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Satyendra Narth Chakrabartty
Indian Ports Association, Indian Maritime University, chakrabarttysatyendra3139@gmail.com

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REVIEW

Improve Quality of Pain Measurement

Satyendra Narth Chakrabartty
Indian Ports Association, Indian Maritime University

ABSTRACT

Objectives: To review limitations of various single-item and multi-items scales of pain measurement and suggest remedial actions for better use of them leading to meaningful comparison of patients and group of patients in terms of pain scores across time and space.

Methods: Stages to obtain proposed score of a single item scale are: (1) Item Raw scores → (2) Equidistant scores → (3) Normalized equidistant scores → (4) Conversion to a desired score range. For multi-item scale, further stages are (5) Summation of normalized equidistant scores with a desired score range. For transition from a stage to the next stage, method described along with empirical verification of transformation for an item to help clinicians to understand the main features of the proposed methods of scoring and to use them effectively.

Results: The proposed method resulted in continuous, monotonic scores satisfying equidistant and normality conditions with a desired score range. Normalized equidistant scores help to compare patients' scores from different distributions and facilitate application of statistical techniques in parametric set up.

Conclusions: Proposed scores reflecting intensity of pain by continuous variable satisfying equidistant property. Normality, help meaningful comparison in terms of pain intensity, change in pain intensity and drawing path of progress for better prognostication. It is possible to compute split-half reliability and theoretical reliability as ratio of true score variance and observed score variance. Future studies suggested.

KEYWORDS: Pain Assessment; Equidistant scores; Normality; Weighted Sum; Reliability.

Correspondence: Dr Satyendra Narth Chakrabartty, N 304, Vivek Vihar, Sector 82, Noida – 201304, India.
Email: chakrabarttysatyendra3139@gmail.com

INTRODUCTION

Pain is frequent among individuals under various state of health. Pain may also be associated with psychological and emotional factors like fear, anxiety, depression, etc. Acute or chronic pain can result in altered behavior, dysfunction or disability. Multidimensional aspects of pain are Sensory (Intensity, location, character of the pain sensation), Affective (Emotional and perceived components) and Impact (Disability or dysfunctions). Pain intensity is the most important dimension of pain which needs to be assessed, analyzed and interpreted in objective fashion. Commonly used self-reported scales for measurement of pain are the following.

METHODS

Single Item Rating Scales.

Visual Analogue Scale (VAS): subjects mark part of a given straight line of 100-mm length, to denote severity of their pain. It assumes that length of the line from the bottom of the scale indicated by a subject is directly proportional to the perceived intensity of his/her pain. "No pain" and "Worst imaginable pain" are placed at the beginning/bottom and end/ top of the line, respectively. VAS with ratio properties [1] suffers from the following major limitations:

- VAS-scores may differ depending on whether the line is horizontal or vertical [2].
- VAS-scores from horizontal and vertical lines had varying correlations [3],[4].
- Vertical scale showed less error than the horizontal scale for Chinese patients [5] but for English speakers,7% failure rate was found for vertical scale [6].
- VAS-scores with poor sensitivity fail to detect small change in pain and generated data can be misunderstood [7].
- More prone to measurement errors than a rating scale. Mechanical systems of VAS have been found well associated with original VAS [8].

- For non-normal distribution of VAS score, non-parametric tests suggested having less power [9], [2].

Verbal Rating Scale (VRS): Contains a list of ordered adjectives like no pain; mild pain; moderate pain; and severe or intense pain. The subjects to choose the adjective which fits best to the pain intensity. However, VRS may lead to misapprehension that intervals between a successive pair of adjectives are equal and thus induce error [10]. VRS is less precise and less sensitive than VAS [11]. Out of 15 adjectives in a VRS, patients used only six of them and 4 of these 6 adjectives covered 78% of responses [12].

Numerical Rating Scale (NRS) : Here, the two extreme points 'no pain" and "worst pain" are presented in 11-point or 21-point or 101-point scale. Researchers differed in terms of Minimal Clinically Important Difference (MCID) of NRS, while comparing with other patient reported scales of overall improvement. Reduction of few response categories of NRS, which amounts to a good percentage of NRS score are clinically important [13], [14], [15]. Sensitivity of NRS also differed at different scale points [16]

NRS is taken as a segmented numeric version of VAS where a subject selects an integer from 0–10 that best reflects the intensity of his/her perceived pain[17] .

Sensitivity of the scale is reduced as it fails to detect changes of pain in the score ranges 1 – 3 or 4 – 6 or 7 – 10. Summative NRS score is proportional to pain intensity. Pain assessment by NRS is better than VRS or VAS [7]

Multi-Item Scales.

Self-reported multi-item scales are used primarily for measurement of neuropathic pain caused by a lesion or disease of nervous system. Illustrative list is:

Leeds Assessment of Neuropathic Symptoms and Signs (LANSS) Pain Scale: To assesses autonomic change.

Douleur Neuropathique en 4 Questions (DN4): Yes – No type items where "Yes" response gets a score of 1. Maximum possible score = 10. A score ≥ 4 is taken as neuropathic pain [18].

Pain DETECT Questionnaire (PD-Q): Primarily to detect neuropathic pain components in chronic LBP patients. Seven items each with six response categories (0 to 5) for quality of neuropathic pain symptoms plus one item on Pain course pattern and one more item on Radiating pain [19].

McGill Pain Questionnaire (MPQ): To assesses both quality and intensity of subjective pain of patients with a number of diagnoses. 20 subgroups of words describing 4 dimensions viz. sensory–discriminative (subgroup 1–10 and score range 0 – 42), motivational–affective (11–15 and score range 0 to 14), cognitive–evaluative (16 and score range 0 to 5), and miscellaneous components of pain (17–20). Each subgroup contains a list of words with a given ranking. Here, the Pain Rating Index (PRI) is the sum of ranked scores and Present Pain Intensity (PPI) is assessed on a six-point scale (0 to 5) [20]. Major weaknesses of MPQ:

- Takes long time to complete, especially the pain intensity.
- Three pain patterns of the MPQ are not adequate to account for changes in pain experienced by participants (say cancer patients) [21].
- Varied number of items and different score ranges in the sub-categories result in different contribution of the domains. Aggregation of scores of domains and miscellaneous items by summative score to get PRI fails to satisfy many desired properties.

Brief Pain Inventory (BPI): 17-item scale, where a patient indicates the site(s) of his/her pain by shading a body diagram. To assess the pain intensity in the previous 24 hours, it also uses an 11-point NRS consisting of seven domains of usual activities/functions and mood (e.g. work, sleep, mood, relations with other people). Thus, BPI assesses pain experience of patients through different scales. Aggregation is done ignoring inter-relationships among those scales, distribution of scores from each scale and thus, properties being satisfied by the chosen aggregation method are not known.

Neuropathic Pain Score (NPS): To assess qualities of pain associated with neuropathic pain based on intensity of 11 descriptors [22]. However, neuropathic pain includes a heterogeneous group of etiologically different diseases from cancer to diabetes. Thus, a single cut-off score for NPS may not be valid for all diseases. It has good sensitivity to treatment effect.

The above motivates need to review limitations of various scales for measurement of pain and suggest remedial actions for better use of them leading to meaningful comparison of individuals or group of patients in terms of intensity of pain across time and space.

The rest of the paper is organized as follows: The next section discusses major limitations of scales which is followed by the proposed remedial actions and associated benefits. The paper concludes with salient observations of the proposed actions.

RESULTS

Limitations of Scales as Measurement Tools.

Zero as an Anchor Value :

Zero as an anchor value can change mean, standard deviation (SD) skew, kurtosis of the scales [23]. Subjects with zero score are taken as those having no pain. If zero scores $\Leftrightarrow$ No pain, then variance of the sub-group of patients with "no pain" should be small and variance between sub-groups should be high. However, consideration of zero anchor values implies mean = variance = 0 for the "no pain" sub-group and creates difficulties in computation of between group variance.

For multi-item scales, large number of zero responses to an item lowers the covariance and correlation with that item. Expected values of level-wise score are not meaningful because zero is attached to a level.

Suggestion: Use positive anchor values.

Nature of Data and Summative Scores:

Generated data are ordinal and discrete. Assumptions of summative scoring include:

- Items of a multi-item scale are of equal importance, despite different values of inter-item correlations, item-

total correlations and factor loadings for the items. Hence, the assumption is not justified.

- Component scores are equidistant i.e. Distance between No pain and Mild pain (d_{12}) = distance between Moderate pain and Mild pain (d_{23}) = distance between Severe and Moderate pain (d_{34}) and also a rating of 10 is equal to twice as much pain as a rating of five. Thus, addition/averaging may not be meaningful [24]. Moreover, the subjects do not perceive items as equidistant.

Suggestion: Transform the ordinal score to continuous scores in interval/ratio scales satisfying equidistant property by assigning different weights to different response categories of different items.

Assumptions of Statistical Techniques:

Applications of parametric statistics are not appropriate with ordinal data. Pearson correlation assumes among others that each variable is continuous, normally distributed and satisfies condition of linearity. For testing equality of two means, *t*-test assumes normal distribution of data, adequacy of sample size, equality of variance, etc. Similar assumptions are made for testing equality of average pain intensity of same group, at pre-treatment and post- treatment stages using the paired *t*-test.

Note that linearity ⇒ high correlation but not the converse. If X= 1, 2, 3,….., 30, correlation between X and $X^2 > 0.9$. Thus, even if $|r_{XY}| \approx 1$, linearity need to be tested before fitting linear regression of the form $Y = \alpha_1 + \beta_1 X$ or $X = \alpha_2 + \beta_2 Y$ or to undertake principal component analysis (PCA), factor analysis (FA), path analysis, structural equation modeling, etc. which use simple correlations and/or their extensions. A simple way to know linearity between Y on X is to fit a linear regression line of the form (say) $Y = \alpha + \beta X + \epsilon$ followed by testing significance of standard error $S_E = \sqrt{\frac{1}{n}\sum(Y_i - \hat{Y}_i)^2}$ where $\hat{Y}_i$ and n are predicted value and sample size respectively. For visual purpose, residual plots may help.

Suggestion: The transformed continuous scores satisfying equidistant property should further be transformed to ensure normally distributed data.

Domains and Items under a Domain:

Multi-item scales often involve selection of dimensions/domains and items under each chosen domain. Choice of items and domains depend on the purposes like diagnosis of pain, assessment of pain intensity or physical dysfunctions due to pain or all. Increasing number of domains or items to get better picture of the multi-dimensional nature of pain may not always be right. Correlation pattern of items or domains may be considered in this context. High correlation implies repeated measurement of same trait. However, despite poor correlation, items may be retained, if considered to be important from clinical point of view.

Normalization/Scaling of Raw Data:

Different score-ranges of item scores (like MPQ) may be normalized to have desired score range for all items. However, different methods of normalizing result in change in shape of distributions in different fashions and may influence the final pain scores.

Suggestion: Use transformations to ensure same/similar distribution of item scores, preferably in a desired range.

Aggregation procedures:

Summative scores giving equal weights to items and domains may not be meaningful since items/domains may contribute differently to the finally aggregated score. Summative scores suffer from compensatory approach, where a low score of a domain can be compensated by high score in another domain.

Suggestion: Ensure similar distribution of score of each item, sub-scale (e.g. BPI).

Suggested Remedial Action.

Pre–adjustment of Data:

i) Ensure positive relationship between each item and Pain intensity i.e. higher the score in the item, higher is pain intensity.

ii) Assign 1, 2, 3, 4, 5, etc. to the response categories of items avoiding zero for meaningful application of mathematical operations like expected values.

Converting Ordinal Score:

Ordinal scores generated by a scale may be converted to continuous, monotonic, equidistant scores following the methods proposed by [25] is described briefly for a 5-point scale:

Let X_{ij} denote raw score of the *i*-th patient in the *j*-th item, for $i = 1,2, \ldots, n$. For a single item scale $j = 1$ and for a multi-item scale $j = 1, 2, \ldots \ldots, m$. X_{ij} takes discrete value 1, 2, 3, 4 and 5.

Find weights $W_{ij}'s$ which are different for different levels for different items satisfying

$W_{ij} > 0, \sum_{j=1}^{5} W_{ij} = 1$ and satisfying the equidistant condition i.e. $W_1, 2W_2, 3W_3, 4W_4, 5W_5$ forms an arithmetic progression with a positive value of the common difference. One way to find such weights is given below:

i) Let f_{ij} be the frequency of *i*-th item for the *j*-th level. For each item, find maximum (f_{max}) and minimum frequency (f_{min}).

ii) Find proportions $\omega_{ij} = \frac{f_{ij}}{n}$. Note, $\omega_{ij} > 0$ *and* $\sum_{j=1}^{5} \omega_{ij} = \frac{\sum_{j=1}^{5} f_{ij}}{n} = 1$.

iii) Put initial weights$W_{i1} = \omega_{i1} = \frac{f_{min}}{n}$. Find the common difference $\alpha = \frac{5f_{max} - f_{min}}{4n}$.

Define$W_{i2} = \frac{\omega_{i1} + \alpha}{2}$; $W_{i3} = \frac{\omega_{i1} + 2\alpha}{3}$; $W_{i4} = \frac{\omega_{i1} + 3\alpha}{4}$ and $W_{i5} = \frac{\omega_{i1} + 4\alpha}{5}$

Here, $W_{ij} > 0$ and $\sum_{j=1}^{5} W_j \neq 1$.

iv) Get final weights $W_{ij(Final)} = \frac{W_{ij}}{\sum_{j=1}^{5} W_j}$ so that $\sum W_{ij(Final)} = 1$

Computation of equidistant scores of an item with 5 response categories is given in Table – 1.

The procedure can be well applied for *k*-point scale for *k*= 3, 4, 5, 6,…. and so on.

Observations:

i) Here, item scores and patient scores are taken as expected values and provide measurement of continues variables satisfying conditions of linearity.

ii) If all patients ignore a particular response category of an item, frequency of that level is zero. The method may fail and can be taken as zero value for scoring items as weighted sum.

Normal Distribution:

To facilitate application of statistical techniques, the equidistant scores (X) may be transformed to follow $N(0,1)$ using $Z = \frac{X-\bar{X}}{SD(X)}$ where $-\infty < Z < \infty$. Normalized equidistant scores help to compare patients' scores from different distributions.

To avoid negative values, Z -scores may further be transformed by a linear function to have a desired range. Proposed score (P) in the range of [1, 5], can be obtained from Z by

$$= \frac{(5-1)(Z_{ij} - Min(Z_{ij}))}{Max\,(Z_{ij}) - Min(Z_{ij})} P + 1.$$

Similar transformation may be used to have score range [1, 10] or [1, 100].

Empirical clarifications of the above are given in Table - 2 with the data considered in the previous table.

Table – 1 Equidistant Scores of a single item

Raw score	Frequency	Proportion (ω_i)	Initial Weights (W_{ij})	Final weights ($W_{ij(Final)}$)	Equidistant score (Raw score × $W_{ij(Final)}$)	Successive Difference
1	36(Max)	0.36	0.07	0.052443	0.052442641	
2	31	0.31	0.25125	0.188232	0.376463243	0.324021
3	16	0.16	0.311666	0.233495	0.700483846	0.324021
4	10	0.10	0.341875	0.256126	1.024504448	0.324021
5	7(Min)	0.07	0.36	0.289705	1.618230061	0.324021
Total	**100**	**1.0**	**1.334792**	**1.0**		

Table – 2Normalized equidistant scores and transformation to [1, 5]

Description	Raw score	Equidistant score	Normalized equidistant scores	Transformed to [1, 5]
	1	0.052443	-0.694273491	1.0
	2	0.376463	-0.372683383	1.348555453
	3	0.700484	0.24642057	2.019571296
	4	1.024504	1.163038367	3.013047531
	5	1.618230	2.99627396	5
Mean	2.21	1.564701	0.00	1.40
Variance	1.52111	4.744505	1.00	1.34

Proposed Score:

Stages involved to obtain proposed score of a single item scale are :

Raw scores → (II) Equidistant scores → (III) Normalized equidistant scores → (IV) Conversion to a desired score range. For multi-item scale, additional stages are (V) summation of normalized equidistant scores with a desired score range

Such score reflecting intensity of pain by continuous variable satisfy monotonic condition, equidistant property and normality. The method helps to compare scores of patients from

Let P_j denotes the score obtained for the j-th item after following the procedures 3.2 and 3.3 above. Domain score (D_i) of the i-th domain can be obtained as $\sum P_j$ where summation is taken over all j's belonging to the domain. P-score is the sum of the domain scores or equivalently as sun of all item scores assuming equal importance to the domains and items. Summative P-scores follow normal distribution.

Advantages:

Proposed scores (P) reflecting intensity of pain by continuous variable satisfying equidistant property and normality have the following advantages:

i. P-scores are monotonic since choice of (j+1)-th level of an item will result in higher score than the choice of j-th level for j= 1, 2, 3, 4, 5 and so on.

ii. Facilitate ranking and classification of group of patients.

iii. Equidistant property and normality ensure admissibility of the operation "addition" and find sample mean and SD of a group of patients and to estimate population mean, population variance and confidence interval of population mean from a large sample and to test statistical hypothesis $H_0 : \mu_1 = \mu_2$ against $H_1 : \mu_1 \neq \mu_2$ using t-statistic.

iv. Assess progress/deterioration of a patient across time by $\frac{P_{it} - P_{i(t-1)}}{P_{i(t-1)}} \times 100$ where P_{it} denotes P-score of the i-th patient in t-th time period. The ratio reflects responsiveness of the scale and evaluates effectiveness of a treatment plan. A positive value of $\frac{P_{it} - P_{i(t-1)}}{P_{i(t-1)}} \times 100$ indicates $P_{it} > P_{i(t-1)}$ i.e. deterioration of the i-th patient at t-th period against the previous period requiring a relook to the treatment plan for the patient. Similarly, $\overline{P_t} > \overline{P_{(t-1)}}$ indicates increase in average pain intensity for the group in the t-th period over the previous period and thus, require immediate action plan. $SD\,(P_t) > SD\,(P_{t-1})$ implies that pain intensity of the sample at the t-th period was more heterogeneous than the previous period.

v. Path of improvement/decline of one or a group of patients over time may facilitate drawing useful conclusions including better prognostication.

vi. Reliability in terms of internal consistency using Cronbach's alpha cannot be computed for a single-item measure of pain. Test-retest reliability will be high if pain intensity remains unaltered (zero effect of treatment) during the period of time gap.

Method proposed by [5] can be applied here to find split-half reliability or even theoretical reliability as ratio of true

score variance and observed score variance. This involves two parallel sub-groups say *g*-th sub-group and *h*-th sub-group. The theoretical reliability is given by $r_{tt} = 1 - \frac{2{S_{Pg}}^2(1-r_{gh})}{N{S_P}^2}$, where N is the sample size; ${S_P}^2$ is the sample variance; ${S_{Pg}}^2$ is variance of the g-th sub-group and r_{gh} is the correlation between the *g*-th and *h*-th sub-groups (Split half reliability).

vii) Avoiding the problems of criterion validity, structural validity of *P*-scores is proposed by exploratory factor analysis (EFA) followed by confirmatory factor analysis (CFA) along with checking of measurement invariance across type of pains or causes of pain using multigroup CFA. Conducting the EFA and the CFA on the same sample pool has been widely used in validation studies [3], [23].

CONCLUSION

After reviewing limitations of scoring of various scale of pain measurement, the paper proposes a multi-stage method of scoring an item by continuous variable reflecting intensity of pain satisfying equidistant property and normality, either for single item scale or multi-item scale. Proposed scores have many advantages and facilitate meaningful comparison of patients and group of patients including assessment of progress or effectiveness of treatment, drawing of path of progress over time for useful conclusions including better prognostication. With a large representative sample, it will be possible to find sample mean and SD of a group of patients; estimate population mean, variance and confidence interval of mean and to test statistical hypothesis $H_0 : \mu_1 = \mu_2$ against $H_1 : \mu_1 \neq \mu_2$ using *t*-statistic for independent samples or using paired *t*-statistic for dependent samples e.g. pre-treatment and post-treatment to a group.

Reliability as per theoretical definition and split-half reliability of multi-item scale have been proposed which can be computed from single administration of the scale. Structural validity of the proposed scoring was recommended along with checking of measurement invariance across type of pains or causes of pain using multigroup CFA.

Empirical verification of the proposed methods and associated properties using real life data is left for future studies.

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COMPETING INTERESTS

The authors declare no competing interests with this case.

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