Scand J Rehab Med 27: 145–151, 1995

RASCH ANALYSIS OF VISUAL ANALOG SCALE MEASUREMENTS BEFORE AND AFTER TREATMENT OF PATELLOFEMORAL PAIN SYNDROME IN WOMEN

Roland Thomeé,[1] Gunnar Grimby,[1] Benjamin D. Wright[2] and John M. Linacre[2]

From the [1]Department of Rehabilitation Medicine, Göteborg University, Sahlgrenska University Hospital, Sweden, and [2]Department of Education, University of Chicago, Chicago, U.S.A.

ABSTRACT. The Visual Analog Scale (VAS) can be used to record subjectively experienced pain in different situations (items). By a mathematical method, the Rasch analysis, the original VAS recordings can be converted to an interval scale. Forty women with Patellofemoral Pain Syndrome (PFPS) reported their pain on the VAS from 12 different situations (items) before and after 12 weeks of rehabilitation. The items recorded pain during the last 3 months, during provocation tests, and during activities such as walking up stairs, jumping and strength testing. It was concluded that the items used for the patients with PFPS were hierarchically ordered in a statistically equivalent manner before and after rehabilitation. Subjectively reported pain after 12 weeks of rehabilitation was significantly alleviated for 23 (58%) of the 40 patients, compared with before rehabilitation. The patients with PFPS did not use the VAS as a linear scale over the full range. Rasch analysis of recordings made with the VAS gave a more detailed pain assessment.

Key words: knee pain, VAS, Rasch model, rehabilitation.

INTRODUCTION

Pain is a common symptom of many different musculo-skeletal disorders. It is essential to be able to follow and evaluate pain over time and to study the effects of treatment. A common syndrome characterized by pain is Patellofemoral Pain Syndrome (PFPS), being one of the most common knee problems, especially in adolescents and young adults (9, 11). Its etiology is obscure in many patients. The most common symptom of PFPS is pain during and after activity, especially body weight loading of lower extremities such as walking up/down stairs, squatting or during physical activity (7, 14, 19, 24). For patients with PFPS it is of interest to measure subjectively experienced pain during different situations such as maximal, minimal and average daily pain, pain during physical activity and pain provoked in the laboratory.

A Visual Analog Scale (VAS) (20) was chosen, as it has proved both reliable and appropriate for measuring pain (18). The VAS, usually presented as a 10 cm line with the end-phrases 'no pain' and 'pain as bad as it could be' (21), correlate well with verbal scales and numerical rating scales (6). The VAS has been found more satisfactory for patient self-rating of pain intensity than three- to five-point verbal scales (12, 17, 20). However, Carlsson (3) questioned the basis for these claims and found that, despite practice, subjects appeared to differ considerably in their ability to use the VAS. Harms-Ringdahl et al. (10) showed the VAS to be as reliable in assessing intensity levels of perceived pain elicited by loading joint structures as Borg's category scale (CR-10 scale) with ratio properties for intermodal and interindividual comparisons (2).

The VAS scores, which in principle should be looked upon as data on an ordinal scale (4, 20), can be converted to an interval scale by using the Rasch analysis (25). This will allow for analysis of the hierarchical order which is of interest for understanding different pain-provoking situations in relation to memory assessment pain and also gives individual measure values with errors for testing changes in individual patients before and after treatment. The Rasch Analysis is based on the subject's ability and the difficulty of the item (test situation). In this study the subject's ability was replaced by the subject's pain level. The item 'difficulty' was replaced by how high pain scores the item gave. The items can correspondingly be positioned along a measure line from the most to the least pain-provoking item. Fit statistics

will be presented on how well different items described the group of subjects and how well individual subjects fitted the whole group. This can add valuable information to the clinical assessment of patients with PFPS. A patient who does not fit the Rasch model can be identified together with the items where the patient misfits. Such information can be used to gain a better understanding of the symptoms in the particular patient and be of value when designing the rehabilitation program. The Rasch analysis has been widely used to evaluate aptitude tests (25) and functional assessment tests in rehabilitation medicine (8, 15, 16). However, Rasch analysis of the VAS has not been found in the literature. For clarity, a distinction should be made between the ordinal VAS 'scores' of observed pain recordings and the Rasch constructed linear 'measures' (26).

The aim of this study was to evaluate pain recordings made with the VAS by converting the VAS scores to an interval scale by using a mathematical model (Rasch analysis) and thereby assessing pain in different situations before and after rehabilitation of patients with PFPS.

MATERIALS AND METHODS

Subjects

The patient group consisted of 40 women with a mean age, weight and height of 20.2 years (SD 3.2, range 15–28), 64.1 kg (SD 8.8, range 50–85) and 169 cm (SD 6.4, range 156–180). The control group consisted of 20 healthy women with corresponding figures of 22.5 years (SD 3.3, range 17–28), 60.6 kg (SD 8.8, range 46–83) and 168 cm (SD 6.4, range 159–178). No significant differences were found between patients and controls regarding age, weight and height. Twenty-three (58%) of the 40 patients were students and 17 (42%) were full-time employees, which was not significantly different from the 9 (45%) students and 11 (55%) full-time employed controls. Twenty-two (55%) of the patients had during the last 4 weeks prior to entering the study more than one day of absence from college or work due to patellofemoral pain which was significantly ($p < 0.0001$) more than for the controls, who had no absence (22).

Patients with pain from the patellofemoral joint were referred by local orthopaedic surgeons and re-examined by the first author (R.T.). The patients were included in the study if three of the following four **inclusion criteria** were fullfilled:

Complaints of pain from the patellofemoral joint:
- during and/or after activity
- during and/or after sitting
- while walking up/down stairs
- while squatting

The **exclusion criteria** were:
- history of recurrent patellar subluxation or dislocation,
- history of intermittent or persistent knee joint swelling,
- other injuries to the knee joint such as laceration of the menisci, ligaments or joint capsule, damage to the articular cartilage, or overuse symptoms such as tendinitis or bursitis,
- muscle/tendon ruptures of the lower extremities,
- surgery carried out on the lower extremities.

Table I. *Number, name and description of the 12 items used in text, tables and figures*

No.	Name	Description
1	MAX	Maximum pain during last 3-month period
2	MIN	Minimum pain during last 3-month period
3	AVER	Average daily maximal pain during last 3-month period
4	PALP S	Pain on palpation of most painful site on more symptomatic knee
5	PALP H	Pain on palpation of most painful site on less symptomatic knee
6	COMP S	Compression test on more symptomatic knee
7	COMP H	Compression test on less symptomatic knee
8	STAIRS UP	Pain while climbing three flights of stairs
9	STAIRS D	Pain while going down three flights of stairs
10	JUMP	Pain during vertical jumping
11	ISOM	Pain during test of isometric strength
12	DYN	Pain during test of dynamic strength

Pain assessment

A VAS from zero to ten was used in order to assess subjective pain experienced from the patellofemoral joint in 12 different situations. Zero on the VAS denoted 'no pain' and 10 'pain as bad as it could be' (20, 21). The patients were asked to make marks on a 10 cm long horizontal line. The distance was measured from zero with a standard ruler to the nearest tenth of a centimetre.

Twelve different situations (items) used to assess pain are described in Table I. First the patients were asked to report pain experienced during the preceding 3 months. The first mark was made for the maximum level of pain (MAX), the second for the minimum level of pain (MIN) and the third for the average daily maximum pain level (AVER).

For the next four items, pain was provoked by a compression test and by palpation of the patella. A constant force of approximately 35 Newtons was used and the force was standardized by pressing on a Myometer (No: D60107 Mk4, Penny & Giles Transducers, Christchurch, England) that digitally showed the pressure exerted in Newtons. The most painful spot on the patella was palpated with the tip of the index finger and the patient made marks on the VAS for the more symptomatic knee (PALP S) and for the less symptomatic knee (PALP H). During the compression test the examiner's index finger pressed superior to the patella and perpendicular to the femur. The subject was then asked to slowly activate the quadriceps muscle. Pain from the more symptomatic knee (COMP S) and from the less symptomatic knee (COMP H) was registered with the VAS.

The five remaining items were pain experienced during

Table II. *Individual item statistics with Rasch analysis measure, error and mean squares (MNSQ), OUTFIT MNSQ being a standardized outlier-sensitive mean-square fit statistic, more sensitive to unexpected behaviour by patients on items far from the patient's pain level. INFIT MNSQ is a standardized mean square statistic, more sensitive to unexpected behaviour by patients on items near the patient's pain level*

Item	Measure	Error	INFIT MNSQ	OUTFIT MNSQ
2 MIN	0.62	0.12	0.99	0.73
7 PALP-H	0.62	0.12	0.81	0.55
5 COMP-H	0.54	0.11	0.94	0.71
11 ISOM	0.21	0.08	0.96	0.87
10 JUMP	0.20	0.09	1.69	2.20
4 COMP-S	0.17	0.08	1.27	1.07
12 DYN	0.05	0.08	1.47	1.60
8 STAIRS-UP	−0.89	0.07	0.94	0.90
6 PALP-S	−0.81	0.07	0.95	0.78
9 STAIRS-D	−0.77	0.07	1.17	1.28
3 AVER	−0.52	0.07	0.46	0.42
1 MAX	−1.59	0.07	0.92	0.91
Mean	0.00	0.08	1.05	1.00
S.D.	0.54	0.02	0.30	0.47

different physical activities. The patients were asked to climb three flights of stairs, totalling 90 steps, each 17 cm in height and to report on the VAS (STAIRS UP) and then go down the same flights of stairs and report on the VAS (STAIRS D). Next the patients were asked to report pain from a vertical jump test (JUMP), a sitting isometric knee extension strength test (ISOM) and a sitting concentric and eccentric dynamic knee extension strength test (DYN).

After 12 weeks of rehabilitation (described in greater detail elsewhere), consisting of a specified, gradually increasing rehabilitation model, pain assessment was repeated.

A Rasch analysis was made on all VAS recordings using a software program for PC (BIGSTEPS, BD Wright, 5835 S Kimbark Ave, Chicago, Ill 60637, USA) (27). The conventional unit for Rasch analysis is the logit (log-odds unit) and the centre of the scale was set at 0. This scaling was used in Table II and Figs. 1 and 2. For Fig. 3 the scaling was set with a centre of 5 to achieve a scale range for the Rasch measures from approximately 0 to 10.

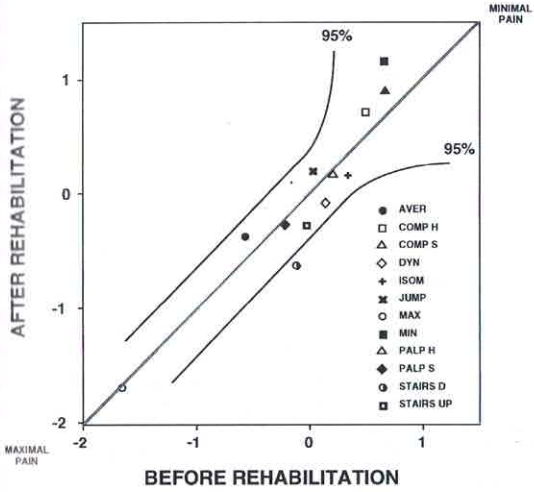

Fig. 1. Item measure relation, expressed in logits (log-odds units) equal interval scale (24), before and after 12 weeks of rehabilitation, with identity line and 95% quality control lines (95% confidence interval). Higher VAS pain scores are achieved on items with lower logits compared with items with higher logits. Centre of the Rasch scales (*x*-axis and *y*-axis) is set at 0.

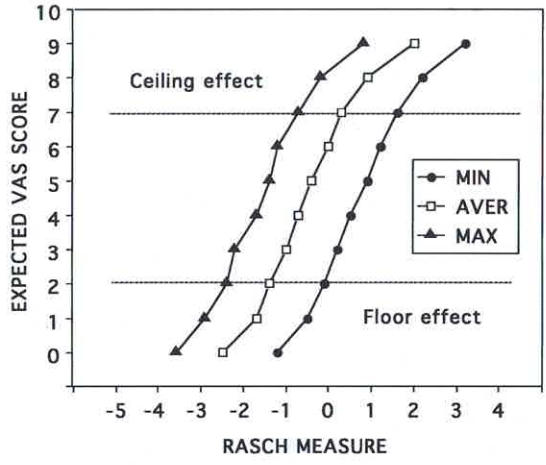

Fig. 2. Expected VAS score in relation to Rasch measure, illustrating the linearity of the VAS, for items: MIN – Minimal pain during past 3 months. AVER – Average daily maximum pain during past 3 months. MAX – Maximum pain during past 3 months. Centre of the Rasch scale (*x*-axis) was set at 0.

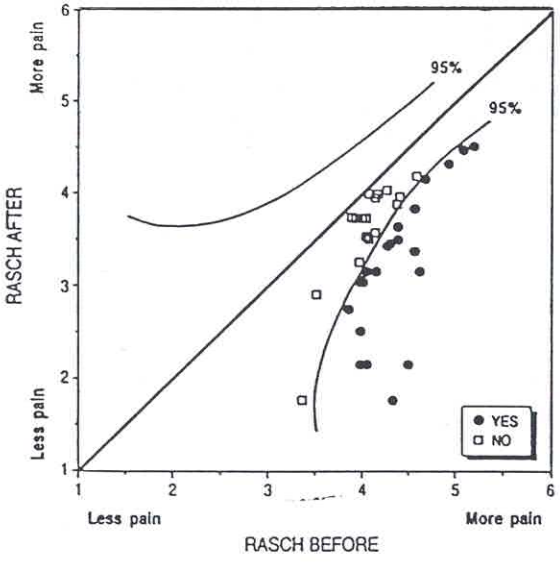

Fig. 3. Forty patients before and after 12 weeks of rehabilitation, with identity line and 95% quality control (95% confidence interval) lines. ● = YES and □ = NO, indicates if patients improved the total Rasch measure significantly ($p < 0.05$). Centre of the Rasch scale (x-axis and y-axis) was set at 5 to achieve a scale range from approximately 0 to 10.

10 JUMP						
Patient no:	1	4	12	17	24	26
Before						
Response:	0	7	9	4	2	5
Residual:	-2	4	3	0	2	1
After						
Response:	0	3	0	3	4	4
Residual:	0	5	-1	5	2	2

12 DYN			
Patient no:	13	24	26
Before			
Response:	0	8	5
Residual:	-1	2	2
After			
Response:	4	6	2
Residual:	2	3	5

Fig. 4. Items JUMP ($n = 30$) and DYN ($n = 40$) are presented with individual patient VAS scores and corresponding misfit levels. RESPONSE = The VAS score that the patient reported. RESIDUAL = Indicates the level of misfit. 1 = 50% probability that the reported VAS score deviates from the expected, 2 = 80%, 3 = 90%, 4 = 94% and 5 = 96%. The minus sign indicates that the score is lower than expected.

Statistics

Conventional methods have been used on Rasch measures for calculation of means, standard deviations, correlations and 95% confidence intervals. Nonparametric statistics have been used to evaluate effects of treatment.

RESULTS

There was a close correlation ($r = 0.94$) between items calibrated separately by the Rasch analysis before vis-à-vis after rehabilitation (Fig. 1). However, the item STAIRS D was a relatively less pain provoking item at the pain assessment after vis-à-vis before rehabilitation. The patients used the VAS in a fairly linear fashion between one and seven. Floor and ceiling effects can be observed in the lower and upper ends of the scale as exemplified by the curves to items MIN, AVER and MAX (Fig. 2). Similar curves were seen for the other items.

Analysis of items in three separate groups (items 1–3, items 4–7 and items 8–12) did not produce any further information. Additionally, the number of items in each group would be small and it was therefore decided to analyse all 12 items together in a single group. Individual item statistics are presented in Table II. Furthermore, in order to analyse the effects of rehabilitation, all 12 items and all individual results from before and after rehabilitation were calibrated together.

A significance test of individual results revealed a significant ($p < 0.05$) reduction in experienced pain after rehabilitation in 23 of the 40 patients (Fig. 3).

The Rasch analysis points out items and patients where given scores on the VAS deviated from expected scores. Items JUMP and DYN showed the highest misfit MNSQ's (Table II) and had the highest frequency of misfits (deviating responses) (Fig. 4). Six patients reported unusual pain on JUMP (Residual ≥ 2) before or after rehabilitation and for DYN, 3 patients.

Patients 8, 10, 12 and 24 had misfits (deviating responses with Residuals ≥ 2) (Fig. 5). The patients reported more than expected pain on items JUMP, STAIRS D & UP, PALP S & H, COMP S, DYN and MIN. One patient reported less than expected pain on MAX.

DISCUSSION

This study, using a Rasch analysis of the VAS, is part of a larger study on patients with Patellofemoral Pain Syndrome (PFPS) (22, 23). A selection of different

Patient:		1 MAX	2 MIN	3 AVER	4 PALP S	5 PALP H	6 COMP S	7 COMP H	8 STAIRS UP	9 STAIRS D	10 JUMP	11 ISOM	12 DYN
8 Before	Response:	8	2	5	0	0	0	0	9	9	4	4	2
	Residual:				-1		-2		2	2			
8 After	Response:	5	0	2	0	0	0	0	7	7	0	4	0
	Residual:						-1		2	2	1		
10 Before	Response:	6	0	6	8	4	4	0	0	0	0	0	0
	Residual:			1	3	2				-1	-1		-1
10 After	Response:	5	0	3	7	3	3	0	0	0	0	0	0
	Residual:				4	2			-1				
12 Before	Response:	7	6	6	0	0	1	0	1	2	9	0	0
	Residual:		3		-1		-1		-1		3		-1
24 After	Response:	1	0	1	1	0	3	0	0	3	4	0	6
	Residual:	-3									2		3

Fig. 5. Patients 8, 10, 12 and 24 are presented with VAS scores for all 12 items and corresponding misfit level. RESPONSE = The VAS score that the patient reported. RESIDUAL = Indicates the level of misfit. 1 = 50% probability that the reported VAS score deviates from the expected, 2 = 80%, 3 = 90%, 4 = 94% and 5 = 96%. The minus sign indicates that the score was lower than expected.

situations in which it is common to experience pain was chosen. The Rasch analysis shows that the 12 items define a measure, as they spread out in a hierarchical manner (Fig. 1) from items giving the lowest VAS scores (MIN, PALP H and COMP H) to items giving the highest VAS scores (MAX, AVER and STAIRS D). The 12 items being a combination of items dealing with memories of pain (MAX, AVER and MIN) and pain-provoking items, were in this study treated as a group. A separation of the items into two or more groups did not yield different information with respect to the objective of this study or the conclusions drawn. It was not surprising that the minimum amount of pain during the last 3 months (MIN) together with palpation (PALP H) and compression (COMP H) of the less symptomatic knee were the situations in which the patients reported the least pain. Likewise that the maximum amount of pain (MAX) during the last 3 months period, together with average maximum daily pain (AVER) and pain during walking downstairs (STAIRS D) gave the highest VAS scores. Among activity-related items, such as STAIRS D, there is, however, a lack of items for high-level pain assessment. Fig. 1 shows a gap between the item MAX and the other items. We suggest that additional items be added, such as prolonged sitting, running up stairs, running in hilly terrain and hopping to fill in this gap. At the low end of the VAS scale where patients who benefit from treatment arrive (Fig. 3), there are similarly too few low pain-provoking items to make the measures of low levels of pain precise. This is illustrated by the wide 95% control lines (95% confidence interval) in the lower left corner of Fig. 3, caused by the large standard errors of measurements for low-pain patients.

Information from Figs. 4 and 5 can be useful in the clinic, together with anamnestic and clinical findings, to increase our understanding of the patient's symptomatology. Such comparisons will be further described in a forthcoming article, but a few comments are made below.

Patient 4 went from a VAS score of 7 down to 3, but both before and after treatment her pain level at JUMP was statistically higher than typical for her overall pain level, as indicated by the high RESIDUAL 4 before rehabilitation and 5 after (Fig. 4). Patient 12, in contrast, had extreme pain, a 9 on the VAS, at JUMP before but could perform JUMP with no pain at all after treatment. Patient 17 began with a typical 4 for her pain level at JUMP, but after treatment her pain level was down to 3, statistically too much pain for the general level she had progressed to. A summary of JUMP gives one patient who both before and after treatment had too much pain (patient no. 4), one patient who progressed from extreme pain

to no pain at all (patient no. 12) and one patient for whom treatment had insufficient effect (patient no. 17).

DYN shows similar specific information for 3 patients (Fig. 4). Patient 24 went from a VAS score of 8 to 6, but pain at DYN continued to be exceptional. Patient 27 went from a VAS score of 5 to 2, but considering her general recovery at the end of treatment, even a 2 was significantly too much pain at DYN.

Fig. 5 shows misfitting patients. We find patients 8, 10 and 12 again, together with patient 24. Patient 8 had more pain than expected before and after treatment on STAIRS and patient 10 had more pain before and after treatment on PALP on both knees. As already mentioned, patient 12 had unusual pain with JUMP, but no pain after rehabilitation. She also reported more pain than expected on MIN before rehabilitation. Patient 24, however, only emerged with an unexpectedly high level of pain on JUMP and DYN and a less than expected maximum pain after treatment. Despite the overall gain in pain improvement, treatment was unable to alleviate her pain on JUMP and DYN as much as for other items.

The items JUMP and DYN had the highest frequency of responses deviating from what was expected by the Rasch model (items showing high misfit in Table II). One explanation for this could be that JUMP and DYN are items where relatively high loads are applied to the patellofemoral joint. Furthermore, difficulties in standardizing the JUMP test and varying pain expectation among patients during the maximum dynamic knee extensor strength test (DYN) could contribute to the high frequency of deviating responses. Other test items, such as STAIRS, PALP and COMP, are more standardized in that respect.

In the present study it was shown that patients with PFPS use the VAS in a fairly linear way in the range from 1 to 7. Greater caution should be used, however, when dealing with the outer ranges of the VAS, as it appeared to be quite a large step to proceed from 7 to 8 and a still larger step from 8 to 9.

From this study it is concluded that:

- The items used for the patients with PFPS were hierarchically ordered in a statistically equivalent manner before and after rehabilitation. Thus the Rasch analysis measure can be used for individual statistical analysis of the effects of rehabilitation.
- Subjectively reported pain after 12 weeks of rehabilitation was significantly alleviated for 23 of the 40 patients, compared with before rehabilitation.
- The patients with PFPS did not use the VAS as a linear scale over the full range.

The results from this study and conclusions drawn are specific to the set of items and group of patients used, but imply the importance of including high, medium and low pain-provoking items. Preferably, items dealing with memory psychophysics (MAX, AVER AND MIN) should be treated separately. In the present study, these items were too few, however. How patients with other diagnoses use the VAS with a different set of items cannot be predicted, but the possibilities to further analyse VAS scores could be of great advantage for a deeper understanding of pain syndromes caused by various musculo/skeletal disorders.

ACKNOWLEDGEMENTS

This research was supported by grants from the Swedish Medical Research Council (project 03888), the Labour Environment Foundation and the Center for Sports Research. Thanks to Valter Sundh, BSc, for performing part of the analysis.

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Address for offprints:

Roland Thomeé
Department of Rehabilitation Medicine
University of Göteborg
Sahlgrenska Hospital
S - 413 45 Göteborg
Sweden