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Validity of a computer-based risk assessment method for visual ergonomics

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ABSTRACT

Objective: To describe the development of a computer-based risk assessment method for visual ergonomics, and assess its face validity, content validity, and internal consistency.

Methods: The risk assessment method contained a questionnaire for the worker, an evaluation form for the evaluator, a section of follow-up questions based on the worker's responses, and a section for recommended changes, including an overall risk assessment with respect to daylight, lighting, illuminance, glare, flicker, work space, work object and work postures, respectively. Forty-eight trained evaluators used the method to perform 224 workplace evaluations. Content validity of the method was assessed by the completeness and distribution of responses, and internal consistency was assessed by Cronbach's alpha, Spearman's rank correlation between items and indices, and exploratory factor analysis.

Results: The proportion of missing values in items was generally low (questionnaire: 0–2.3%; evaluation form: 1.4–4.1%). In the questionnaire, items about double vision, migraine and corrective lenses had limited information content. Cronbach's alpha and item-index correlations for the indices frequency of eyestrain, intensity of eyestrain, visual symptoms, lighting conditions, frequency of musculoskeletal discomfort and intensity of musculoskeletal discomfort were satisfactory. Based on the factor analysis, suggestions for improving some of the indices were made.

Conclusion: Our findings suggest that this computer-based method is a valid instrument for assessing risks in the visual work environment. By incorporating subjective ratings by the worker as well as objective measurements of the work environment, it provides a good basis for recommendations with respect to daylight, lighting, work surfaces/material, and work object.

Relevance to industry: Visual environment factors, such as glare, can cause eyestrain, headache and musculoskeletal discomfort. This method satisfies the need of a valid tool for determining risks associated with the visual work environment. It contains both worker's ratings and objective measurements, and is designed to be used in different types of work.

1. Introduction

The visual work environment can affect our well-being in many ways. Glare from luminaries or windows may cause discomfort and reduced performance in visually demanding work tasks (Anshel, 2007; Rosenfield, 2011). In addition, non-visual exposures such as flicker from luminaries may cause eyestrain and headache (Osterhaus et al., 2014). Although mostly recognized in computer work (Blehm et al., 2005; Dainoff et al., 2005; Habibi et al., 2014; Shieh and Lin, 2000), the impact of high visual demands on workers' well-being has been demonstrated in other types of occupations as well (Bogdanova et al., 2016; Fritzsche et al., 2012; Hemphälä, 2014; Juslén and Tenner, 2005; Lindegård et al., 2012, 2016). Studies have shown that visual fatigue and eyestrain can lead to musculoskeletal discomfort, which may even aggravate with time when visual demands are high (Zetterberg, 2016).

In order to detect risks in the visual environment, and to evaluate workplace interventions, valid and reliable risk assessment methods are needed. Preferably, they should cover all aspects of the work environment, such as workstation arrangement, task demands, and the worker's perceived visual comfort (Jackson et al., 1997; Long, 2014). Leccese et al. (2016) argued that objective measurements of luminance should be performed at the workstation (*e.g.*, the desk) as well as in the

Abbreviations: VERAM, Visual Ergonomics Risk Assessment Method

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surroundings (*e.g.*, the surrounding walls) to get a complete assessment of the lighting conditions. Further, they stressed the need to also consider the worker's perception of visual comfort in the assessment (Leccese et al., 2017).

Questionnaires for assessing visual fatigue and eyestrain associated with office work have been introduced previously (Knave et al., 1985; Rajabi-Vardanjani et al., 2014; Segui et al., 2015). In Knave et al. (1985), a comprehensive set of questions about the frequency and intensity of eye discomfort, as well as skin and musculoskeletal symptoms, was distributed to office employees, some of whom performed computer work most of their working day. The study showed associations between ratings of eye discomfort, musculoskeletal discomfort, headache and skin disorders (Knave et al., 1985). Rajabi-Vardanjani et al. (2014) described the development of the 15-item Visual Fatigue Questionnaire for video display terminal (VDT) users, including questions about eyestrain, impaired vision, and symptoms from the eyes. They confirmed its validity and reliability relative to physiological measurements of fatigue (Rajabi-Vardanjani et al., 2014). Segui et al. (2015) designed and validated a Computer Vision Syndrome Questionnaire for assessing ocular and visual symptoms related to VDT use. While these questionnaires may be useful for assessing exposures during office work, there is a need for more generic visual risk assessment methods that are applicable to all kinds of occupations.

The Ocular Surface Disease Index is a 12-item questionnaire concerning symptoms and function of the eyes. It has been shown to be a valid and reliable instrument for assessing dry eye syndrome (Schiffman et al., 2000; Özcura et al., 2007), and can be used for screening for symptoms among workers in any occupation. Conlon et al. (1999) also demonstrated validity of the Visual Discomfort Scale for assessing frequency of perceived visual discomfort. When evaluating workplace exposures, however, complementary information about the work station and task demands would be needed to determine the presence of risks in the visual environment. To satisfy the need for a generic risk assessment tool, we have developed a computer-based Visual Ergonomics Risk Assessment Method (VERAM) that can be used in a variety of work types. It contains subjective ratings by the worker as well as objective measurements of the work environment. Together, they form the basis for assessing risks associated with the visual environment.

The aim of this study was to describe the development of VERAM, and assess its face and content validity. Further, we aimed to assess the internal consistency of VERAM in a sample of workers with different types of work.

2. Material and methods

VERAM was developed through an iterative process in collaboration with Swedish practitioners and a reference group consisting of Nordic researchers and practitioners. Throughout the process, trained evaluators from occupational health services have used VERAM in different types of work. Workers as well as evaluators were informed about the study, and signed an informed consent to participate. The study was conducted in accordance with the Declaration of Helsinki, and approved by the Regional Ethical Review Board in Lund, Sweden (No. 2015/2).

2.1. Development of VERAM

Initially, the authors reviewed existing literature and instruments, and drafted a preliminary version of VERAM that contained 1) ratings by the worker (*e.g.*, eyestrain, headache, musculoskeletal discomfort), 2) objective measurements of the work environment (*e.g.*, luminance, glare, workstation arrangement, task demands), and 3) individual factors (age, gender, ocular status). The drafted version was sent to the reference group, and revised several times based on the feedback received from the group. The final version was implemented electronically, to be used on computers or tablets.

In the next step, mainly practitioners from occupational health services were offered a 7-day course in visual ergonomics risk assessment in exchange for performing workplace evaluations using VERAM. In total, 27 participants performed 275 workplace assessments. After the course, a two-day seminar was held to evaluate the method with respect to its usability and applicability in different settings, the order and relevance of the items, and the response alternatives. The input from the seminar formed the basis for further revisions of VERAM.

During 2015 and 2016, courses in visual ergonomics risk assessment were offered to practitioners from occupational health services with the same structure and requirement as before. Each course participant performed workplace evaluations using VERAM, thus providing the data needed for this validation study.

2.2. Content of VERAM

VERAM consists of four parts: a questionnaire for the worker, an evaluation form for the evaluator, a section of follow-up questions based on the worker's responses, and a section for recommended changes. Each part is described below.

2.2.1. Part 1 – worker's ratings

The first part of VERAM contains questions to the worker about eyestrain, visual symptoms, lighting conditions, and musculoskeletal discomfort during the past four weeks (Table 1). For eyestrain and musculoskeletal discomfort, the worker is first asked to rate the frequency of perceived strain/discomfort. If the worker reports any strain/discomfort (*i.e.*, frequency > 0, see Table 1), he/she is asked to rate the intensity of the strain/discomfort. In addition, questions are included about corrective lenses, headache, migraine, stress, whether symptoms persist over time, and whether they affect performance at work. For frequency and intensity of eyestrain, respectively, the average of a worker's nine item scores can be used as an index. Similar calculations can be performed to obtain indices for frequency and intensity of musculoskeletal discomfort, and of the lighting conditions perceived by the worker. For visual symptoms, however, the response alternatives may be normalized to 0–100 before averaging. This implies recoding the five response alternatives for *overall visual function* to 0, 25, 50, 75 and 100, and recoding the four response alternatives for *blurred vision*, *double vision* and *ability to focus* to 0, 33.3, 66.7, and 100, so that higher values implies more visual symptoms.

2.2.2. Part 2 – evaluator's assessment

The second part of VERAM is answered by the evaluator. First, the worker's main work task is described, and the average amount of hours per week spent performing the task is estimated. This is followed by a series of questions about daylight, lighting, illuminance, glare, flicker, work space, work object and work postures, some of which require objective measurements to be answered (Table 2). In the computer-based method, worker's ratings from part 1 automatically appear in part 2, as additional input for the evaluator when judging the risk associated with a workplace factor. For example, the worker's rating of disturbing daylight appear in connection with items related to the daylight factor in part 2. For each of the eight workplace factors, the evaluator makes an overall judgment of the risk associated with the factor: no risk, low risk, or high risk. The evaluator also has the option to make notes relating to his/her risk assessments.

2.2.3. Part 3 - follow-up questions

The third part of VERAM serves as a basis for discussion about the worker's ratings and the evaluator's assessment. If strain or discomfort was reported by the worker, or workplace factors were judged a risk by the evaluator, follow-up questions appear automatically. The follow-up questions cover visual ability, allergies, medications, and disease. They also include questions about whether the worker or evaluator believes that the symptoms are caused by the work environment.

Table 1
Content of part 1 of VERAM.

	Items	Response alternatives
Frequency of eyestrain	Smarting/itching/gritty/aching/sensitive to light/reddened/teary/dry/fatigued eyes	0-3: never/occasionally/a few times per week/almost daily
Intensity of eyestrain	Smarting/itching/gritty/aching/sensitive to light/reddened/teary/dry/fatigued eyes	0-3: no/mild/moderate/severe
Visual symptoms	Overall visual function	0-4: very good/good/satisfactory/bad/very bad
	Blurred vision	0-3: never/occasionally/a few times per week/almost daily
	Double vision	0-3: never/occasionally/a few times per week/almost daily
	Ability to focus	0-3: never/occasionally/a few times per week/almost daily
Lighting conditions	Disturbing daylight	0-3: never/sometimes/often/almost always
	Satisfactory lighting for work task	0-3: never/sometimes/often/almost always
	Disturbing bright light sources	0-3: never/sometimes/often/almost always
	Disturbing reflexes from work object/surface	0-3: never/sometimes/often/almost always
	Disturbing reflexes from computer screen[a]	0-3: never/sometimes/often/almost always
Frequency of musculoskeletal discomfort	Neck/shoulders/upper back/arms or hands	0-3: never/occasionally/a few times per week/almost daily
Intensity of musculoskeletal discomfort	Neck/shoulders/upper back/arms or hands	0-10: 0 = no pain/discomfort; 10 = worst imaginable pain/discomfort
Headache	Frequency/intensity/placement/time of day	Frequency and intensity scales as for musculoskeletal discomfort; placement: around eyes/forehead or temples/elsewhere; time of day: a.m./p.m
Migraine		yes/no
Stress	Frequency/intensity	Frequency and intensity scales as for musculoskeletal discomfort
Corrective lenses		yes/no
Affected work ability	Follow-up question to reported eyestrain, musculoskeletal discomfort and headache	0-2: no/to some extent/a lot
Recovery after work	Follow-up question to reported eyestrain, musculoskeletal discomfort and headache	0-2: overnight/over weekend/no

[a] Only applicable to computer work.

2.2.4. Part 4 - recommendations

The fourth part of VERAM consists of recommendations by the evaluator based on the worker's ratings, the evaluator's assessment, and the follow-up discussion. If a workplace factor was judged a risk by the evaluator, the level of risk (*i.e.*, low risk or high risk) automatically appear on the screen together with notes made in relation to the risk assessment. Depending on the need for improvement, recommendations can be made with respect to daylight, lighting, work surfaces/work material, or work object. The recommendations may also include a visual examination, referral to optometrist, or other workplace evaluations, and can be incorporated in a report to the worker and/or the employer.

2.3. Statistical analysis

All analyses were performed in IBM SPSS Statistics 22.0 for Windows (IBM Corp., Armonk, NY, USA). The content validity of VERAM was assessed by the completeness of item responses and the distribution of the proposed indices. Furthermore, the information content of each item in part 1 of the method was estimated by calculating the maximum response frequency, i.e., the response frequency of the response alternative that was most frequently chosen. Items with maximum response frequency higher than 80% were considered having limited information content (Streiner and Norman, 1990).

The internal consistency of VERAM was assessed by Cronbach's alpha and by Spearman's rank correlation between individual items and proposed indices in part 1 of the method. Questions with item-total correlation below 0.2 were considered non-representative for the index (Streiner and Norman, 1990). An exploratory factor analysis with Varimax rotation was also performed on the items. Bartlett's test of sphericity and Kaiser-Meyer-Olkin's measure of sampling adequacy (KMO) was used as goodness-of-fit indicators, where $p < 0.05$ was considered significant and KMO > 0.6 was considered acceptable (Tabachnick and Fidell, 2001). Items with missing values were

Table 2
Content of part 2 of VERAM.

Workplace factor	Items	Units/response alternatives
Daylight	Sufficient daylight/possibility for view	yes/no
	Risk of daylight glare	no risk/low risk/high risk
Lighting	Direct light/indirect light/satisfactory color rendering	yes/no
	Ability to alter illumination	yes (individually)/yes (group)/yes (venue)/no
Illuminance	Measurements of illuminance	lux
	Illuminance requirements fulfilled	yes/no
Glare	Measurements of luminance	cd/m^2
	Luminance conditions	no risk/low risk/high risk
	Risk of glare from luminaries	no risk/low risk/high risk
Flicker	Visual flicker	yes/no
	Non-visual flicker	yes/no
Work space	Glare/reflexes from work surface or material	yes/no
	Too shiny, bright or dark surfaces	yes/no
	Shadows on work space	yes/no
Work object	Distance between the eye and work object in relation to size of the work object	no risk/low risk/high risk
	Gaze angle	no risk/low risk/high risk
Work postures	Adverse postures in neck: flexion/extension/rotation/lateral flexion/protraction	not at all/a small amount of time/about half of the time/almost all the time
	Adverse postures in back: flexion	not at all/a small amount of time/about half of the time/almost all the time

Table 3
Characteristics of workers that were risk assessed using VERAM.

Number of workers	224
Age (mean ± standard deviation)	48 ± 10 years
Gender (% men)	35%
Type of work	Office work (90%)
	Maintenance work (2%)
	Engineering work (2%)
	Primary care (1%)
	Surgery (1%)
	Pedicure (1%)
	Mail sorting (< 1%)
	Delivery work (< 1%)
	Assembly work (< 1%)
	Truck driving (< 1%)
	Sea transportation (< 1%)

excluded in the analyses. For the factor analysis, listwise deletion was used.

3. Results

A total of 224 risk assessments using VERAM were performed by 48 different evaluators. Among the evaluators, 9 were men and 39 were women, and their mean age (standard deviation) was 52.3 (8.7) years. All had experience in performing risk assessments at workplaces prior to learning VERAM. The risk assessments were performed on workers in different types of work, although the majority of the assessments were made in office work (Table 3).

3.1. Content validity and interpretability

The face validity of VERAM is partly assured by the developmental process, where practitioners as well as experts in visual ergonomics participated (see section 2.1). In part 1 of the method, the average proportion of missing values was 0.7%, and the item with the highest rate of omissions (2.3%) concerned whether the reported complaints in the arm(s) had affected the worker's ability to perform their work. In part 2 of the method, the items with the highest proportion of missing values concerned work postures in the neck (4.1%). The rate of omissions in remaining items ranged between 1.4% and 3.6%.

Among the proposed indices in part 1 of VERAM, the magnitude of floor effects ranged between 14% and 17%. Thus, a non-negligible portion of the sample consisted of workers who reported no symptoms and/or experienced good lighting conditions during work. The magnitude of ceiling effects, that is, the proportion of scores that reached maximum, ranged between 0% and 2%, where the largest ceiling effect appeared in the *Frequency of musculoskeletal discomfort* index. Fig. 1 shows the distribution of the eight risk assessments regarding daylight, lighting, illuminance, glare, flicker, work space, work object, and work postures made by the evaluators in part 2 of VERAM.

For each of the items in part 1 of VERAM, the maximum response frequency is shown in Fig. 2. With the exception of three items about frequency of experiencing double vision at near sight (0 = never to 3 = almost daily), migraine (yes/no), and wearing glasses or lenses (yes/no), no item exceeded 80% in maximum response frequency.

3.2. Internal consistency

Table 4 shows Cronbach's alpha for the proposed indices in part 1 of VERAM. The highest internal consistency was achieved for frequency and intensity of eyestrain, although these indices were also the ones containing most items. Spearman's correlations between the items and the index ranged between 0.47 and 0.81 for *frequency of eyestrain*, 0.33 and 0.68 for *intensity of eyestrain*, 0.49 and 0.86 for *visual symptoms*, 0.60 and 0.73 for *lighting conditions*, 0.67 and 0.81 for *frequency of musculoskeletal discomfort*, and 0.50 and 0.82 for *intensity of musculoskeletal discomfort*. Thus, all of the item-total correlations exceeded 0.2.

In the factor analysis of the 35 items forming proposed indices in part 1 of VERAM, Bartlett's test of sphericity was significant ($\chi^2 = 7167$, df = 595, $p < 0.001$) and KMO was 0.78, thereby justifying the use of factor analysis. Ten factors were extracted with eigenvalues above 1. Together, they explained 77% of the variance in the data. Table 5 shows the factor loadings for each of these factors. Among the items about eyestrain and musculoskeletal discomfort, frequency and intensity aspects loaded high (*i.e.*, ≥0.5; Maskey et al., 2018) on the same factors. This was not surprising, since they were highly correlated (24–73% of the items scored no frequency, and hence no intensity). Several of the eyestrain items loaded high on different factors, which may suggest that they cover different dimensions of eyestrain. Only the item about sensitivity to light loaded high on the same factor as items in another proposed index, namely *lighting conditions*. Three of the items, *i.e.*, intensity of fatigued eyes, double vision, and satisfactory lighting for work task, did not load high on any of the ten factors.

In light of the results from the factor analysis, Cronbach's alpha was calculated for the eyestrain intensity index when the item about fatigued eyes was excluded. The internal consistency of the index was then reduced to 0.85. When the item about sensitivity to light was excluded from the eyestrain indices, Cronbach's alpha did not change for the frequency index, while for the intensity index it was reduced to 0.86. When considering the items that loaded high on the fourth factor (*i.e.*, incorporating the items about sensitivity to light into the *lighting conditions* index, and removing the item about satisfactory lighting for work task), Cronbach's alpha increased from 0.73 to 0.84 (Table 4). Finally, when excluding the item about double vision from the *visual symptoms* index, Cronbach's alpha increased to 0.77. Spearman's correlations between the items and the revised indices were larger than 0.2 except for disturbing bright light sources in the *lighting conditions* index (rho = 0.1).

4. Discussion

In the present study, a new risk assessment method for visual ergonomics was introduced. VERAM contains subjective ratings by the worker as well as objective measurements of the work environment, which form the basis for an overall risk assessment with respect to daylight, lighting, illuminance, glare, flicker, work space, work object and work postures, respectively. The results showed that VERAM's content validity and internal consistency was adequate in the population studied, which consisted of mainly women performing office work.

The low proportion of missing values in part 1 of VERAM (*i.e.*, worker's ratings) suggests that workers in different occupations could understand and respond to the questions. About 14% of the workers reported no eyestrain. A previous study with similar items of eyestrain (albeit 8 instead of 9 items) reported higher proportions: 36% of VDT operators reported no eye discomfort, while 54% of office workers who did not perform VDT work reported no eye discomfort (Knave et al., 1985). In that study, the workers were slightly younger (~40 years on average) than the workers in this study (48 years on average), which may have contributed to the higher proportion of symptom-free workers, as noted in Blehm et al. (2005). On the other hand, Amalia et al. (2010) found that 93% of computer science students (age 18–26 years) had ocular complaints.

Most of the items in part 1 of VERAM appeared to have a sufficient number of response alternatives. The exceptions were items about double vision (where the majority reported no symptoms), migraine (where the majority reported no symptoms), and wearing glasses or lenses (where the majority responded affirmative). Possibly, some or all of these questions could be excluded from VERAM, since they have limited information content. Another aspect to consider, however, is the importance of identifying the presence of double vision and

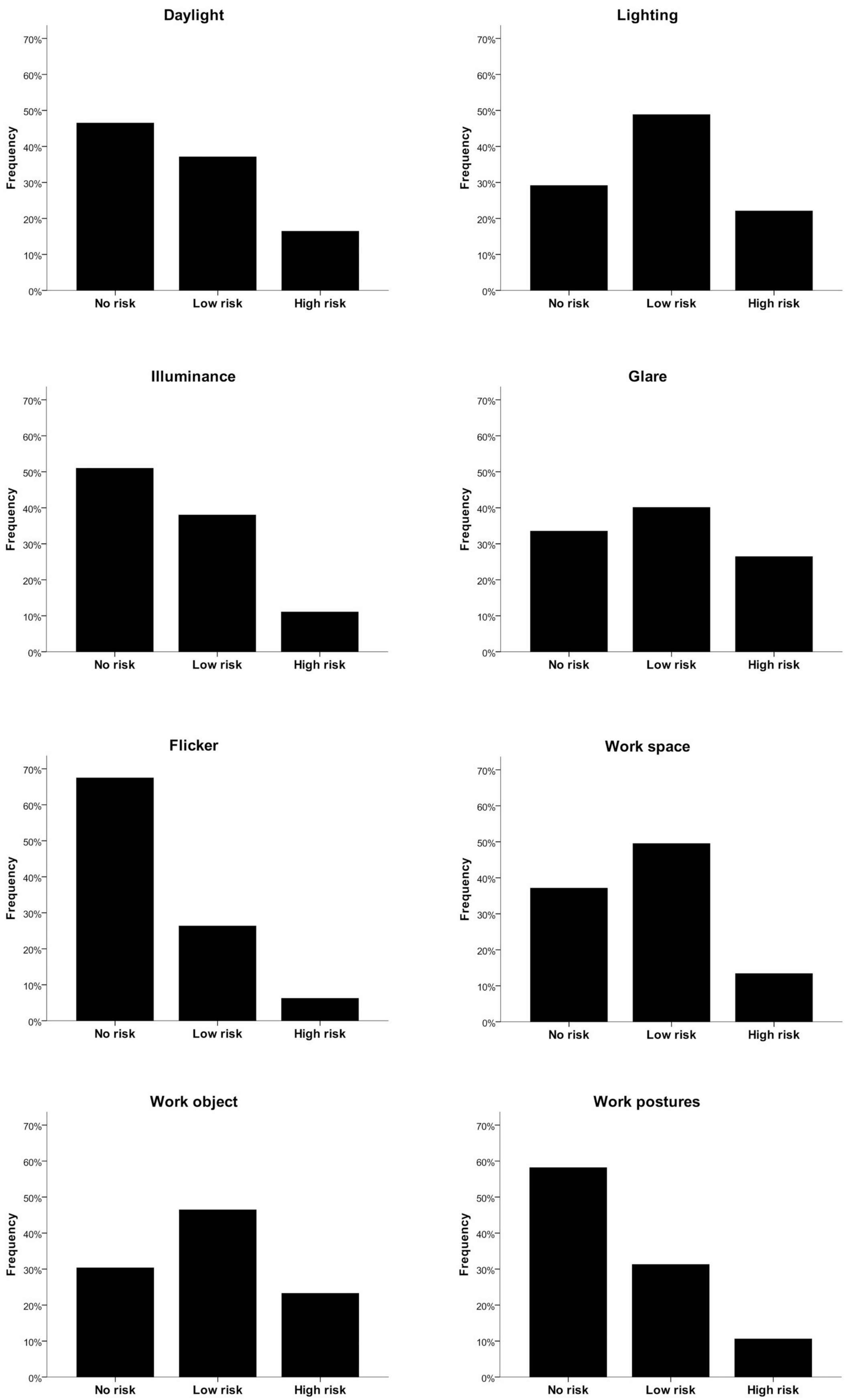

Fig. 1. Distribution of risk assessments in part 2 of VERAM.

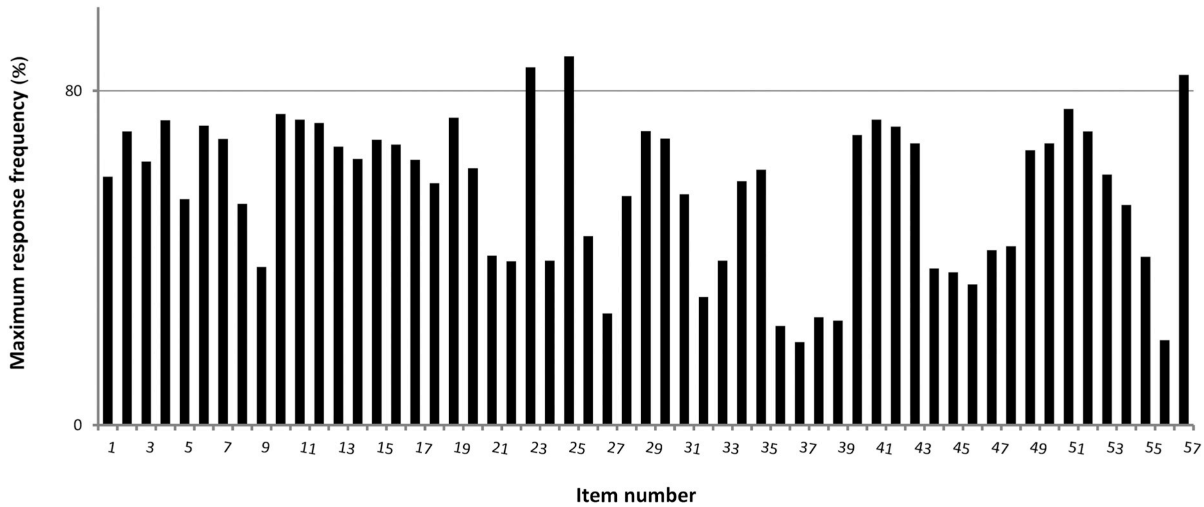

Fig. 2. Maximum response frequency in part 1 of VERAM. Item 1–9: frequency of eyestrain; item 10–18: intensity of eyestrain; item 19–20: follow-up questions to reported eyestrain; item 21–24: visual symptoms; item 25: migraine; item 26–31: headache and follow-up questions to reported headache; item 32–35: frequency of musculoskeletal discomfort; item 36–39: intensity of musculoskeletal discomfort; item 40–47: follow-up questions to reported musculoskeletal discomfort; item 48–54: lighting conditions during bright and dark season; item 55–56: stress; item 57: corrective lenses.

migraine when it occurs, since it would likely affect the suggested recommendations (Danchaivijitr and Kennard, 2004; Weatherall, 2015). Among the three items, the question about double vision is the only one that is included in an index. Hence, it may be worthwhile to exclude it from this index.

In part 2 of VERAM, where the evaluator assesses the workplace, the proportion of missing values indicated that the most difficult items to rate concerned the worker's neck posture. This should be considered in the training given to the evaluators before performing workplace evaluations. With more knowledge and practice of postural ergonomic assessments, they can provide more confident recommendations to the worker and/or the employer.

A high-quality instrument should have high internal consistency. Cronbach's alpha for the indices in part 1 of VERAM were all larger than 0.7, indicating adequate internal consistency (Wiitavaara and Heiden, 2018a, b). The numbers were similar to Cronbach's alpha reported for the Visual Fatigue Questionnaire ($\alpha = 0.75$) (Rajabi-Vardanjani et al., 2014) and the Computer Vision Syndrome Questionnaire ($\alpha = 0.78$) (Segui et al., 2015) except for frequency and intensity of eyestrain which were higher. Furthermore, correlations between each of the items and the corresponding index were larger than 0.2. Thus, they could be considered representative for the index (Björklund et al., 2007, 2012). The highest item-index correlation for indices of eyestrain (frequency as well as intensity) was obtained for fatigued eyes. Interestingly, this particular item was not included in Knave et al. (1985) or Bergqvist and Knave (1994). For visual symptoms, the highest correlation was obtained for blurred vision. Concerning lighting conditions, the highest correlation was obtained for disturbing reflexes from work object/surface. For frequency and intensity of musculoskeletal discomfort, item-index correlations were highest for the neck region, suggesting that they are important for the workers' perceived musculoskeletal discomfort.

Although all item-index correlations were higher than 0.2, some of them were rather low. For frequency of eyestrain, the lowest correlation was obtained for teary eyes. This item also had correlation < 0.5 with intensity of eyestrain, but the lowest correlation with that index was obtained for aching eyes. Not surprisingly, the lowest item-index correlation for visual symptoms was obtained for double vision. This may partly be explained by the skewed distribution of the ratings. The item with the lowest correlation with frequency and intensity of musculoskeletal discomfort was ratings from the arms or hands, suggesting they are least important for the workers' perceived musculoskeletal discomfort.

As expected, the exploratory factor analysis showed that all items in the same index did not load high (*i.e.*, ≥ 0.5) on the same factor, and items in different indices did not exclusively load high on different factors. While the items about frequency and intensity of eyestrain consistently loaded high on the same components, considering them as separate indices may be important for making proper recommendations. The skewed distribution of the item about double vision, and its

Table 4
Cronbach's alpha for the indices in part 1 of VERAM.

	No. observations	No. items	Cronbach's alpha
Proposed indices:			
Frequency of eyestrain (*smarting/itching/gritty/aching/sensitive to light/reddened/teary/dry/fatigued eyes*)	221	9	0.85
Intensity of eyestrain (*smarting/itching/gritty/aching/sensitive to light/reddened/teary/dry/fatigued eyes*)	221	9	0.87
Visual symptoms (*overall visual function/blurred vision/double vision/ability to focus*)	221	4	0.75
Lighting conditions (*disturbing daylight/satisfactory lighting for work task/disturbing bright light sources/disturbing reflexes from work object/surface/disturbing reflexes from computer screen*)	221	5	0.73
Frequency of musculoskeletal discomfort (*neck/shoulders/upper back/arms or hands*)	220	4	0.76
Intensity of musculoskeletal discomfort (*neck/shoulders/upper back/arms or hands*)	219	4	0.77
Revised indices:			
Frequency of eyestrain (*smarting/itching/gritty/aching/reddened/teary/dry/fatigued eyes*)	221	8	0.85
Intensity of eyestrain (*smarting/itching/gritty/aching/reddened/teary/dry/fatigued eyes*)	221	8	0.86
Visual symptoms (*overall visual function/blurred vision/ability to focus*)	221	3	0.77
Lighting conditions (*sensitive to light (frequency and intensity)/disturbing daylight/disturbing bright light sources/disturbing reflexes from work object/surface/disturbing reflexes from computer screen*)	222	6	0.84

Table 5
Standardized factor loadings for items in part 1 of VERAM.

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
Frequency of eyestrain										
Smarting	**0.76**	0.15	0.27	0.17	0.11	0.12	0.14	0.11	0.10	0.00
Itching	**0.81**	0.03	0.14	0.02	0.02	0.17	0.21	0.18	−0.01	0.23
Gritty	0.44	0.16	**0.60**	0.06	0.17	0.10	0.11	0.04	0.22	−0.10
Aching	0.23	0.12	0.14	0.12	0.07	**0.89**	0.06	0.04	0.03	0.08
Sensitive to light	−0.03	0.01	0.23	**0.64**	0.19	0.31	0.38	0.20	0.07	0.10
Reddened	0.30	0.03	0.21	0.03	0.13	0.09	0.09	**0.85**	0.02	0.03
Teary	0.28	0.11	0.04	0.05	0.09	0.03	**0.89**	0.07	0.11	0.05
Dry	0.18	0.13	**0.80**	0.07	0.08	0.08	0.02	0.13	0.01	0.30
Fatigued	0.18	0.26	**0.50**	0.16	0.30	0.39	0.01	0.27	0.02	0.02
Intensity of eyestrain										
Smarting	**0.76**	0.09	0.22	0.24	0.08	0.17	0.11	0.11	0.13	−0.05
Itching	**0.82**	0.00	0.08	0.05	0.01	0.13	0.23	0.20	−0.02	0.15
Gritty	0.48	0.18	**0.59**	0.07	0.13	0.13	0.13	0.09	0.19	−0.20
Aching	0.23	0.06	0.14	0.15	0.09	**0.88**	0.03	0.06	0.02	0.06
Sensitive to light	0.02	0.02	0.21	**0.66**	0.19	0.36	0.35	0.20	0.09	0.05
Reddened	0.30	0.12	0.23	0.07	0.13	0.08	0.08	**0.82**	0.04	0.04
Teary	0.33	0.09	0.07	0.08	0.06	0.02	**0.88**	0.09	0.06	−0.01
Dry	0.21	0.11	**0.78**	0.16	0.10	0.08	0.04	0.20	0.01	0.20
Fatigued	0.15	0.22	0.49	0.16	0.30	0.46	0.02	0.31	0.08	−0.05
Visual symptoms										
Overall visual function	0.00	0.06	0.21	0.11	**0.77**	0.10	0.16	0.18	0.02	0.02
Blurred vision	0.08	0.07	0.11	0.14	**0.83**	0.04	0.05	0.02	0.01	0.15
Double vision	−0.04	−0.06	0.09	0.10	0.44	0.03	0.05	0.33	−0.01	0.32
Ability to focus	0.12	0.20	0.00	0.07	**0.75**	0.07	−0.06	−0.01	0.11	−0.07
Lighting conditions										
Disturbing daylight	0.13	−0.03	0.09	**0.77**	0.04	0.03	0.01	0.20	0.08	−0.01
Satisfactory lighting for work task	0.09	0.15	0.32	0.38	−0.06	0.23	0.37	−0.22	−0.17	0.12
Disturbing bright light sources	−0.05	−0.05	0.46	**0.50**	0.03	0.17	0.10	0.11	0.19	0.11
Disturbing reflexes from work object/surface	0.11	0.15	0.09	**0.76**	0.13	0.08	0.01	−0.17	0.00	−0.01
Disturbing reflexes from computer screen	0.19	0.24	−0.09	**0.70**	0.10	−0.07	−0.12	−0.06	−0.11	−0.01
Frequency of musculoskeletal discomfort										
Neck	0.10	**0.72**	0.09	0.07	0.15	0.25	−0.01	0.16	0.15	0.26
Shoulders	0.04	**0.86**	0.13	0.05	0.06	0.03	0.05	−0.11	0.12	0.04
Upper back	0.18	0.42	0.20	0.03	0.13	0.10	0.04	−0.04	0.23	**0.71**
Arms or hands	0.11	0.20	0.11	0.03	0.10	0.01	0.04	−0.02	**0.89**	0.13
Intensity of musculoskeletal discomfort										
Neck	0.07	**0.78**	0.08	0.12	0.15	0.10	0.07	0.20	0.09	0.25
Shoulders	0.06	**0.88**	0.12	0.10	0.03	−0.02	0.13	−0.01	0.10	0.03
Upper back	0.11	0.40	0.16	0.02	0.08	0.07	0.05	0.09	0.25	**0.76**
Arms or hands	0.07	0.19	0.07	0.05	0.03	0.06	0.09	0.07	**0.90**	0.15

Factor loadings ≥0.5 are indicated in bold. Factor 1 explained 11% of the variance in the data; factor 2 explained 10%; factor 3 10%; factor 4 9%; factor 5 7%; factor 6 7%; factor 7 6%; factor 8 6%; factor 9 6%; factor 10 5%.

low loadings in the factor analysis, suggest that it should not be included in the *visual symptoms* index. Indeed, the internal consistency of the index increased when the item was removed. For the *lighting conditions* index, we suggest that the items about frequency and intensity of light sensitivity are included, and the item about satisfactory lighting for work task is excluded, as it substantially improved the internal consistency of the index. Possibly, the item about disturbing bright light sources could also be excluded from the *lighting conditions* index, as it had a weak correlation with the revised index.

4.1. Limitations

During the development of VERAM, workers' opinions on its content were not explicitly documented and processed. Each evaluator provided their feedback after thorough practice with the method in different settings, and we believe that this feedback also reflected the opinions of the workers, especially with respect to the first part of VERAM. Although VERAM can be used in different types of work, the sample in the present study consisted mostly of office workers. Further studies are needed to verify VERAM's validity in other types of work. In the index calculations of worker's ratings, the items were not weighted. Reasonably, the items are not equally important for eyestrain, visual symptoms, perceived lighting conditions, and musculoskeletal discomfort, respectively. Therefore, a systematic analysis of their relative importance could benefit the index calculations in VERAM.

For VERAM to be of use in practice, it not only needs to have adequate content validity and internal consistency. It should also be reliable when used repeatedly by the same evaluator on the same workstation, and when used by different evaluators on the same workstation. This has been investigated by Zetterberg et al. (2019).

5. Conclusions

The present study suggests that VERAM is a valid instrument for assessing risks in the visual work environment. By incorporating subjective ratings by the worker as well as objective measurements of the work environment, it provides a good basis for recommendations with respect to daylight, lighting, work surfaces/work material, and work object.

Declarations of interest

None.

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