Variation in measurements of grip strength

A study in reflex sympathetic dystrophy patients

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The clinical picture of reflex sympathetic dystrophy (RSD) is characterized by a combination of the triad: autonomic, motor and sensory changes. In this study, the grip strength is measured in 29 upper extremity RSD patients. We used the generalizability theory to assess the extent of the disagreement or differences (errors in measurement) within or between observers and interactions between observer-session and repetition of the measurements. The aims of our study were to determine the different sources of variation in grip strength tests and the smallest detectable differences (SDD) as well as the reliability of upper extremity grip strength tests in RSD patients. The main sources of variation of measurement errors were observer, patient/observer interactions and patient/session/observer interaction and a random source.

We found that the generalizability theory is useful for estimating the sources of measurement error. Clinical examinations for muscle strength measurements, as a part of a total clinical examination, for example for a disability payment or worker's compensation in case of RSD patients should be done by more than one observer in more than one session and more than once.

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Reflex sympathetic dystrophy (RSD) is classified as a Complex Regional Pain Syndrome (type I) (Atkins et al. 1990, Merskey and Bogduk 1994). It is characterized by pain, regional edema, hyperemia, hyperesthesia, hyperhidrosis and limitation of motion or joint stiffness (Veldman et al. 1993, Blumberg and Jänig 1994, Geertzen et al. 1994). It mainly affects the extremities (Veldman 1995). "RSD always occurs in the region of a joint. Thus, the RSDs, taken as a whole, make up a third group of arthropathies, in addition to the arthroses and the inflammatory arthritides" (Arlet 1996). Longstanding RSD may lead to impairments in range of motion and sensibility of the affected extremity (Subbarao and Stillwell 1985, Field et al. 1992). In recent studies, lack of muscle strength is mentioned as a long-term impairment in RSD patients (Blumberg and Jänig 1994, Veldman 1995). Most long-term outcome studies in RSD do not quantify the severity of muscle weakness (Subbarao and Stillwell 1985, Atkins et al. 1990, Field et al. 1992, Veldman et al. 1993). The studies which quantify muscle weakness seldom report the reliability of the measurement procedure and the measuring instruments. Only one study has reported reliability of muscle strength measurements in RSD patients (Bickerstaff and Kanis 1994).

Several muscle-strength grading scales (Kendall and Kendall or MRC-scale) for manual muscle-testing exist which are based on ranking (Kendall et al. 1971, Medical Research Council 1975, van der Ploeg 1992). For the upper extremity, a grading scale for functional testing, the Brooke upper extremity scale, has been developed (Brooke et al. 1981). These scales assess muscle strength by means of gravity and the observer's own perception of strength. Such tests are subjective as regards the observer's perception.

It has been shown that strength can be quantified reliably with different types of dynamometers (Mathiowetz et al. 1984, 1985, van der Ploeg 1992, Roebroeck 1994). Reliability of muscle strength measurements is determined by many factors: accuracy of the dynamometer, cooperation of the patient and standardization of the test technique and test procedure (van der Ploeg 1992).

In general, reliability studies assess the extent of agreement in or between observers. Almost no attempts have been made to assess the extent of the disagreement or differences (errors of the measure-

ments) within or between observers. Only when the extent of the errors of the measurement within or between observers is known is it possible to determine whether a true change in a variable took place between two observations or whether there is merely a difference in observations due to errors in measurement. Errors in the measurement can be estimated by means of the generalizability theory (Brennan 1992).

Variation in the measurement results obtained can be attributed to different sources of variation: variation between patients (pt), variation within patients occurring between measurement sessions (se), variation due to the observer (ob) and repetition (re); the two-way interaction variations due to interactions between patient and session (pt/se), between patient and observer (pt/os), between session and observer (se/ob), between patient and repetition (pt/re), between session and repetition (se/re), between observer and repetition (ob/re); the three-way interactions for patient, session, observer and repetition (pt/se/ob; pt/se/re; pt/ob/re; se/ob/re) and, finally, a residual four-way interaction, the random error, (pt/se/ob/re).

These sources of variation have the following clinical and practical implications:

Pt: variation attributed to differences between patients (inter-patient variation);

Se: variation attributed to the different sessions. Clinically, this means an increase or decrease in measurement results due to training or fatigue;

Ob: variation attributed to differences between observers (inter-observer variation). Clinically, this means that one observer systematically measures differently from the other;

Re: variation attributed to different repetitions. Clinically, this means that the measurement results differ systematically in a single session;

Pt/se: variation attributed to the interaction of patients and sessions. Clinically, this means that not all patients perform alike in both sessions;

Pt/ob: variation attributed to the interaction of patient and observer. Clinically, this means that not all patients perform alike for both observers: an increase or decrease in measurement results due to differences in verbal and nonverbal behavior between patient and observer;

Se/ob: variation attributed to the combination of session and observer. Clinically, this means that the observers systematically measure differently between the sessions;

Pt/re: variation attributed to the combination of patient and repetition. Clinically, this means that not all patients perform alike in all three repetitions;

Se/re: variation attributed to the combination of session and repetition. This means that measurement results differ systematically in one session between repetitions;

Ob/re: variation attributed to the combination of observer and repetition. Clinically, this means that the observers systematically measure differently between the repetitions.

The three-way interactions mentioned earlier are combinations of the different sources of variation to which systematic variance is attributed.

Pt/se/ob/re: variation due to nonsystematic errors.

These sources of variation can be evaluated by analysis of variance according to the generalizability theory (Brennan 1992, Roebroeck 1994). The standard error of the measurement (SEm) is calculated as the square root of the sum of the variances attributed to all sources identified, minus the between-patient variation (Table I). The standard error of the measurement is given in the same units as those of the original measurement. The smallest detectable difference (SDD) is the smallest amount of change in a variable which can be measured with statistical significance ($p \leq 0.05$), and it is calculated as the square root of $2*1.96*SEm$ (Brennan 1992).

The aims of this study were:

1) to identify the different sources of variation in hand muscle-strength measurements and to quantify the amount of variation attributed to these sources;
2) to estimate the SEm and the SDD for hand muscle-strength measurements in RSD patients, by analyzing repeated measurements according to the generalizability theory, and
3) to determine the amount of agreement for upper extremity hand muscle-strength measurements in RSD patients.

Table I. Calculation of the standard error of the measurement (SEm) and smallest detectable difference (SDD)

Sources of variation	
session	
observer	
repetition	
patient/session	
patient/observer	
session/observer	
patient/repetition	
session/repetition	
observer/repetition	
patient/session/observer	
patient/session/repetition	
patient/observer/repetition	
session/observer/repetition	
patient/session/observer/repetition	+
	= (Sum)

$\sqrt{(Sum)} = SEm$; $SDD = \sqrt{2}*1.96*SEm$

Figure 1. Full-fist grip.

Figure 2. Three-point grip.

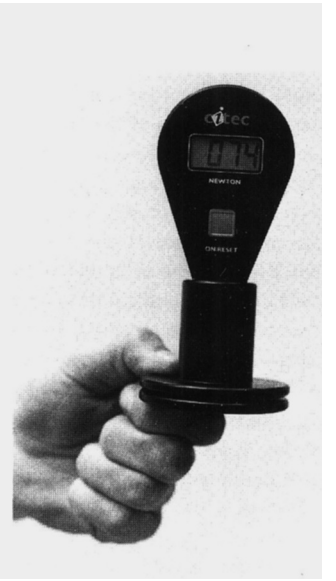

Figure 3. Pinch-grip.

Patients and methods

Patients

Patients in an outcome assessment study of upper extremity RSD were asked to participate in this reliability study. After written informed consent, 29 patients (19 women, 10 men, mean age 49, SD 13) participated in the study. The time span between this study and the initial diagnosis of RSD was 5.7 years (SD 1.9).

Methods

The muscle strength of the hand, the three-point grip, pinch-grip and full-fist grip were measured with a hand-held dynamometer, accuracy 0.1% (CITEC; Center for Innovative Technics BV; The Netherlands). All the muscle-strength measurements were performed on the affected and unaffected sides, according to a standardized protocol (Figures 1–3). The patient was seated in a chair with arms in a comfortable position. The minimum rest period between the contractions was 5 seconds. Between the measurements, the different devices were changed. Once during each strength measurement, the patient was encouraged verbally. The display could be read only by the observer.

Full-fist grip: two extra devices were added; the patient positioned the hand around the applicator (Figure 1).

Three-point grip: the distal phalanx of the thumb was positioned under the applicator, the distal two phalanges of the 2nd and 3rd fingers were positioned above it. The observer had to prevent the 4th and 5th fingers from compressing the dynamometer also (Figure 2).

Pinch-grip: the distal phalanx of the thumb was positioned above the applicator, the radial side of the middle phalanx of the index finger was positioned under it (Figure 3).

In total, measurements were made in each patient 12 times; in two sessions, the patient was measured by both observers, three repeated measurements for each observer. Between the two sessions came a 30-minute break. The sequence of the observers was the same in both sessions for each individual patient. The measurement sequence of the observers was determined randomly for each patient.

Prior to the study, the observers attended a ten-hour calibration training.

Furthermore, the pain experienced in the last 24 hours week prior to the evaluation and the pain experienced just after evaluation was asked about. This was assessed in a semiquantitative way, on a 10 cm straight line (0 = no pain, 10 = severe pain; VAS pain).

The values from the affected side of one patient were excluded from the analysis, because she was unable to perform any of the grip-strength tests.

Statistics

Statistics in GENOVA and SPSS pc™ were: descriptive statistics; analysis of variance, according to the generalizability theory, to estimate sources of variation and their absolute and proportional contributions to the total variation for each individual measurement and for the mean of each session; calculation of the correlation coefficient; paired t-tests to analyze VAS-pain before and after the muscle-strength measurements.

Results

The mean muscle strength values of the 29 upper extremity RSD patients for the full-fist, three-point and pinch-grip of the affected and unaffected sides are summarized in Table 2.

The results of the ANOVA, according to the generalizability theory, are summarized in Tables 3 and 4, as are the estimates of variance components for all sources and their interactions.

Important sources of variation (> 1%) in measurement results obtained (besides the patient variation), expressed as a percentage of the total error variance in the mean measurement results, are:

session for: pinch-grip, unaffected side;

observer for: pinch-grip, affected and unaffected sides;

patient/session for: full-fist grip, affected side and three-point grip for unaffected side;

patient/observer for: full-fist grip, affected side and pinch-grip for affected and unaffected sides;

patient/session/observer: (random errors) are important sources of variation in all measurements.

The main sources of variation (> 1%) in measurement results obtained (besides the patient variation), expressed as a percentage of the total error variance in the individual measurement results are the same as for the mean measurement results:

Table 2. The mean muscle strength values (N) of 29 upper extremity RSD patients for the full-fist, three-point and pinch-grip measurements

	Mean	SD	Range
Full-fist-grip			
affected side	84	51	0–192[a]
unffected side	123	66	29–275
Three-point-grip			
affected side	67	35	0–148[a]
unaffected side	94	35	33–164
Pinch-grip			
affected side	56	23	0–86[a]
unaffected side	67	19	33–113

[a] The values from the affected side of one patient were excluded from the analysis, because she was unable to perform any of the strength tests.

patient/session/observer for: all 3 measurements on both sides;

patient/session/repetition for: full-fist grip on the unaffected side;

patient/observer/repetition for: full-fist grip and pinch-grip on the unaffected side;

patient/session/observer/repetition: (random errors) are, in almost all measurements, important sources of variation.

The SDDs for the mean of three repetitions are 71 N for the full-fist grip on the affected side and 66 N on

Table 3. Sources of variation and the estimated contribution to variation in mean measurements results of upper extremity muscle strength in 29 RSD patients; results of mean measurements in 2 sessions by 2 observers

	Full-fist grip		Three-point grip		Pinch-grip		Mean%
	affected side	unaffected side	affected side	unaffected side	affected side	unaffected side	
patient (pt)	9145	12448	880	914	408	287	
session (se)	5	28	1	0[a]	1	6	
observer (ob)	34	11	4	1	36	41	
pt/se	157	89	0[a]	25	0[a]	2	
pt/ob	258	0[a]	0[a]	1	23	20	
se/ob	13	0[a]	0[a]	0	0[a]	0[a]	
pt/se/ob	180	438	90	68	34	26	
total variance	9791	13014	973	1009	503	380	
SUM	646	566	94	95	95	94	
SEm	25	24	10	10	10	10	
SDD	71	66	27	27	27	27	
Variance expressed as percentage of the total variance							
patient (pt)	93	96	90	91	81	75	88
session (se)	0.0	0.2	0.1	0.0	0.1	**1.5**	0.3
observer (ob)	0.3	0.1	0.4	0.1	**7.2**	**10.7**	**3.1**
pt/se	**1.6**	0.7	0.0	**2.4**	0.0	0.5	0.9
pt/ob	**2.6**	0.0	0.0	0.1	**4.7**	**5.2**	**2.1**
se/ob	0.1	0.0	0.0	0.0	0.0	0.0	0.0
pt/se/ob	**1.8**	**3.4**	**9.2**	**6.7**	**6.8**	**6.7**	**5.8**

See Table 1 for calculation of SEm and SDD. [a] Negative estimates are replaced by zero.
Mean %: Proportional contribution of the sources of variation to the total variance averaged over all variables. Sources of variation which contribute more than 1% of the total variation are printed bold.

Table 4. Sources of variation and the estimated contribution to variation in individual measurement results of upper extremity muscle strength in 29 RSD patients; results of the measurements in 2 sessions and 3 repetitions by 2 observers

	Full-fist grip		Three-point grip		Pinch-grip		Mean%
	affected side	unaffected side	affected side	unaffected side	affected side	unaffected side	
patient (pt)	9160	12470	877	913	408	287	
session (se)	3	28	1	0 [a]	0	6	
observer (ob)	34	10	4	1	36	41	
repetition (re)	0 [a]	5	1	0 [a]	0 [a]	0	
pt/se	132	25	0 [a]	24	0 [a]	2	
pt/ob	243	0 [a]	0 [a]	5	22	17	
se/ob	14	0 [a]	0 [a]	1	0 [a]	0 [a]	
pt/re	0 [a]	0 [a]	7	3	2	0 [a]	
se/re	6	0 [a]	0 [a]	1	1	0 [a]	
ob/re	0 [a]	3	0 [a]	1	2	0	
pt/se/ob	111	359	70	46	24	16	
pt/se/re	74	194	3	3	3	1	
pt/ob/re	44	138	0 [a]	0 [a]	4	8	
se/ob/re	0 [a]	0 [a]	1	0 [a]	0 [a]	0 [a]	
pt/se/ob/re	207	237	58	65	32	29	
total	10029	13468	1021	1062	532	407	
SUM	869	998	144	150	125	120	
SEm	30	32	12	12	11	11	
SDD	82	88	33	34	31	30	
Variance as percentage of the total variance							
patient (pt)	91	93	86	86	77	71	84
session (se)	0.0	0.2	0.1	0.0	0.0	**1.4**	0.3
observer (ob)	0.3	0.1	0.4	0.1	**6.7**	**10.1**	**2.9**
repetition (re)	0.0	0.0	0.1	0.0	0.0	0.1	0.0
pt/se	**1.3**	0.2	0.0	**2.2**	0.0	0.4	0.7
pt/ob	**2.4**	0.0	0.0	0.4	**4.2**	**4.2**	**1.9**
se/ob	0.1	0.0	0.0	0.1	0.0	0.0	0.0
pt/re	0.0	0.0	0.6	0.3	0.4	0.0	0.2
se/re	0.1	0.0	0.0	0.1	0.1	0.0	0.0
ob/re	0.0	0.0	0.0	0.1	0.3	0.0	0.1
pt/se/ob	**1.1**	**2.7**	**6.9**	**4.3**	**4.4**	**3.9**	**3.9**
pt/se/re	0.7	**1.4**	0.3	0.3	0.5	0.3	0.6
pt/ob/re	0.4	**1.0**	0.0	0.0	0.7	**1.9**	0.7
se/ob/re	0.0	0.0	0.1	0.0	0.0	0.0	0.0
pt/se/ob/re	**2.1**	**1.8**	**5.7**	**6.1**	**6.1**	**7.1**	**4.8**

See Table 1 for calculation of SEm and SDD. [a] Negative estimates are replaced by zero.
Mean %: Proportional contribution of the sources of variation to the total variance averaged over all variables. Sources of variation which contribute more than 1% of the total variation are printed bold.

the unffected side. For both the three-point grip and pinch-grip and on both sides, this value is 27 N (Table 3).

The SDD for the 12 individual measurements are 82 N for the full-fist grip on the affected and 88 N on the unaffected side. For the three-point grip and pinch-grip these values are 33 N and 34 N, 31 N and 30 N, respectively (Table 4).

Agreement, expressed as the correlations between the muscle-strength measurements of the affected and unaffected sides ranged from 0.68 to 0.99 for the individual measurements and from 0.82 to 0.98 for the mean of three repetitions (Table 5).

The mean VAS-pain scores directly before our evaluation were 1.3 (SD 1.8) and directly after evaluation 2.7 (SD = 2.6); this difference was significant ($p < 0.02$).

Discussion

Sources of variation

Observer and observer/patient interactions and the random error were important sources of variation, which contributed 1% or more to the total variance, for the mean of the three repetitions per observer. In the individual measurement results, observer, patient/observer interactions, patient/session/observer interactions and the random error were important sources of variation to which 1% or more of the total variance was attributed.

The observer, as a source of variation, means that the two observers systematically measured differently from each other. This systematic difference in measurement performance resulted in 11% of the total variance for pinch-grip of the unaffected side. Appar-

Table 5. Correlations for each individual and mean measurements in 29 RSD patients for the 3 different grip-strengths on the affected and unaffected sides in 2 sessions by 2 observers

	Affected side		Non-affected side	
	individual	mean	individual	mean
Full-fist grip				
highest	0.98	0.98	0.99	0.97
lowest	0.91	0.94	0.90	0.96
Three-point grip				
highest	0.97	0.95	0.97	0.97
lowest	0.82	0.90	0.81	0.87
Pinch-grip				
highest	0.97	0.97	0.94	0.93
lowest	0.78	0.88	0.68	0.82

ently the observers instructed the patients systematically in a different way despite the calibration training.

The interaction patient/observer, as a source of variation, accounted for a part of the variation, up to 5.2% of the total variance for pinch-grip, unaffected side. Clinically, this means that not all patients perform identically for the two observers. The interactions of the personalities and between the behaviors of the observer and patient are the cause of such variations.

When the proportional contribution of the sources of variation to the total variance averaged over the 6 variables, was calculated, it appeared that observer and patient/observer were also the main systematic sources of variation.

The patient/session/observer interactions, as a source of variation, in the individual measurements, show that some patients show greater muscle strength during that specific combination of session and observer, whereas other patients show less muscle strength for the same combination.

The random error (patient/session/observer in the mean of the three repetition measurements and patient/session/observer/repetition in the individual measurements) may arise from inaccuracy of the measuring device, according to the technical specifications, the random variation in muscle strength occurring with time or from some disturbance in the measurements, such as might occur when somebody enters an examination room in the middle of a test or when the telephone rings, etc. (Roebroeck 1994).

SDD

The SDDs for the various grip-strengths in this study are clinically considerable in relation to the group means. These SDDs were found, despite measurement protocol and a ten-hour calibration training. If the mean of the three repetitions was used in GENOVA, the SDDs could be reduced by at least 11% of the original SDD. The SDD gives information about the minimal amount of significant change in muscle strength which can be detected between two measurements. Consequently, the SDDs will decrease and the real change in muscle strength will become smaller when the mean of three repetitions is used. For instance, the mean muscle strength of full-fist grip on the affected side of the 29 RSD patients was 84 N (Table 2). The corresponding SDD was, in the mean measurement, 71 N (Table 3). So RSD patients had to increase or decrease the full-fist grip by at least 71 N in a following session to show a real change in strength. In view of the considerable SDDs, it is hard to make clinical decisions on the basis of a single assessment.

Agreement

The agreements in the different muscle-strength tests are good to very good (5).

Our investigation shows that the muscle-strength measurements with a hand-held dynamometer, in upper extremity RSD patients, can be performed reliably for all three hand muscle strength tests with a good agreement but with poor SDD.

Repeated measurements during more repetitions can reduce the contribution of a variance component to the total error variance (Roebroeck 1994). In this study, we measured the muscle forces in the three positions three times as suggested in literature (Doege and Houston 1993, Mathiowetz et al. 1985, van der Ploeg 1992). Therefore, different observers may obtain different values for muscle strength in the same patients.

Pain

During our evaluation, the VAS-pain score showed a significant increase. It can be expected that, as a result of the increase in pain, muscle strength would decrease during the measurements in the sessions and repetitions. However, session, repetition, patient/session interaction, patient/repetition interaction, and patient/session/repetition interaction were unimportant sources of variation. Therefore, the increase in pain was not a disturbing factor in the grip-strength measurements.

Clinical consequences

Observer: This source of variance may be reduced by better standardization for the pinch-grip handling with respect to the instructions for the patient.

Patient/Observer: The patient/observer interaction could be reduced by eliminating the personal interaction between observer and patient. Therefore,

the observer must refrain from any personal remarks, verbal or nonverbal behavior towards the patient. This also has repercussions on medical examinations regarding the rating of permanent physical impairments concerning disablement payments. Although both experienced (12- and 20-year) observers trained themselves to assess the patients similarly, the patient/observer variation is still considerable (Tables 3 and 4). The personality of an observer remains a source of variance which cannot be eliminated. Therefore, in the medical examination room, the interaction between observer and patient is an important factor in relation to the "objective" findings regarding muscle strength.

In the Guides to the Evaluation of Permanent Impairments of the American Medical Association it is stated: "It must be stressed that, in general, grip and pinch measurements are functional tests not to be used for evaluating impairment. Only if the observer feels that the muscle strength must be taken into account, may the muscle strength be measured and the loss rated. The observer must be certain that the patient is in a stable condition in an evaluation regarding permanent impairment. This is best made with measurements over a period of time. It must be taken into account that many factors, including fatigue, handedness, time of day, state of nutrition, pain and the cooperation of the patient, as well as all other sources of variation, influence the strength of grip (Doege and Houston 1993)."

RSD is a syndrome closely associated with psychosocial problems, either as a causative factor or as a result of the disease (Bruehl et al. 1996, Geertzen et al. 1994, van Houdenhove 1986, Zucchini et al. 1989). The personal behavior of a physician towards a RSD patient is important and can be a disturbing factor in making an objective medical report.

The clinical relevance in toto of these hand-muscular strength tests was that they were not performed as laboratory tests, but merely as tests performed daily in every medical examination room. This study showed, with the aid of the generalizability theory, that the muscle strength measurement gives values which are to be treated with scepticism. It must be taken into account that measurements done only once in a medical examination room should not be the only results on which a physician can decide to continue or stop physical therapy or—worse—to report definite medical impairments.

In 90% of RSD patients, active muscular strength is reduced and often involves all muscles of the affected distal extremity, especially those affecting the strength of the hand grip (Baron et al. 1996). According to this author, this disability is not explained by passive impairment of motion due to pain, edema or contractures.

RSD is a complex disease with long-standing impairments, regarding muscle strength. This can have, as already mentioned, medico-legal implications. For objective medical reports, we suggest measurements of hand muscle strength three times in more than one session and, if possible, by more than one physician. In order to observe RSD patients during their treatment, we suggest measuring the hand muscle strength three times in one session.

Conclusion

The generalizability theory is used to estimate the sources of measurement error. Clinical examinations for muscle-strength measurements as a part of a total clinical examination—for example, a disability payment or worker's compensation, in case of RSD patients—should be done by more than one observer in more than one session/repetition.

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References

1. Atkins R, Duckworth T, Kanis JA. Features of algodystrophy after Colles' fracture. J Bone Joint Surg 72B 1990; 1: 105-110.
2. Arlet J. The history of reflex sympathetic dystrophy. In: Reflex sympathetic dystrophy (Ed. Ficat CCJ). London, Baillière's Clinical Orthopaedics. International practice and research. 1996; 1: 209-221.
3. Baron R, Blumberg H, Jänig W. Clinical characteristics of patients with complex regional pain syndrome in Germany with special emphasis on vasomotor changes. In: Reflex Sympathetic Dystrophy: A Reappraisal. Progress in Pain Research and Management (Eds. Jänig W, Stanton-Hicks M). IASP Press, Seattle 1996; 2, 6: 25-48.
4. Bickerstaff DR, Kanis JA. Algodystrophy: an under-recognized complication of minor trauma. Br J Rheum 1994; 33: 240-248.
5. Blumberg H, Jänig W: Clinical manifestations of reflex sympathetic dystrophy and sympathetically maintained pain. In: Textbook of Pain. 3rd edition. (Eds. Wall PD, Melzack R). Edinburgh, London, Madrid, Melbourne, New York and Tokyo, Churchill Livingstone 1994; 685-698.
6. Brennan RL. Elements of generalizability theory. Iowa City, Iowa, Revised Edition 1992.

7. Brooke MH, Griggs RC, Mendel JR et al. Clinical trial in Duchenne dystrophy. I.Design of protocol. Muscle Nerve 1981; 4: 186-197.
8. Bruehl S, Husfeldt B, Lubenow TR, Nath H, Ivankovich AD. Psychological differences between reflex sympathetic dystrophy and non-RSD chronic pain patients. Pain 1996; 67: 107-114.
9. Doege TC, Houston TP. Guides to the Evaluation of Permanent Impairment. 4th edition. American Medical Association, Chicago, 1993.
10. Field J, Warwick D, Bannister C. Features of algodystrophy ten years after Colles' fracture. J Hand Surg 1992; 17B: 318-320.
11. Geertzen JHB, de Bruijn H, de Bruijn-Kofman AT, Arendzen JH. Reflex sympathetic dystrophy: early treatment and psychological aspects. Arch Phys Med Rehabil 1994; 75: 442-446.
12. Houdenhove van B. Neuro-algodystrophy: a psychiatrist's view. Clin Rheum 1986; 5: 399-406.
13. Kendall HG, Kendall FP, Wadsworth GE. Testing and function. Baltimore, Williams and Williams, 1971.
14. Mathiowetz V, Weber K, Volland G, Kashman N. Reliability and validity of hand strength evaluation. J Hand Surg 1984; 9A: 222-226.
15. Mathiowetz V, Kashman N, Volland G et al. Grip and pinch strength: normative data for adults. Arch Phys Med Rehabil 1985; 66: 69-74.
16. Medical Research Council. Aids to the investigation of the peripheral nervous system. Her Majesty's Stationary Office. London 1-2, 1975.
17. Merskey H, Bogduk N: Classification of Chronic Pain: Descriptions of chronic pain syndromes and definition of terms. 2nd edition, IASP Press, Seattle 1994.
18. Ploeg van der RJO: Hand-held Dynamometry. Thesis, Rijks Universiteit Groningen, The Netherlands, 1992.
19. Roebroeck M. Clinical assessment of muscle function with a computer-assisted hand-held dynamometer. Thesis, Vrije Universiteit Amsterdam, the Netherlands, 1994.
20. Subbarao J, Stillwell GK. Reflex sympathetic dystrophy syndrome of the upper extremity: analysis of total outcome of management of 125 cases. Arch Phys Med Rehabil 1985; 62: 549-554.
21. Veldman PHJM, Reynen HM, Arntz IE, Goris RJA: Signs and symptoms of reflex sympathetic dystrophy: prospective study of 829 patients. Lancet 1993; 342: 1012-1016.
22. Veldman PHJM. Clinical aspects of reflex sympathetic dystrophy. Thesis, University of Nijmegen, The Netherlands, 1995.
23. Zucchini M, Alberti G, Moretti MP. Algodystrophy and related psychological features. Funct Neurol 1989; 4: 153-156.