satisfaction, this issue has been addressed in limited studies.

3.2.1. Harness standards

The study of standards related to safety harnesses demonstrated the importance of such factors as safety and technical inspection and requirements related to strength, dynamic, and static tests. The comfort and ergonomics of the harnesses were emphasized, as well.

3.3. The psychometric properties of the tool

In this study, the qualitative face validity of the comfort questionnaire was assessed. At this stage, the number of questions was reduced from 15 to 13. Additionally, the quantitative face validity was separately evaluated for the comfort and usability questionnaires. Only questions with face validity scores >1.5 were considered acceptable. According to the results presented in (Tables 2 and

Table 1
The number of people participating in different stages of the study.

No.	Reason for the interview	Number of people	Place of interview	Interview
1	Interview about not using harnesses	8 Iranian workers and 5 Afghan workers	Construction site	Construction workers
2	Interviewing experts on the workers' response to not using harnesses	10	University	Specialists in safety (3), ergonomics (2), occupational health (3), and civil engineers (2)
3	Determining the qualitative face validity	10	University	Occupational health and safety specialists (3), ergonomics expert (1), construction engineer (1), safety engineer (1), foreman (2), and worker (2)
4	Determining the quantitative face validity	10 (7 Iranian workers and 3 Afghan workers)	Construction site	Construction workers
5	Determining the qualitative content validity	8	University	Occupational health, ergonomics, and safety specialists
6	Determining the quantitative content validity	15	At work	Specialists in occupational health (4), ergonomics (4), and safety (5) and civil engineers (2)
7	Reliability	20 (13 Iranian workers and 7 Afghan workers)	Construction site	Construction workers

3), the face validity scores were higher than 1.5 for all the questions.

Considering the content validity, the CVR was calculated for each question. According to Lawshe's table, the number obtained from the CVR equation had to be greater than 0.49 for 15 specialists. This implied that in case the resulting number was larger than the table number, the existence of the relevant item with an acceptable level of statistical significance ($p < 0.05$) was necessary and important. Baghestani stated that by calculating the number of carcasses using the Bayesian approach, the CVR had to be more than 0.53 for 15 specialists. This was taken into account for the comfort and usability questionnaires, and the results have been presented in (Tables 2 and 3). Accordingly, all CVRs were acceptable.

In this study, CVIs >0.79 were considered acceptable. The items were separately evaluated concerning relevance, clarity, and simplicity. Then, the total CVI was calculated and the results have been presented in (Tables 2 and 3). Afterward, based on the mean CVIs of all the questionnaire items, the S-CVI/Ave was computed. According to Polite and Beck, a score of 0.9 was considered acceptable. The results revealed that the S-CVI/Ave was 0.97 for the comfort questionnaire and 0.991 for the usability questionnaire.

The reliability of the instrument was estimated by calculating its internal consistency using Cronbach's alpha coefficient. Accordingly, alpha values between 0.6 and 0.7 were considered acceptable. In this study, Cronbach's alpha coefficient was computed as 0.83 for the comfort questionnaire and 0.79 for the usability questionnaire. Additionally, the ICC was obtained as 0.78 for the comfort questionnaire and 0.73 for the usability questionnaire.

4. Discussion

In this study, a valid and reliable tool was presented for evaluating the satisfaction, comfort, and usability of harnesses. To develop this tool, all the necessary steps such as the opinion of experts and specialists in the field of safety and ergonomics were taken. Face and content validity and the related indicators, as well as the reliability of the questionnaire were evaluated. The results showed that the mentioned instrument had appropriate psychometric properties. The comfort questionnaire contained 13 questions with Cronbach's alpha coefficient of 0.83, content validity index of 0.97, and face validity index of 3.89. Besides, the usability questionnaire included 10 questions with Cronbach's alpha coefficient of 0.79, content validity index of 0.991, and face validity index of 4. Therefore, this tool can be used to make informed decisions about the design of safety harnesses in terms of satisfaction, comfort, and usability, so that workers will be able to use harnesses comfortably without fear of pressure. The fitness of the harness to body dimensions can also lead

Table 2
Quantitative content and face validity indices for the harness comfort questionnaire.

No.	Questions	Relevance	Clarity	Simplicity	CVI	CVR	Comparison with Lawshe's table	Comparison with Bayesian approach	Impact factor	Result
1	I feel good and comfortable working with harnesses.	0.93	0.93	1	0.95	0.73	[a]	[a]	3.6	Accept
2	I feel good while working with the harness and because of this feeling, I am not afraid of falling from a height while working with the harness.	1	0.93	1	0.97	0.6	[a]	[a]	3.15	Accept
3	I can easily wear a harness.	1	1	1	1	1	[a]	[a]	2.87	Accept
4	I can do my job easily when I wear a harness.	1	1	0.86	0.95	1	[a]	[a]	4.7	Accept
5	I can easily adjust and fasten the harness waistbands.	1	0.93	1	0.97	0.73	[a]	[a]	3.96	Accept
6	The harness straps do not twist when fastened and used.	1	1	1	1	0.86	[a]	[a]	3.52	Accept
7	I feel the harness fits my body.	1	1	1	1	1	[a]	[a]	4.8	Accept
8	When suspended with a harness, there is not much pressure on my body.	0.93	1	1	0.97	0.86	[a]	[a]	3.22	Accept
9	It is easy for me to use safety harnesses when working at heights.	1	0.93	0.93	0.95	1	[a]	[a]	4.22	Accept
10	When working at heights, I am satisfied with the use of safety harnesses.	1	1	1	1	0.73	[a]	[a]	4.5	Accept
11	When working at heights, I can easily follow the necessary safety instructions associated with the use of harnesses.	1	1	0.86	0.95	0.73	[a]	[a]	4.32	Accept
12	I only use safety harnesses when I am comfortable.	1	1	1	1	1	[a]	[a]	4.6	Accept
13	While working with the harness, the harness straps do not interfere with my work.	0.93	0.93	0.93	0.93	1	[a]	[a]	3.44	Accept

[a] = Significant.

Table 3
Quantitative content validity and face validity indices for the harness usability questionnaire.

No.	Questions	Relevance	Clarity	Simplicity	CVI	CVR	Comparison with Lawshe's table	Comparison with Bayesian approach	Impact factor	Result
1	I think I should always use harnesses when working at heights.	1	1	1	1	0.86	[a]	[a]	3.52	Accept
2	I think wearing a harness is too complicated and difficult.	1	0.93	1	0.97	1	[a]	[a]	4.4	Accept
3	I think the harness is easy to use and adjustable.	1	1	1	1	0.86	[a]	[a]	3.87	Accept
4	I think I can use the harness well with the guidance of a technician or safety specialist.	1	1	0.93	0.97	0.73	[a]	[a]	3.78	Accept
5	In my opinion, different parts of the harness are well designed and adjusted.	1	1	1	1	1	[a]	[a]	4.14	Accept
6	I think there is a lot of difficulty and inconsistency between the straps in wearing the harness.	1	1	1	1	1	[a]	[a]	4.23	Accept
7	I think most people can learn how to use harnesses very quickly.	1	1	1	1	1	[a]	[a]	3.44	Accept
8	In my opinion, the harness is unsuitable for use and working at heights.	0.93	1	1	0.97	0.86	[a]	[a]	4.5	Accept
9	I am very safe and comfortable when using the harness.	1	1	1	1	1	[a]	[a]	3.87	Accept
10	I need to learn how to wear and use the harness before using it.	1	1	1	1	1	[a]	[a]	4.5	Accept

[a] = Significant.

to comfort and satisfaction. In the research carried out by Hsiao, to adjust the size and length of the harness, three-dimensional anthropometric data were used to accurately calculate the body dimensions appropriated to the harness design) [23](. In the tools prepared in the current study, questions were asked about the fit of the harness to the body dimensions. Hsiao in another study mentioned that traditional linear anthropometric data couldn't well present the anthropometric dimensions required for harness design and weren't suitable for harness design in practice [25]. Moreover, studies have shown that the relationship between anthropometric data and harness suspension tolerance might lead to better harness design, which can result in satisfaction and comfort) [26]. Fang et al. reported that construction workers refused to use PPE including protective harnesses because they did not feel comfortable) [27](. To design a satisfactory harness, it is required to 1- determine the body sizes for each component of the harness, 2- design harnesses with an adjustable size range, 3- develop the size of the harness according to the relevant standards, and 4- ask for users' suggestions. One study found that the carpenters who used harnesses complained about the lack of fitness and were dissatisfied with body pressure) [28]. Furthermore [29], emphasized the importance of the angle between belt and body as well as place of the D ring for reducing the pressure from harness in both normal and suspended positions) [29]. Zhang et al. also revealed that discomfort was one of the reasons why Chinese scaffolders didn't use harnesses) [8]. In the present study also, questions were asked about the exerted pressure by harness on the body as well as the importance of harness straps for its comfort. Contractors generally provide equipment only according to its price and durability, not considering usability for workers) [30]. On the other hand, PPE is very difficult to use because it feels like a nuisance at work. Scaffolders who do not feel comfortable using a safety harness may decide not to wear it at all) [31]. These individuals do not wear harnesses due to discomfort as well as restrictions on movement [7]. Therefore, the comfort and usability of harnesses are vitally important. In the present study, a scale was designed to measure harness comfort and usability.

The design of safety harnesses should be improved to minimize complaints about their inadequacy and discomfort that can lead to their non-utilization. This should be done by using methods based on the principles of user-centered design. Moreover, taking consumer expectations into account, considering the design quality, and combining the design process can provide better results for acceptance amongst users. Prior research indicated that workers' participation in choosing a harness and evaluating its appropriateness as well as their overall satisfaction had a significant impact on the use of harnesses) [32]. The instrument designed in the present study aimed to provide information regarding the users' feedback, leading to a better harness design. In a previous study exploring harness systems for backpacks, a subjective survey was conducted on the level of skin discomfort on shoulders, trapezius, lumbar muscles, and overall comfort using a five-option Likert scale. In this way, the individuals' comfort levels were assessed) [33]. In another research, Chae et al. used semi-structured interviews to evaluate two harnesses concerning comfort and satisfaction using a scale ranging from one (not satisfied at all) to seven (highly satisfied). The comfort scale was investigated as the sense of warmth, humidity, and overall comfort. Humidity and heat values were measured, as well. The results revealed a correlation between the mental scale and the measurements made [20]. In the research carried out by Angles, subjective assessment including discomfort rating was employed to evaluate the usability of the harness. In doing so, a pressure measuring system was developed in fabric straps for installation in harnesses and was used to rank discomfort on a ten-degree scale, with zero and ten representing not uncomfortable and very uncomfortable, respectively. The results showed a significant correlation between the subjective assessment of discomfort ratings and pressure on the body achieved in the experiments [34]. In the present study, the items were assessed using a five-option Likert scale ranging from strongly disagree to strongly agree. Since this study was conducted on the workers who used harnesses, the five-point Likert scale was used to make responding to questions easier for the participants. Comfort is the main issue because users work with the harness all the time and should feel comfortable; otherwise, they will not use the harness [35]. In another study, musculoskeletal disorders were investigated to evaluate the comfort of working with a rope (harness rig) in suspension. The results indicated that the workers who used rig harnesses while working were more likely to suffer from pain in their lower extremities compared to other workers [36]. In Gregory's study, the comfort of the harness was assessed by determining the pressure on muscles and the exerted forces [37]. In Nam's study, the pressure caused by harnesses was measured in different areas of the waist and thighs using a pressure gauge sensor. It was concluded that an optimal harness design could overcome the existing harness limitations and lead to user comfort [15]. Lee et al. evaluated the pressure on people's bodies when using commercial harnesses and found that the pressure caused by harnesses made people uncomfortable, in such a way that they were not willing to use harnesses. In the present study, a tool was designed, because access to pressure sensors to measure discomfort and pain may be impossible or expensive, while questionnaires can easily and inexpensively measure discomfort among individuals.

5. Conclusions

The study findings showed the acceptable psychometric properties of the designed tools. Therefore, they can be used to make informed decisions about the design of safety harnesses in terms of satisfaction, comfort, and usability, so that people can easily wear the harnesses without fear of pressure. Overall, the existence of evaluation tools is essential, because users can express their opinions and designers can use these comments to produce useable products. This research prepared a valid and reliable tool to determine the level of comfort, satisfaction and usability of safety harnesses by end-users. This tool can be used for different harnesses. By using this tool, users' opinions are determined and it can help designers to develop the harness design. This study had some limitations. Firstly, most of the people who used harnesses were construction workers who had low levels of education, so it was time-consuming to justify them. Secondly, most of the construction workers are daily wage workers, therefore, there was a time limit for conducting the research, and the interview was conducted prayer and rest time. Finally, this study was conducted only in Tehran due to financial and administrative constraints.

Ethical approval

The study protocol was reviewed and approved by the Research Ethics Committees of the School of Public Health & Neuroscience Research Center - Shahid Beheshti University of Medical Sciences, Tehran. Iran" with the Approval ID: R. SBMU.PHNS.REC.1401.083.

Author contribution statement

Parvin Sepehr: Performed the experiments; Wrote the paper.
Mousa Jabbari: Conceived and designed the experiments; Wrote the paper.
Hassan Sadeghi Naeini, Amin Kazemi: Conceived and designed the experiments.
Ali Salehi Sahl Abadi: Contributed reagents, materials, analysis tools or data
Mansour Ziaei: Analyzed and interpreted the data.
Asma Zare: Analyzed and interpreted the data; Wrote the paper.

Funding statement

Mousa Jabbari was supported by Shahid Beheshti University of Medical Sciences [31938].

Data availability statement

Data included in article/supp. material/referenced in article.

Declaration of interest's statement

The authors declare no competing interests.

Acknowledgments

The authors would like to thank all the people who cooperated in the process of conducting the research.

References

[1] E.A. Nadhim, C. Hon, B. Xia, I. Stewart, D. Fang, Falls from height in the construction industry: a critical review of the scientific literature, Int. J. Environ. Res. Publ. Health 13 (2016) 638.
[2] M.B. Casali, A. Blandino, S. Grignaschi, E.M. Florio, G. Travaini, U.R. Genovese, The pathological diagnosis of the height of fatal falls: a mathematical approach, Forensic Sci. Int. 302 (2019), 109883.
[3] F. Li, J. Zeng, J. Huang, J. Zhang, Y. Chen, H. Yan, W. Huang, X. Lu, P.S.F. Yip, Work-related and non-work-related accident fatal falls in Shanghai and Wuhan, China, Saf. Sci. 117 (2019) 43–48.
[4] M. Shafique, M. Rafiq, An overview of construction occupational accidents in Hong Kong: a recent trend and future perspectives, Appl. Sci. 9 (2019) 2069.
[5] K. Baszczyński, Effects of full body harness design on fall arrest performance, Int. J. Occup. Saf. Ergon. 27 (2021) 938–945.
[6] X. Zhang, W. Zhang, L. Jiang, T. Zhao, Identification of critical causes of tower-crane accidents through system thinking and case analysis, J. Construct. Eng. Manag. 121 (2020) 606–618.
[7] W. Fang, L. Ding, H. Luo, P.E.D. Love, Falls from heights: a computer vision-based approach for safety harness detection, Autom. ConStruct. 91 (2018) 53–61.
[8] M. Zhang, D. Fang, A cognitive analysis of why Chinese scaffolders do not use safety harnesses in construction, Construct. Manag. Econ. 31 (2013) 207–222.
[9] E.A.N.A. Xiashow, N.K.H. H K H H, Falls from height in the construction industry: a critical review of the scientific literature, Int. J. Environ. Res. Publ. Health 28 (13) (2016) 638, 7.
[10] J.M. Beverly, M.N. Zuhl, J.M.B. White, E.R. Beverly, T.A. Vandusseldorp, J.J. Mccormick, J.D. Williams, J.R. Beam, C.M. Mermier, Harness suspension stress: physiological and safety assessment, J. Occup. Environ. Med. 61 (2019) 35–40.
[11] H. Hsiao, M. Friess, B. Bradtmiller, F.J. Rohlf, Development of sizing structure for fall arrest harness design, Ergonomics 52 (2009) 28–43.
[12] P. Seddon, Harness Suspension: Review and Evaluation of Existing Information: Health and Safety Executive Contract Research Report *Her*, Majesty's Stationery, Norwich, UK, 2002, p. 451.
[13] H. Hsiao, N. Turner, R. Whisler, J. Zwiener, Impact of harness fit on suspension tolerance, Hum. Factors 54 (2012) 346–357.
[14] K. Shamsuddin, M.O. Ani, A.G. Ismail, M.S.M. Ibrahim, Investigation the safety, health and environment (SHE) protection in, Constr. Area Int. Res. J. Eng. Techn. 2 (2015) 624–636.
[15] D. Nam, M. Kwon, J. Kim, B. Ahn, Development of pant-type harness with fabric air-pocket for pain relief, Appl. Sci. 9 (2019) 1921.
[16] H. Hsiao, B. Bradtmiller, J. Whitestone, Sizing and fit of fall-protection harnesses, Ergonomics 46 (2003) 33–58.
[17] J.M. GóMEZ-de-Gabriel, J.A. FernáNDEZ-Madrigal, A. LóPEZ-Arquillos, J.C. Rubio-Romero, Monitoring harness use in construction with BLE beacons, Measurement 131 (2019) 329–340.
[18] S.M. Rafiee, H. Sadeghi Naeini, A. Kohan, Designing the manual tools of the tetraplegia handicapped C5-C7 BY UCD method, Iran Occup. Healt. J. 12 (2015) 27–37.
[19] F.-G. Wu, M.-Y. Ma, R.-H. Chang, A new user-centered design approach: a hair washing assistive device design for users with shoulder mobility restriction, Appl. Ergon. 40 (2009) 878–886.
[20] U.R. Chae, K. Kim, J. Choi, D.J. Hyun, J. Yun, G.H. Lee, Y.G. Hyun, J. Lee, M. Chung, Systematic usability evaluation on two harnesses for a wearable chairless exoskeleton, Int. J. Ind. Ergon. 84 (2021) 103–162.
[21] G. Ursachi, I.A. Horodnic, A. Zait, How reliable are measurement scales? External factors with indirect influence on reliability estimators, Procedia Econ. Finance 20 (2015) 679–686.
[22] S.H. Han, M. Hwan Yun, K.-J. Kim, J. Kwahk, Evaluation of product usability: development and validation of usability dimensions and design elements based on empirical models, Int. J. Ind. Ergon. 26 (2000) 477–488.
[23] H. Hsiao, B. Bradtmiller, J. Whitestone, Sizing and fit of fall-protection harnesses, Ergonomics 46 (2003) 1233–1258.
[24] A. Ng, H. Lo, A. Chan, Measuring the usability of safety signs: a use of system usability scale (SUS), in: Lecture Notes in Engineering and Computer Science, proceedings of the International MultiConference of Engineers and Computer Scientists, 2, 2011, pp. 1296–1301.
[25] H. Hsiao, J. Whitestone, T. AndKau, Evaluation of fall-arrest harness sizing scheme, Hum. Factors 49 (2007) 447–464.
[26] A. Adisesh, C. Lee, K. Porter, Harness suspension and first aid management: development of an evidence-based guideline, Emerg. Med. J. 28 (2011) 265–268.
[27] W. Fang, P.E.D. Love, H. Luo, L. Ding, Computer vision for behaviour-based safety in construction: a review and future directions, Adv. Eng. Inf. 43 (2020), 10098.
[28] W. Gibbons, S. Hecker, Participatory approach to ergonomic risk reduction: case study of body harnesses for concrete work, Proc. Hum. Factors Ergon. Soc. Annu. Meet. 44 (2000) 687–690, a.
[29] N.L. Turner, J.T. Wassell, R. Whisler, J. Zwiener, Suspension tolerance in a full-body safety harness, and a prototype harness accessory, J. Occup. Environ. Hyg. 5 (2008) 227–231.
[30] R.A. Haslam, S.A. Hide, A.G.F. Gibb, D.E. Gyi, T. Pavitt, S. Atkinson, A.R. Duff, Contributing factors in construction accidents, Appl. Ergon. 36 (2005) 41–51.
[31] J. Bohm, D. Harris, Risk perception and risk-taking behavior of construction site dumper drivers, Int. J. Occup. Saf. Ergon. 16 (2010) 55–67.
[32] W. Gibbons, S. Hecker, Participatory approach to ergonomic risk reduction: case study of body harnesses for concrete work, Proc. Hum. Factors Ergon. Soc. Annu. Meet. 44 (2000) 5–687, 5-690.
[33] S.A. Southard, G.A. Mirka, An evaluation of backpack harness systems in non-neutral torso postures, Appl. Ergon. 38 (2007) 541–547.
[34] J.N. Angles, Usability of Fall Arrest Harnesses. Virginia Tech, 2013. http://hdl.handle.net/10919/23089.
[35] J. Arteau, H.E.P. Gomez, Y. Beauregard, Anthropometry and selection of full body harness: beyond stature and body mass as selection criteria, Arbeitswissenschaftlichen Kongress 21 (2018) 23 (Februar).
[36] H. Vikne, E. Jebens, S. Elka, S. Knardahl, K.B. Veiersted, Working suspended in a harness rig: a comparative study of musculoskeletal health complaints in rope access technicians and controls, Work 56 (2017) 291–300.
[37] D.E. Gregory, S. Milosavljevic, J.P. Callaghan, Quantifying low back peak and cumulative loads in open and senior sheep shearers in New Zealand: examining the effects of a trunk harness, Ergonomics 49 (2006) 968–981.