

The structure, reliability and validity of pain expression: Evidence from patients with shoulder pain

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Abstract

The present study examined psychometric properties of facial expressions of pain. A diverse sample of 129 people suffering from shoulder pain underwent a battery of active and passive range-of-motion tests to their affected and unaffected limbs. The same tests were repeated on a second occasion. Participants rated the maximum pain induced by each test on three self-report scales. Facial actions were measured with the Facial Action Coding System. Several facial actions discriminated painful from non-painful movements; however, brow-lowering, orbit tightening, levator contraction and eye closing appeared to constitute a distinct, unitary action. An index of pain expression based on these actions demonstrated test–retest reliability and concurrent validity with self-reports of pain. The findings support the concept of a core pain expression with desirable psychometric properties. They are also consistent with the suggestion of individual differences in pain expressiveness. Reasons for varying reports of relations between pain expression and self-reports in previous studies are discussed.

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Keywords: Pain; Shoulder pain; Pain expression; Facial expression; Facial Action Coding System

1. Introduction

Pain is often accompanied by changes in behavior, among which facial expressions have attracted significant attention [3,28]. Like expressions of emotion [13], facial expressions during pain are thought to play a critical role communicating information about the experience [5,21,25]. Furthermore, they provide an alternative to common indices of pain, such as verbal reports, and the information they provide may be more useful and valid in certain circumstances [16].

Research into pain expression was stimulated by the development of the Facial Action Coding System

(FACS) [4] a technique that allows any visible facial expression to be decomposed into its constituent movements. Studies that have applied the FACS have identified several actions that increase in likelihood or intensity during pain. Based on a study of facial expressions during four different types of experimental pain, and a review of existing evidence, Prkachin [19] proposed that four actions – brow-lowering, tightening the eyelids or raising the cheeks (orbit tightening), nose wrinkling or upper-lip raising (levator contraction) and eye closure – showed sufficient consistency to be considered a “core” expression of pain. Several studies have reported other actions to be associated with pain. For example, LeResche [17] reported that horizontal lip stretching produced by the risorius muscle, was associated with pain. Likewise, Craig and colleagues [2,18] reported that oblique lip raising, the action of

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zygomaticus major that happens in smiling, increased with increasing pain. One purpose of the present study was to re-examine the question of what facial actions accompany pain.

A second purpose was to re-examine the validity of pain expression. In particular, to what extent do facial expression and self-reports of pain correspond? Several studies have indicated that the two sources of information are largely unrelated [2,6,7,9,10,19], prompting some to conclude that facial expression and verbal report provide different kinds of information. Others [1,8,15,20,24] have reported significant and occasionally substantial correlations between self-report and facial measures. One potential explanation for discrepancies among the studies is psychometric. Studies that have failed to find significant relations between facial and self-report measures have tended to employ few measures of subjective report, facial expression or both. The psychometric principle of aggregation suggests that, by using multiple measures of the same construct, error variance associated with individual measurements will cancel, resulting in a clearer representation of the true relationship. In the present study, we used multiple measures of self-report and facial expression to examine the relationship between the two domains.

A third purpose was to examine the stability of pain expression. Few studies have addressed this issue. Prkachin [19] reported modest correlations between measures of pain expression stimulated by different modalities of experimental pain. Substantial test–retest correlations between measures of facial expression during physical examinations separated by two or 3 days have been reported in subacute low-back pain patients [22]; however, in that case, measurements were performed in real-time by observers making global judgements.

2. Method

2.1. Participants

Participants were 63 men and 66 women (M age = 42.23 years, SD = 14.48) who self-identified as having a problem with shoulder pain. Participants were recruited from three active physiotherapy clinics and by advertisements posted on the campus of McMaster University. Demographic characteristics of the sample are provided in Table 1. Approximately 25% of the participants were students. The rest were distributed across a variety of occupations including management (7%), health-care (7.8%), civil service (7.8%), the cultural sector (2.3%), service (7.8%), trades (7.8%), primary industry (1.8%), manufacturing (2.3%) and other (4.7%). The sample was generally well-educated and displayed an ethnic diversity that reflected the urban Canadian community from which it was recruited. Seventy percent of the participants had attended a physician or physiotherapist for their shoulder pain and had received a diagnosis. Diagnoses varied considerably and included arthritis, bursitis, tendonitis, subluxation, rotator cuff

Table 1
Sample demographic characteristics

Employment	Education	Ethnicity
Unemployed	12.4	Grades 1–6 .8
Employed	44.2	Some high school 9.3
Homemaker	2.3	High school 15.5
Student	24.8	Some post-secondary 31.8
Retired	16.3	Post-secondary 16.3
		Graduate equivalent 25.4
		Chinese 9.3
		German 3.9
		Polish 1.6
		Jewish .8
		Jamaican .8
		Filipino .8
		Ukrainian 2.3
		Other 14.7

Note. Figures are percent of total sample.

injuries, impingement syndromes, bone spur, capsulitis and dislocation. Sixty-five patients (50.4%) reported use of medication for their pain. Of these, 47 reported using a non-steroidal anti-inflammatory, 18 acetaminophen, 9 a salicylate, 5 a narcotic analgesic, 4 a muscle relaxant, 3 a tricyclic anti-depressant, 2 a corticosteroid, 2 a herbal medicine, 1 a selective serotonin uptake inhibitor, 1 capsaicin and 1 other (numbers exceed 65 due to individuals using multiple medications).

2.2. Apparatus and materials

Participants were tested in a laboratory room which had a bed for performing passive range-of-motion tests. Two Sony digital video cameras were used to record participants' facial expressions.

A card, listing verbal pain descriptors, was available to help participants provide verbal ratings of the pain produced on each test. Each card displayed two descriptor scales taken from Heft et al. [11]. One set consisted of words reflecting the sensory intensity of pain. The other consisted of words reflecting the affective-motivational dimension. These scales have been subject to intensive psychophysical analyses, which have established their properties as ratio-scale measures of the respective underlying dimensions. Each scale had 15 items labelled "A" to "O." The sensory scale started at "extremely weak" and finished at "extremely intense," the affective-motivational scale started at "bearable" and finished at "excruciating." In addition, participants used a series of 10 cm Visual Analog Scales (VAS), anchored at each end with the words, "No pain" and "Pain as bad as could be" to rate each test.

2.3. Procedure

The procedures of the study were approved by the Research Ethics Boards of McMaster University and the University of Northern British Columbia. Participants were told that the intent of the study was to help understand where and how their pain affects them and what kind of impact it has had on their

lives. They were given descriptions of the range-of-motion tests to be employed, the fact that some would be painful and that the procedures would be recorded on video. Participants were paid \$20.00 Canadian for their time.

After consent and information procedures were complete, participants underwent eight range-of-motion tests involving commonly used and standardized abduction, flexion, internal and external rotation of the arm [23]. Abduction movements involved lifting the arm sideways and up in the frontal plane. Flexion involved lifting the arm forward and up in the sagittal plane. In internal rotation, the arm was bent 90 degrees at the elbow, abducted 90 degrees and turned internally. External rotation was the same, except that the arm was turned externally. Abduction, flexion, internal and external rotations were performed under active and passive conditions. Active tests differed from passive tests in being under the control of the patient who was instructed to move the limb as far as possible. These tests were performed with the patient in a standing position. Passive tests were performed by a physiotherapist who moved the limb until the maximum range was achieved or was told to stop by the patient. During passive tests, the participant was resting in a supine position on the bed with his or her head supported and stabilized by a pillow. Active tests were performed prior to passive tests because that is the usual sequence in which they are conducted clinically. The order of tests within active and passive conditions was random. Tests were performed on both the affected and the unaffected limb to provide a within-subject control.

After each test, participants rated the maximum pain it had produced using the sensory and affective verbal pain descriptors and the VAS.

Each test was recorded on digital videotape with the camera focused on the face. Active tests were recorded from a frontal direction, passive tests from above at an approximate angle of 70 degrees to the plane of the participant's body.

After range-of-motion tests were completed, participants underwent a series of psychometric tests. The tests were the focus of a different aspect of the study and will not be discussed further here. After the participant had completed the psychometric tests, the same range-of-motion tests were performed for a second time on both affected and unaffected sides. The test–retest interval varied according to the speed with which the participant completed the tests, but was generally approximately 20 min. The retests were also recorded on video.

After testing was completed, participants underwent a further consent process to indicate their willingness to allow their video recordings to be used for analysis and further purposes.

2.4. Measurement of facial expression

Each test was extracted from the digital video record and coded using the FACS. Each facial action is described in terms of one of 44 individual action units (AUs). Because there is a considerable literature in which FACS has been applied to pain expression, we restricted our attention to only those actions that have been implicated in previous studies as possibly related to pain: brow-lowering (AU 4), cheek-raising (AU 6), eyelid tightening (AU 7), nose wrinkling (AU 9), upper-lip raising (AU 10), oblique lip raising (AU 12), horizontal lip stretch (AU 20), lips parting (AU 25), jaw dropping (AU 26), mouth stretching (AU 27) and eye closing (AU 43). With

the exception of AUs 25, 26, 27 and 43, each action was coded on a 5 level intensity dimension (1 = trace–5 = maximum) by one of three coders who had previously demonstrated proficiency by passing the FACS Final Test. Actions were coded on a frame-by-frame basis. All coding was then reviewed by a fourth coder who had also demonstrated proficiency on the final test. Finally, 1738 frames, selected from one affected-side test and one unaffected-side test of 20 participants randomly sampled from the data set, were coded by a FACS-proficient reliability coder. Interrater reliability, as calculated using the Ekman–Friesen formula [4], was .95, which compares favourably with other research in the FACS literature.

The recordings of each test were processed using custom software, which summed the intensity scores of the selected actions on each frame of video. The segment of each test selected for study was the action that obtained the highest score. In other words, on each range-of-motion test, the video frame displaying the most intense facial expression was selected for study.

Based on precedent [19], AUs 6 and 7 were combined into a single variable, orbit tightening, which was defined as the maximum intensity score of either action. Similarly, AUs 9 and 10 were combined into a single variable, levator tightening. Finally, AUs 25, 26 and 27 were combined into a four-point degree-of-mouth-opening scale as follows: 0 (no action), 1 (AU 25, mouth open), 2 (AU 26, jaw drop) and 3 (AU 27, mouth stretch). As a consequence of these combinations, seven facial action variables were used in subsequent analyses: brow-lowering, orbit tightening, levator tightening, oblique lip raising, horizontal lip stretch, mouth opening and eye closing. In the subsequent text, action descriptions will be used instead of AU designations to describe outcomes.

Statistical analyses of verbal pain reports and preliminary analyses of facial actions employed 2 (sex) \times 2 (side: affected vs. unaffected) \times 2 (test–retest) \times 2 (active vs. passive procedure) \times 4 (test: abduction, flexion, internal rotation, external rotation) analyses of variance (ANOVAs). Subsequent analyses employed principal components and correlational analyses, as described below.

3. Results

3.1. Self-reports

The ANOVAs of participants' sensory, affective and visual analog scales yielded comparable results. To simplify presentation only results for the visual analog scale will be presented. Side tested had a substantial effect, $F(1,127) = 148.47$, partial $\eta^2 = .54$, $p < .001$. Movements of the affected shoulder were rated as more painful ($M = 3.10$, $SE = .18$) than movements of the unaffected shoulder ($M = 0.98$, $SE = .12$). A significant test effect, $F(\text{Geisser–Greenhouse corrected}) = 7.31$, $p < .001$, partial $\eta^2 = .05$, arose from the fact that the ratings of the flexion tests ($M = 1.82$, $SE = .14$) were rated as less painful than the others, which did not differ among themselves (Ms: abduction: 2.07 (.15), internal rotation: 2.05 (.13), external rotation: 2.24 (.14)). A significant side \times active/passive test interaction,

$F(1, 127) = 17.77$, partial $\eta^2 = .12$, $p < .001$, resulted from the fact that pain on active tests was rated higher than pain on passive tests when the participant was tested on the affected side. There were no differences in rated pain attributable to sex or repeated testing.

3.2. Analysis of facial expression

Preliminary ANOVAs were performed on brow-lowering, orbit tightening, levator tightening, oblique lip pull, horizontal lip stretch, mouth opening and eye closure during test 1 in order to characterize facial actions influenced by pain. An α -level of .005 was set for statistical significance because of the number of tests performed. For the purposes of the present analysis, attention was restricted to differences between the affected and unaffected sides because it was expected that facial actions encoding pain would be more likely and more intense on the affected than the unaffected side of the body. Table 2 summarizes the results. All the facial actions selected for investigation occurred with significantly greater intensity on the affected than the unaffected side ($p < .001$). Based on Cohen's criteria for the description of effect sizes, the effects for brow-lowering, mouth opening, eye closure and especially orbit tightening would be considered large; whereas those for levator tightening, oblique lip pulling and horizontal lip stretching would be considered medium.

Since all the facial actions measured increased during pain, it was of interest to determine whether they represented a common reaction. To do this, principal components analysis with varimax rotation was performed on the reactions during each pain test from the test 1 series. Based on the criteria of eigenvalues exceeding 1.0 and the Scree-test from one to three components were extracted across tests. Examining the first component extracted from each analysis and adopting the requirement that an action needed to have a factor loading of .30 or greater to be considered as loading on that component, each of the eight analyses yielded approximately the same pattern. Brow-lowering and eye closure loaded significantly in 7/8 analyses, orbit tightening and levator contraction in 8/8, while oblique lip pulling, horizontal lip stretch and degree-of-mouth-opening loaded signifi-

cantly in 1, 2 and 1 cases, respectively. According well with our previous work [19] these findings provide considerable justification for treating brow-lowering, orbit tightening, levator contraction and eye closure as “core” pain related actions and combining them into an overall index of pain expression.

Based on the foregoing, a composite measure of pain expression was constructed by summing the participants' scores for brow-lowering, orbit tightening, levator tightening and eye closure on each test. These values, which could range from 0 to 16, were then subject to an ANOVA. This analysis resulted in significant main effects for side, $F(1, 120) = 67.18$, $p < .001$, partial $\eta^2 = .36$; type, $F(1, 120) = 4.94$, $p < .05$, partial $\eta^2 = .04$; and time, $F(1, 120) = 6.89$, $p < .05$, partial $\eta^2 = .05$. In addition, there were significant time \times side \times type, $F(1, 120) = 4.70$, $p < .05$, partial $\eta^2 = .04$ and time \times side \times sex, $F(1, 120) = 10.17$, $p < .01$, partial $\eta^2 = .08$, interactions. The average pain expression score was higher (1.93; SE = .15) when patients were tested on their affected sides, than when tested on the unaffected side ($M = .91$; SE = .09). Pain scores during the second test ($M = 1.33$, SE = .10) were lower than those during the first ($M = 1.51$, SE = .12). The significant time \times side \times type interaction is displayed in Fig. 1. During the first test, active tests were associated with lower pain scores than passive tests on both the affected and unaffected sides. On the second test, the difference between active and passive tests was observed only on the affected side. The time \times side \times sex interaction (Fig. 2) derived from a sex difference in the pattern of responding on tests conducted on the affected side. Men displayed more pain than women on the first test. On the second, pain scores for women and men were virtually identical.

3.3. Reproducibility and concurrent validity

Pain scores on each of the affected-side tests from the first testing occasion were then themselves subjected to a principal components analysis in order to determine whether there was sufficient reason to consider the behavior during individual tests as tapping a common reaction. Eigenvalues and the Scree-test were consistent

Table 2
Results of ANOVAs comparing individual actions on unaffected and affected sides

Action	$F(1, 119)$	p	η^2	M unaffected (SE)	M affected (SE)
Brow-lowering	20.59	<.001	.15	.22 (.04)	.42 (.06)
Orbit tightening	65.54	<.001	.35	.55 (.05)	1.16 (.09)
Levator tightening	13.78	<.001	.10	.11 (.03)	.28 (.04)
Oblique lip pull	20.53	<.001	.15	.51 (.04)	.78 (.07)
Lip stretch	13.77	<.001	.10	.07 (.02)	.15 (.03)
Mouth opening	16.79	<.001	.12	.41 (.04)	.55 (.04)
Eye closure	22.58	<.001	.16	.09 (.01)	.17 (.02)

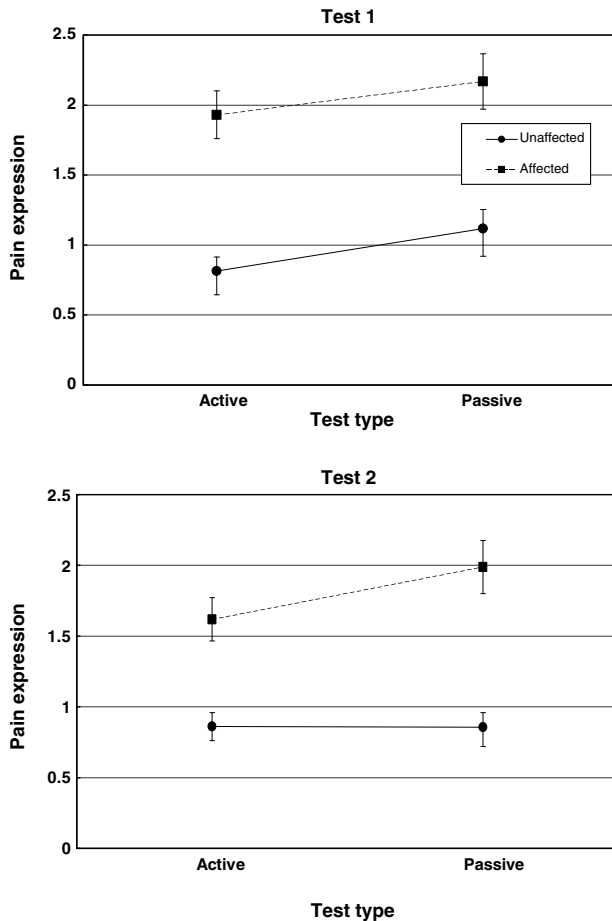


Fig. 1. Mean (\pm SE) pain expression scores on the first and second active and passive test on unaffected and affected sides.

with the existence of a single component accounting for 40.47% of the variance, with significant loadings on all the tests. Consequently, because there was reason to believe the tests sampled a common reaction, overall pain scores were calculated for each testing occasion by averaging the scores of each pain test within occasion. This reduced the complexity of the analysis while taking advantage of the principle of aggregation. The Pearson correlation between these aggregated pain scores on the first and second testing occasions was $r = .74$, $p < .001$.

To investigate the relationship between self-reports and facial expressions of pain, composite indices of each domain were calculated for active and passive tests. Because self-reports were obtained on three different scales, each with separate metrics, standard scores (i.e., z -scores) were calculated. Standard scores for each test type were then averaged separately for active and passive tests. Composite facial pain expression indices were also calculated separately for active and passive tests, averaging over test types. Self-report and pain expression indices were then intercorrelated. Results appear in Table 3 where it can be seen that all indices were sig-

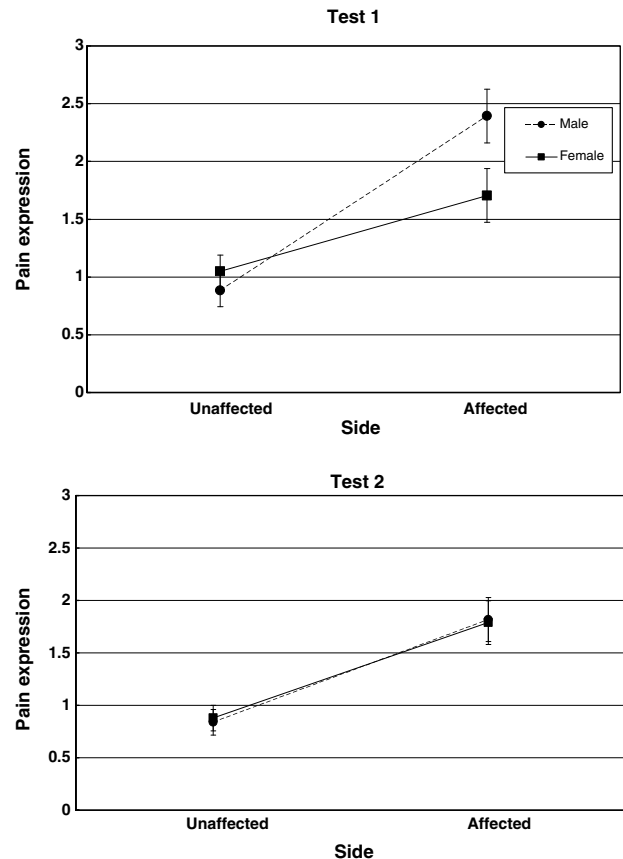


Fig. 2. Mean (\pm SE) pain expression scores on the first and second test of unaffected and affected sides for women and men.

nificantly positively related.¹ Of note, however, is the fact that the within-domain (self-report – self-report; facial expression – facial expression) correlations were substantially higher than the cross-domain correlations. The within-domain correlations were at a level that is conventionally considered strong; whereas the between-domain correlations were in the more moderate range. There did not appear to be a substantial difference between active and passive tests in the degree to which self-reports and pain expressions correlated.

4. Discussion

The results of this study support three main conclusions about the facial expression of pain. First, the set of actions consisting of brow-lowering, orbit tightening, levator contraction and eye closure and identified by sev-

¹ Given the theoretical linkage between emotion and expressive behavior, there is reason to expect that expression would relate more strongly to the affective-motivational than the sensory-discriminative dimension of pain. However, in separate analyses, there was no appreciable difference between the respective correlations, which were all significant and approximately the same magnitude as that reported for the composite scores.

Table 3
Intercorrelations among active and passive pain self-report and expression scores

	Active test Self-report	Passive test Self-report	Active test Facial expression
Passive test Self-report	.84		
Active test	.37	.31	
Facial expression			
Passive test	.31	.36	.63
Facial expression			

Note: All $p < .001$.

eral groups of investigators as associated with pain [2,16,19], do indeed appear to consist of a core expression of pain with unitary properties. These actions were significantly more likely and intense when patients' shoulders were challenged on their affected sides than when challenged on the unaffected sides. Other actions (lip pulling, lip stretching and mouth opening) that have occasionally been reported to be associated with pain also displayed this pattern. However, the results of principal components analyses were clear in showing that brow-lowering, orbit tightening, levator contraction and eye closure loaded together and on a different dimension than the other actions. This pattern of findings justifies considering the four actions as components of a unitary dimension of pain expression and supports use of the term "prototypic expression," to describe such actions in recent research [26]. It should be noted, however, that the four actions have different metrics. Brow-lowering, orbit closure and levator contraction are measured on five-point intensity scales. The inclusion of eye closure, a binary measure, may introduce some distortion to the overall index. Nevertheless, the overall behavior of the index, as discussed below, suggests that it has desirable psychometric properties.

It is, of course, possible that pain might be associated with multiple expressions, communicating different aspects or meanings of the experience. In the present case, we believe it is most plausible to suggest that the actions of lip pulling, lip stretching and mouth opening are secondary reactions to pain. The oblique lip pull is the principal movement in smiling. Horizontal lip stretching is a rare movement that is distinctly noticeable when it occurs. Mouth opening accompanies vocalization. It may be that these actions represent a kind of post-registration reaction to pain, involving movements that play a role in communicating alternative or complementary socio-affective states such as consciousness of the intensity of one's pain reaction with consequent amusement and smiling or coping behavior. Indeed, it would be interesting to examine whether these reactions are more likely in circumstances in which people have consciously registered their initial pain reactions.

Second, pain expression appears to be a reliable phenomenon when the criterion is short-term test–retest reproducibility. Although the ANOVA results indicated that testing on a second occasion resulted in diminished overall pain expression, patients maintained their relative order, resulting in an overall correlation of .74. This is very close to the value of .71 reported for the 3 day correlation of measures of facial expression performed in real-time by observers in a physical examination [22]. To our knowledge, these are the only studies to have investigated the reproducibility of measures of pain expression using samples with clinical pain. That they were obtained with samples experiencing different types of pain and techniques for measuring facial expression that were also quite different (frame-by-frame vs. real-time clinical assessment) adds support to the inference that pain expression demonstrates substantial stability in the short-term. The observation of a high within-domain correlation between pain expression during active tests and pain expression during passive tests ($r = .63$) is also consistent with the conclusion that pain expression shows a robust internal structure. In a study examining four types of experimentally induced pain, pain expression scores comparable to those calculated in the present study were significantly correlated across modalities [19]. This ensemble of findings suggests a certain trait-like stability to individual differences in facial expressiveness.

Third, the findings reflect on the validity of facial expression as an index of pain; notably construct and convergent validity. With respect to construct validity, an index of pain should vary predictably with variation in the expected underlying state. In the present instance, the four-component index of pain expression showed clear and substantial increases when the affected shoulder (the one that would be expected to be associated with movement induced pain) was manipulated, thus supporting its construct validity.

With respect to convergent validity, pain expression and self-reports of pain were significantly related. The correlations, though significant, were low (.36–.37). These findings are the most discrepant with previous literature, much of which has found no relationship between self-report and facial expression. Methodological differences between the present study and those which have not found an association between self-report and pain expression are a likely source of the difference. Studies that have not found a relationship have been characterized by using a limited number (usually single) of measures of pain expression and self-report, or by investigation of populations with possible cognitive impairment. For example, Craig and Patrick [2] reported that components of pain expression were marginally related to a single self-report of pain during the earliest phases of response to cold-pressor pain. Likewise, Hale and Hadjistavropoulos [10] found no rela-

tionship between facial and self-report measures among musculoskeletal pain patients undergoing venipuncture when a single self-report measure was used, while Hadjistavropoulos et al. [9] observed no relationship in a sample of hospitalized elders exposed to a single venipuncture. Such studies are subject to psychometric shortcomings due to the higher theoretical likelihood that the results will be affected by measurement error. In the present study, measures of pain expression and self-report of pain involved considerable aggregation (for pain expression four constituent actions aggregated across four tests; for self-report, three scales aggregated across four tests), a process that in theory should diminish the effects of measurement error. Other studies that have reported significant relationships between self-reports and facial expressions have assessed each domain on multiple occasions. For example, Patrick et al. [18] and Kunz et al. [15], employing variations of within-subject regression, relating self-reports and measures of facial expression taken on multiple occasions demonstrated significant linear relations between the two domains. It is likely that the improved psychometric properties attendant on aggregation thus provide a clearer and more accurate estimate of the true association between subjective report and pain expression.

Previous discussions of the implications of an insignificant relationship between pain expression and self-report have tended to emphasize the idea that statistical independence supports the notion that self-report and pain expression have different determinants or are differentially affected by their underlying processes. From the perspective of convergent validity, the idea that alternative measures of similar processes should agree, such conclusions might be challenged and the argument made that the findings question the validity of expression as an indicator of pain. In the present study, using the principle of aggregation, we found a significant, but low correlation between pain expression and self-report, accounting for 13–14% of variance in common. In demonstrating a significant correlation between self-reports of pain, often referred to as the “gold standard” of pain assessment [5] and pain expression, the findings support the convergent validity of pain expression. The magnitude of the correlation, however, is also consistent with the suggestion offered in previous studies that pain expression and self-report are governed by different underlying processes. Likewise, the observations (1) that the intensity of pain expression diminished between the first and the second assessment while the intensity of self-reported pain did not and (2) that the difference in pain expression on the affected and unaffected sides during passive tests became clearer on repeated testing (Fig. 1) supports the conclusion that the two domains are affected by different processes.

We also found a modest sex difference. Men showed slightly higher pain expression than women when tested

on their affected sides on the first but not the second test. This finding is inconsistent with previous observations of greater pain behaviors among female osteoarthritis patients during standardized testing [12] and among women undergoing the cold-pressor test [27]. It is also inconsistent with a previous study showing no sex differences in facial responses in response to experimental pain [14]. Given the inconsistencies among studies in both findings and methods, it would be perilous to draw any strong conclusion, other than to note that the different patterns of verbal and facial responses of men and women suggest that sex or gender is one of the variables that may affect each domain differently.

In conclusion, the findings support the suggestion that the facial response to pain consists of a core set of facial actions, which may be accompanied by secondary actions conveying different meanings or messages. The core pain expression has robust psychometric properties, including concurrent validity and reproducibility across categories of tests and time.

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