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PAIN IS A MAJOR DETERMINANT OF IMPAIRED PERFORMANCE IN STANDARDIZED ACTIVE MOTOR TESTS

A STUDY IN PATIENTS WITH FRACTURE OF THE PROXIMAL HUMERUS

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ABSTRACT. We have followed the recovery of motor performance and the subsidence of pain for one year in 12 patients after fracture of the proximal humerus. Performance scores during standardized active motor tests were recorded 3, 8, 16, 24, and 52 weeks after injury, and the pain ratings during each of three manoeuvres were assessed on a modified Borg verbal scale. The manoeuvres were: Hand in Neck, Hand in Back, and Pour out of a Pot. In a cross-sectional analysis of data obtained 3 weeks after injury, significant correlations were found between movement-induced pain and impairment of performance in all three tests. A multivariate analysis indicated a strong association between decreasing pain and increasing performance and this was significant after elimination of the influence of healing as measured by time. In contrast, the association between time and increasing performance, after eliminating of the influence of decreasing pain, was weak and non-significant. It is concluded that pain is a major determinant of impaired performance after fracture of the proximal humerus, and that performance scores in standardized active motor tests are inversely correlated with the amount of movement-induced pain.

Key words: shoulder, pain, motor tests, performance scores, impairment, functional assessment.

INTRODUCTION

In clinical physiotherapeutic practice and research, standardized and reliable methods for evaluation of motor performance are of great importance. Such methods should be suitable for analysing motor behaviour in relation to pain and pain eliciting mechanisms. They should also be of assistance in planning of the treatment strategy besides being suitable tools for evaluation of treatment results. Furthermore, they should be as little time-consuming as possible and easy to instruct and practical to perform in a clinical setting.

Codman (3) described the characteristic complaint of patients with stiff and painful shoulders as an inability to put the hand at the back of the neck or behind the small of the back. These manoeuvres have frequently been used by physicians and physiotherapists in order to get a rough estimate of the restriction of motion in patients with shoulder disorders. Standardized rating scales for each of these two manoeuvres and for other functional tests of the shoulder have been developed (2, 5, 13). The Hand in Neck (HIN), Hand in Back (HIB), and Pour out of a Pot (POP) manoeuvres have been described in a preliminary report (13). The HIN manoeuvre was described in detail in a previous publication (14). The scoring systems of the HIB and POP manoeuvres are shown in Figs. 1 and 2.

By studying the pain-avoidance motor strategies in patients with fracture of the proximal humerus, it is possible to analyse the functional consequences of an injury during a healing course. Furthermore, a correlation of function with pain provoked by a particular active motor test offers a possibility of studying the influence of pain on motor performance. In the present investigation we have attempted to answer the question as to whether impairment of motor performance is due primarily to inhibition and modification of motor behaviour caused by movement-induced pain or to purely mechanical restriction caused by the tissue damage.

MATERIALS AND METHODS

From a group of 18 patients with fracture of the proximal humerus (12), a subgroup of 12 patients (11 women and 1 man; mean age 64.6 years, range 53–75) was selected for

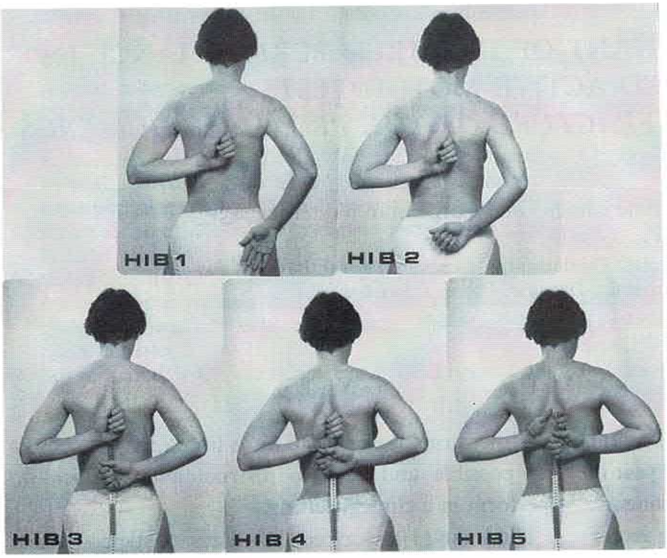

Fig. 1. Scoring system for the Hand in Back (HIB) manoeuvre.
The patient is instructed to put both hands against the back and lift them as far as possible in the midline.
HIB 0: Cannot perform the test on the painful side.
HIB 1: Can get the hand behind the iliac crest.
HIB 2: Can get the hand to the gluteal region.
HIB 3: Can get the hand to the midline of the back. The measured distance between the second MCP joint of the non-painful and the painful side exceeds 10 cm.
HIB 4: The same distance is 5–10 cm.
HIB 5: The same distance is less than 5 cm.

analysis of the HIN, HIB and POP data. This subgroup comprised all patients who had been examined on all five assessment occasions (3, 8, 16, 24 and 52 weeks) after the injury. Six patients, had for various reasons been unable to attend all of these assessments and were therefore excluded from the present analysis for statistical reasons.

On all occasions the patients performed the HIN, HIB and POP tests and rated the pain experienced during each test on a verbal Borg scale (1). All 180 examinations were conducted by the same examiner.

The HIN manoeuvre can be described as having three main components—active abduction and external rotation of the humerus and retraction of the scapula. The scoring system for the Hand in Neck (HIN) manoeuvre is: The patient is instructed to put the hand on the painful side behind the neck with the elbow positioned as far to the side as possible. HIN 0: Cannot reach the back of the neck with the hand. HIN 1: Can hold the hand around the back of the neck, but compensates by holding the neck in ventroflexion and rotation to the opposite side. The shoulder is elevated, the arm adducted. HIN 2: Can hold the hand around the back of the neck, but compensates by elevating the shoulder and adducting the arm. HIN 3a: Can hold the hand around the back of the neck, but compensates by elevating the shoulder. HIN 3b: Can hold the hand around the back of the neck, but compensates by adducting the arm. HIN 4: Can hold the hand around the back of the neck, but cannot extend the upper arm to the coronal plane. HIN 5: Can perform the test normally, i.e. the elbow reaches the coronal plane.

In the HIB manoeuvre, the arm is extended and internally rotated, and the shoulder is protracted to a certain extent. The performance scores range from 0–5 (0 = impossible, 5 = normal function, see Fig. 1).

In the POP manoeuvre the patient is asked to perform a task which involves emptying a one litre pot filled with water with the arm held in front of the body. The movement requires isometric postural fixation of the upper arm in moderate forward flexion combined with eccentrically performed internal rotation with a load that slightly exceeds one kilogram in the hand. The shoulder is protracted. The scores range from 0–4 (0 = impossible, 4 = normal performance, see Fig. 2).

All manoeuvres require good mobility in the elbow, forearm and hand.

Statistical methods

We have analysed data from those patients, who were examined on five occasions during a one-year healing course. This means that each patient contributed the same amount of bivariate data for pain and motor performance.

As both the pain scores and the performance scores were obtained from ordinal scales, all calculations were made after transformation of the scores to ranks. Time, although obtained from an interval scale, was expressed as ranks of time in all calculations.

To provide an overview of the HIN data, Fig. 3 displays the effect of subgrouping according to different criteria namely time and pain ratings. Regarding the individual observations as independent, the Kruskal-Wallis test was applied to the data, using a multicomparison significance level of $p < 0.05$ (4), taking 10 possible pairwise comparisons into consideration for each diagram. Results are only given for comparisons between adjacent groups.

All other statistical comparisons were made by standard regression (univariate and multivariate) techniques applied to ranks (4, 7). Residual analysis was performed, ensuring that the conditions linearity, homoscedasticity, in terms of absence of a significant non-parametric association (Spearman rank correlation) between the absolute values of the residuals and the independent variables, and normality of the residuals were fulfilled (7).

The model for regression analysis presumes that each bivariate observation (a paired observation on pain and performance scores) is independent of all others. The cross-sectional analysis that compares the 12 patients at 3 weeks after the injury fulfils this condition. In the comparisons over time each patient contributes several bivariate observations that cannot be regarded as mutually independent. To compensate for this fact, the error variance, measured by the sum of squares about regression, was regarded as obtained from

Table I. *Partial correlation coefficients derived from multiple regressions of performance on time and pain*

Period A represents 3 through 8 weeks for HIN, and 3 through 24 weeks for HIB. Period B represents 3 through 52 weeks for HIN and HIB. r_{pt} = partial correlation coefficient between performance and pain, controlling for time. r_{pp} = partial correlation coefficient between performance and time, controlling for pain.

		Period A	Period B
HIN	r_{pt}	−0.74**	−0.66*
	r_{pp}	0.39	0.20
HIB	r_{pt}	−0.63*	−0.67*
	r_{pp}	0.10	0.06

*= $p < 0.05$ **= $p < 0.01$.

only 12 observations, i.e. the degrees of freedom were reduced to $12 - 2 = 10$ irrespective of the number of observations. This method gives rather conservative estimates of the *p* values for regression constants. When data are used from parts of or the whole of the healing course, the total variance of the dependent variable, performance, is composed both of the variance between patients and the variance within patients, which is desirable.

There was no indication of any deviation from linearity in the time-performance relationship for the HIB variable. Therefore no quadratic or higher order variables were included in the regression equation that led to the estimation of the partial correlation coefficients in Table I or the r^2 values in Table II. However, for the HIN variable the time-performance relationship was clearly non-linear. Based on logical considerations, it is probably best represented by a segment of a hyperbola, but as pointed out by Stevens (16) the asymptotic regression curve is rather closely approximated by a second-degree polynomial. Therefore a quadratic term (rank of time)^2 was included in the multiple regression equation for the 3 through 52 weeks data for the HIN variable (Table I, period B). In the comparison using only 3 through 8 weeks data (Table I, HIN, period A), there was of course no need to correct for non-linearity.

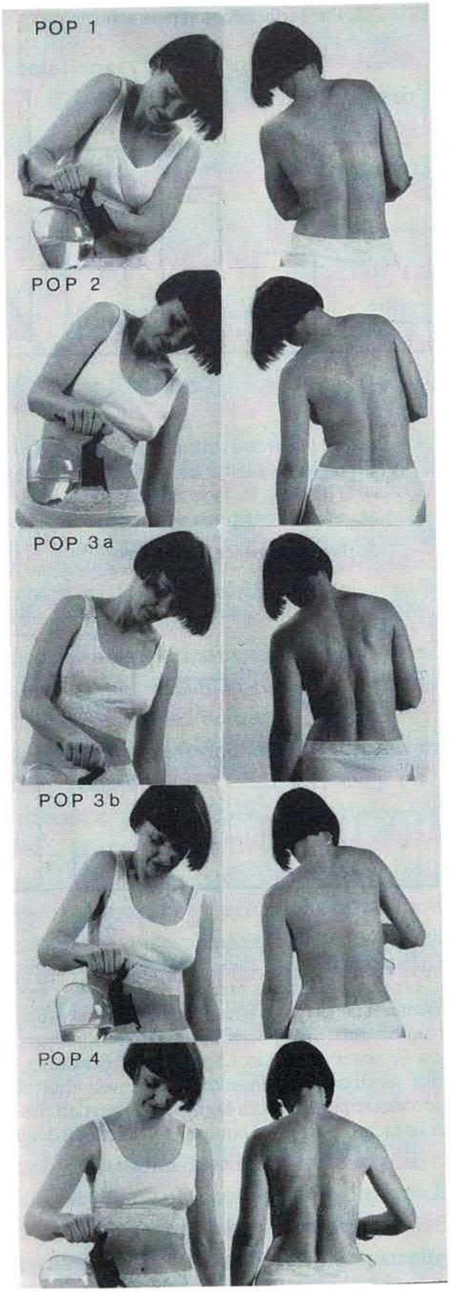

Fig. 2. Scoring system for the Pour out of a Pot (POP) manoeuvre.
The patient is instructed to lift a pot containing 1 litre of water and pour the water out into a sink in front of the patient. The patient is asked to freeze the final position for 3–5 seconds in order to facilitate the observation.
POP 0: Cannot pour the water out of the pot.
POP 1: Can pour the water out of the pot, but compensates by using the other hand for support, by bending to the contralateral side and by elevating the shoulder.
POP 2: Can pour the water out of the pot, but compensates by bending to the contralateral side and elevating the shoulder.
POP 3a: Can pour the water out of the pot, but compensates by bending to the contralateral side.
POP 3b: Can pour the water out of the pot, but compensates by elevating the shoulder.
POP 4: Can pour the water out of the pot normally, i.e. without compensatory movements.

Table II. *Cross-sectional comparisons of pain and performance at 3 weeks and longitudinal comparisons of pain and performance over time*

Period A represents 3 through 8 weeks for HIN, and 3 through 24 weeks for HIB. Period B represents 3 through 52 weeks for HIN and HIB. r^2 = coefficient of determination for the influence of pain on performance in simple regression. R^2 = coefficient of multiple determination for the influence of pain and time on performance in multiple regression.

		Cross-sectional comparisons at 3 weeks	Longitudinal comparisons	
			Period A	Period B
HIN	r^2	0.56**	0.65*	0.63*
	R^2	—	0.70*	0.65*
HIB	r^2	0.56**	0.53*	0.63*
	R^2	—	0.53*	0.63*
POP	r^2	0.52**	—	—
	R^2	—	—	—

*= $p < 0.05$. **= $p < 0.01$.

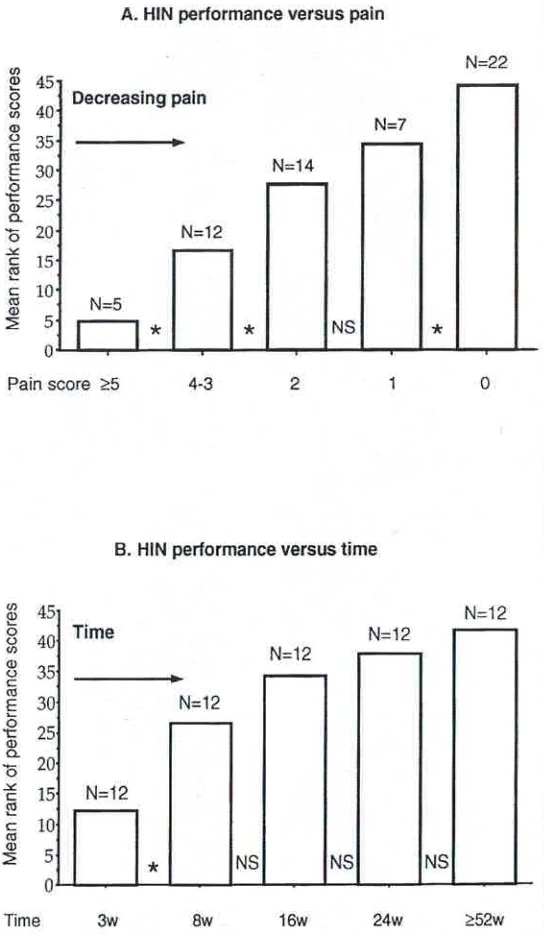

Fig. 3. Performance in the HIN test in different subgroups, expressed as mean rank of performance scores. (A) Performance versus pain irrespective of time. (B) Performance versus time irrespective of pain. Both diagrams are based on 60 observations in 12 patients. * denotes $p < 0.05$. NS = not significant. It should be observed that the pain rating scores are plotted from highest to lowest on the X-axis, in order to facilitate a visual comparison between diagrams A and B.

RESULTS

We have used the HIN-test for the purpose of illustration in Fig. 3. This figure conveys several messages. It describes the healing course, defined as recovery of function in the HIN test, and it strongly suggests an association between decreased movement-induced pain and increased motor performance (Fig. 3A), also, it strongly indicates that performance is more closely related to pain than to the point in time in the healing course (Fig. 3B).

These impressions are substantiated by the results of multiple regression analyses. They are shown as partial correlation coefficients in Table I. The partial correlation coefficient is a measure of the strength of the association between two variables controlling for, i.e. eliminating, the influence of a third correlated variable. As seen in Table I, the associations (r_{pt}) between movement-induced pain and performance *after elimination of the influence of healing of tissue damage*, as estimated by time, were strong and significant. In contrast, the direct associations (r_{pp}) between healing of tissue damage over time and increasing performance *after elimination of the influence of pain* were weak and non-significant.

The reason why we present data not only for the whole one-year period is that the relatively large number of pain-free individuals at 12 months could have a disproportionately high influence on the estimates of the regression coefficients. Therefore, data are also presented for the period 3 through 24 weeks for the HIB test and for the period 3 through 8 weeks for the HIN test. The latter period was chosen mainly because most patients had shown the greatest recovery of function in the HIN test at 8 weeks and many were pain-free thereafter. Pain provoked by the POP test was present 3 weeks after the injury but from 8 weeks and onwards almost all patients were pain-free during this test.

The significant partial correlation coefficients in Table I do not necessarily mean that our study variable—pain—had a large quantitative effect on performance. The coefficient of determination (r^2) is a measure of the proportion of variance of the

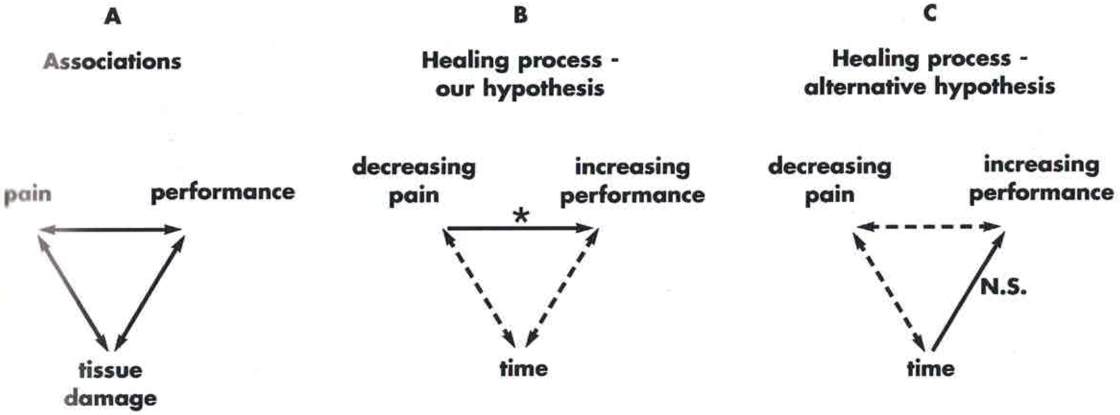

Fig. 4. (A) Internal relationships between performance, pain and degree of tissue damage. The latter parameter is very difficult to estimate quantitatively in cross-sectional studies. During a healing course subsidence of tissue damage can be crudely estimated by the parameter rank of time. In (B) and (C) unidirectional *arrows* indicate possible causal relationships. The two explanatory models can be compared by means of partial correlation technique. For both the HIN and HIB variables we found strong and significant (* = $p < 0.05$) associations between performance and pain after elimination of the influence of time (B), but only weak and non-significant (N.S.) direct associations between performance and time after elimination of the influence of pain (C). Quantitative data are given in Table I.

dependent variable (performance) that is explained by the study variable in simple regression. As seen in Table II, pain explained between 52 and 65% of the ranking order of performance. The coefficient of multiple determination (R^2) measures the proportion of the variance of the dependent variable (performance) that is explained by the independent variables (pain and time) when used together. By comparing the r^2 values from univariate regressions of performance on pain with the corresponding R^2 values, which also incorporate the influence of time, it is readily seen that very little further explanatory power is achieved by also taking time into consideration.

DISCUSSION

Several clinical studies have indicated that pain can be a contributory cause of functional impairment (2, 6, 8, 9, 11, 15). To our knowledge, however, no other study has shown such a strong association between pain and loss of function as we have demonstrated here. Since our conclusions are mainly based on statistical analysis, we will discuss the statistical considerations first.

Hypotheses

1) Pain is a major determinant of impairment of performance in the three active motor tests described, via CNS-mediated modification of motor behaviour.
2) Alternatively, non-pain-mediated effects of tissue damage, i.e. purely mechanical restriction, is responsible for the impaired performance.

Associations between pain and performance

In a cross-sectional analysis of the data obtained 3 weeks after the injury, strong associations were found between pain and performance in all three tests (Table II). As the p value for these correlations never exceeded 0.008, we conclude, that when the HIN, HIB, and POP tests are applied to patients with a fracture of the proximal humerus, there is an association between movement-induced pain and poor performance.

Possible causal relations

An association, even when highly significant, cannot automatically be interpreted as evidence of a causal relationship. As shown in Fig. 4A, the association between pain and performance might be the result of a common underlying cause—the degree of tissue damage. It is not far-fetched to assume that the degree of tissue damage on the one hand determined pain and on the other, performance. If these associations were parallel, i.e. if increasing tissue damage simultaneously caused more severe pain and more disturbance of function, a spurious, secondary, or from a pathogenic point of view easily misleading association might appear. Generally speaking, data from cross-sectional analyses can certainly establish an association between pain and performance in active motor tests, but alone they cannot provide firm evidence of a causal relationship.

Tissue damage is a concept that simultaneously includes purely mechanical aspects and biochemical ones. The latter are mainly consequences of the inflammatory reaction, the most important effect of which—in this particular context—is sensitization of nociceptors (17) which become responsive to traction and/or compression during movements of the shoulder. The multifacetted concept "tissue damage" is of course difficult to estimate quantitatively. However, one aspect of this concept that lends itself to at least crude quantification is well known, i.e., that tissue damage tends to heal with time. Thus, time is an implicit component of the concept "healing process". Since the healing course, as reflected by function, measured by our active motor tests, varied considerably between different patients, we decided to estimate healing by the parameter rank of time.

A multivariate analysis of the healing course made it possible to estimate quantitatively the relative strength of the associations that would decide whether hypothesis 1 or 2 (see Figs. 4B and C) should be preferred. The associations between decreasing pain and increasing performance after elimination of the influence of subsiding tissue damage as measured by time were strong and significant. In contrast, the "direct" associations between healing of tissue damage over time and increasing performance after elimination of the influence of decreasing pain were weak and nonsignificant (Table I).

It is customary to represent an association between two variables diagrammatically with bidirectionally pointing arrows, simply because statistics alone tells us nothing about possible cause and effect relationships. The use of a unidirectional arrow in Fig. 4B was based on logical considerations. If the arrow pointed in the direction from increasing performance to decreasing pain, this would mean that a small movement would cause severe pain, whereas a large movement would instead, decrease the pain. This is not logically tenable. The unidirectional arrow in Fig. 4C just serves the purpose of describing an alternative hypothesis, which excludes pain and pain-elicited CNS reflexes as intervening factors in explaining functional loss. To phrase it explicitly —this unidirectional arrow is not meant to deny a positive effect of active movements on the recovery of function.

We conclude that pain was the most important mediator of function loss in at least the HIN and HIB manoeuvres in our studied group of patients. This does not of course rule out the possibility that the healing process also, to a certain extent involved a slight, direct, mechanical, or non-pain-mediated effect on the recovery of function.

Pain modulation of motor behaviour

We suggest that the chain of fracture-related events can be described as follows: 1) The trauma causes tissue damage, the most important aspect of which is the release of sensitizing substances, which make nociceptors responsive to even moderate mechanical stimulation. 2) Nociceptive impulses reach the CNS. 3) In the CNS a supraspinal loop causes modification of the motor behaviour, which not only involves inhibition of the prime movers and possibly activation of their antagonists, but also activation of remote muscle groups (Fig. 5), for instance leading to flexion and rotation of the neck in the HIN test and flexion of the trunk towards the contralateral side in the POP test. Spinal loops, probably act as protection against further tissue damage.

Pain avoidance strategies

The influx of impulses from nociceptors to the central nervous system will have profound effects on the motor system. A patient with painful coxarthrosis, for instance, has a characteristic gait with a limp, while leaning over to the affected hip during the stance phase (10). A patient with a nerve root compression in the lumbar spine most commonly moves and walks with his back positioned in a lateral and/or forward bend, to move away from the mechanical pressure on pain-provoking tissues. A patient with a painful condition in or around the glenohumeral joint will automatically stop the elevation of the arm at the onset of pain and continue the movement by raising the shoulder and bending over to the contralateral side. This compensatory motor behaviour will indirectly position the arm at a higher level without further movement in the glenohumeral joint. In the compensatory patterns exemplified above, the patient stops the movement or changes the path or muscular

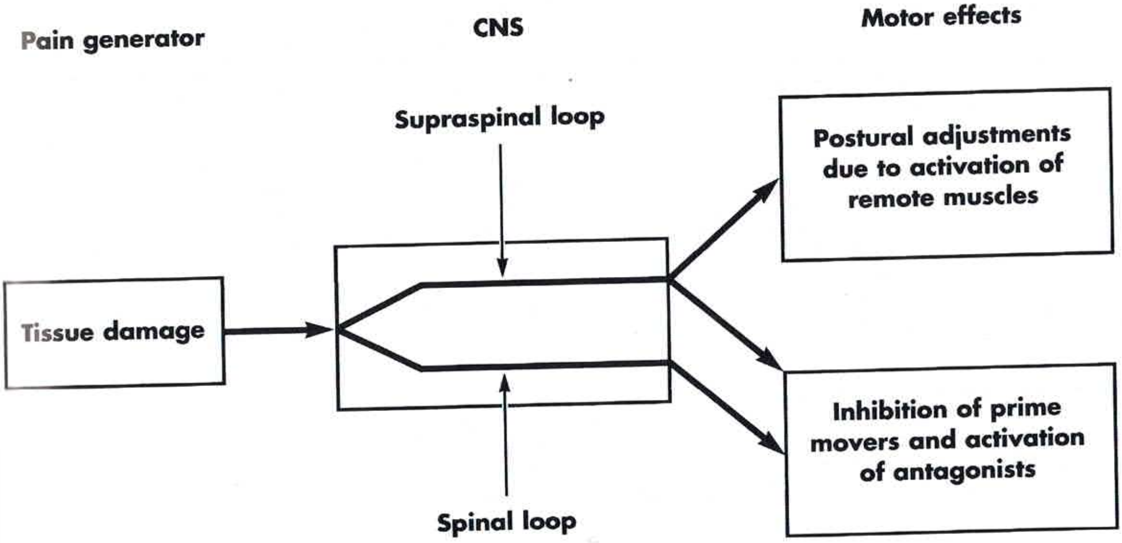

Fig. 5. Scheme to describe the proposed mechanisms of the influence of pain on motor behaviour in active motor tests.

composition of the movement when a certain amount of pain is experienced. These compensations are automatic procedures which are governed by the central nervous system via spinal and supraspinal pathways (Fig. 5), and which may be called *pain avoidance strategies.*

Performance rating scores

It should be emphasized that the construction of the HIN, HIB, and POP tests and the corresponding rating scores were based on previous observations in a large number of patients with fracture of the proximal humerus. The salient empirical observation was that the pain avoidance strategies were very stereotyped. To make this point clear, individual patients did not invent different pain avoidance strategies of their own. This probably means that the modification of motor behaviour by pain is mainly decided by predetermined patterns common to all people. Our success in establishing firm pain-performance relationships may be an indication that our performance rating scores lend themselves as motor measures of pain. In other words: pain can be assessed not only on verbal or visual analogue scales; *pain can also be expressed in motor language.*

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