Operant Conditioning of Facial Displays of Pain

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Objective: The operant model of chronic pain posits that nonverbal pain behavior, such as facial expressions, is sensitive to reinforcement, but experimental evidence supporting this assumption is sparse. The aim of the present study was to investigate in a healthy population a) whether facial pain behavior can indeed be operantly conditioned using a discriminative reinforcement schedule to increase and decrease facial pain behavior and b) to what extent these changes affect pain experience indexed by self-ratings. **Methods:** In the experimental group (n = 29), the participants were reinforced every time that they showed pain-indicative facial behavior (up-conditioning) or a neutral expression (down-conditioning) in response to painful heat stimulation. Once facial pain behavior was successfully up- or down-conditioned, respectively (which occurred in 72% of participants), facial pain displays and self-report ratings were assessed. In addition, a control group (n = 11) was used that was yoked to the reinforcement plans of the experimental group. **Results:** During the conditioning phases, reinforcement led to significant changes in facial pain behavior in the majority of the experimental group ($p < .001$) but not in the yoked control group ($p > .136$). Fine-grained analyses of facial muscle movements revealed a similar picture. Furthermore, the decline in facial pain displays (as observed during down-conditioning) strongly predicted changes in pain ratings ($R^2 = 0.329$). **Conclusions:** These results suggest that a) facial pain displays are sensitive to reinforcement and b) that changes in facial pain displays can affect self-report ratings. **Key words:** facial expression of pain, operant learning, facial feedback, chronic pain, experimental pain.

AU = action unit; **FACS** = Facial Action Coding System; **ECG** = electrocardiogram.

INTRODUCTION

The operant theory of chronic pain has been proposed in the context of the development and maintenance of chronic pain states (1). This theory suggests that pain behavior that is followed by positive consequences (e.g. partner being more solicitous) increases in frequency, whereas negative consequences lead to a reduction of these pain behaviors. Several experimental studies have been conducted so far that aimed at investigating whether pain behavior can indeed be operantly conditioned (2–5). So far, most studies targeted verbal pain behavior, and most of these studies showed that verbal pain responses to noxious stimulation can be successfully increased or decreased, respectively, by operant conditioning techniques (2–5).

Although the verbal pain response is unquestionably an important pain behavior, pain is also communicated via nonverbal behavior. Especially, facial pain displays have been shown to provide an important communication channel that is a regular accompanist of acute pain states. This behavior is thought to be an automatic, reflexive, and inborn response, composed of a distinctive, pain-indicative set of key facial muscle movements that can be reliably recognized and distinguished from other facial expressions (6). Furthermore, facial pain displays have been found to have a substantial impact on the observer, with facial expressions of pain eliciting robust activation in pain-related brain areas possibly reflecting empathetic responses (7–9) and activation in brain regions involved in defense responses (10). Thus, the brain response of the observer suggests a variety of behavioral reactions (ranging from empathic concern to social avoidance) that can be expected to act as powerful social reinforcements of facial pain behavior. These social reinforcements might play an important role in shaping inborn facial pain responses. In fact, the importance of nonverbal behavior, such as facial expressions, within the framework of the operant model of chronic pain has been pointed out right from the beginning (1). However, although the assumption that facial pain behavior can be brought under operant control has often been made (e.g. Turk and Matyas (11) and Salomons et al. (12)), experimental studies investigating whether facial pain behavior, similar to verbal pain behavior, can indeed be brought under operant control have not been conducted. To fill in this gap, the present study aimed at investigating the impact of up- and down-conditioning procedures on facial pain behavior using a discriminative reinforcement schedule. The rationale for applying a discriminative reinforcement schedule was based on the assumption that facial expressions are strongly shaped by reinforcement schedules with discriminative stimuli that reflect which facial behavior should be displayed in which social setting and circumstances (the so-called "display rules" (13)). One obstacle we had to take into consideration when using operant conditioning techniques to change facial pain behavior was the affective impact of applying reinforcement schedules. The reinforcer should merely increase the frequency of a given behavior (in this case, facial pain displays [up-conditioning] or a neutral facial expression [down-conditioning], respectively); however, it cannot be excluded that receiving reinforcements may induce positive affective states. Facial expressions are closely linked to affective states, and thus, it is possible that changes in facial pain displays might not be the direct consequence of operant learning but might result from the potential emotional effects of the reinforcement. To disentangle these effects, the outcome of operant conditioning on facial pain displays was primarily tested during test blocks where no reinforcements were given (early extinction phase). Another obstacle we had to overcome was that subjects should not be aware of the response-reinforcement contingency.

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It is known that awareness of response-reinforcement contingency significantly affects operant conditioning in human subjects, with those subjects who become aware of the contingency rapidly responding in the desired way (14,15). Thus, if subjects of the present study would have been aware of our intention to increase and decrease facial pain behavior, respectively, it can be expected that they may simply voluntarily enhance or suppress their facial behavior. However, because we were interested in involuntary changes in facial behavior, we tried to reduce the possibility of voluntary changes in facial behavior by using a covert (implicit) approach and thus limiting subjects' awareness of contingency. The efficiency of implicit operant conditioning of pain-related responses in humans has been demonstrated in a series of studies on complex motor behavior (16,17) but so far never for facial pain-related behavior.

Another important aim of our study was to investigate whether operantly learned changes in facial pain behavior will affect subjective pain report. The evidence that facial expressions have a significant impact on subjective experience stems from the facial feedback hypothesis that asserts that changes in facial expressions produce parallel effects on subjective states (18–22). In the context of pain, only three studies so far have investigated the impact of changes in facial pain expression on self-report ratings, with two studies finding that modification of facial pain displays affects the perception of experimental pain (12,23), whereas the third study provided no support for the facial feedback hypothesis (24). We aimed to contribute to this research question of whether changes in facial pain behaviors are mirrored by changes in self-report ratings by investigating the impact of conditioned changes in facial pain displays on subjective pain ratings.

In summary, the aim of our study was to investigate whether facial pain displays can be operantly conditioned and to which extent these operantly learned changes in facial pain displays are accompanied by changes in subjective pain behavior. More precisely, our hypotheses were as follows:

1. Facial pain behavior can be significantly increased and decreased using operant conditioning techniques.
2. Conditioned changes in facial pain displays are accompanied by changes in subjective pain reports.

MATERIALS AND METHODS

Subjects

Fifty-five healthy volunteers (female: $n = 27$; male: $n = 28$) between the ages of 18 and 30 years (mean age, 22.8 years; standard deviation [SD], 2.4) were recruited (from May to December 2008) via advertisements posted in the university buildings of the University of Bamberg. None had taken any analgesic medication or alcohol for at least 24 hours before the test session. Exclusion criteria included all acute or chronic diseases. Furthermore, because behavior cannot be reinforced until it occurs and because previous studies have shown that approximately 20% to 30% of individuals do not show facial expressions during experimental pain induction (25,26), those participants who displayed few or no facial responses to the noxious stimulation in the baseline block were excluded from the study. To determine whether a subject was facially responsive to the noxious stimulation, the facial expressions were observed during the baseline block (application of eight painful and eight nonpainful stimuli), and all those subjects who did not show facial expressions of pain in at least two of the eight painful trials were excluded. Moreover, to prevent ceiling effects in the up-conditioning condition, all subjects who displayed pain-indicative facial responses in more than 75% of the painful trials at baseline were also excluded. Figure 1 lists the exact numbers of subjects that participated in the whole study. Forty subjects had been randomly assigned to the experimental group and were tested before the 15 subjects who had been assigned to the control group. This order was necessary because control subjects were yoked to experimental partners. All subjects provided written consent to participate in a study investigating pain perception and received monetary compensation for their participation time. However, to achieve the objective of the study, the subjects were not told explicitly about the specific purpose of the study to minimize attention to and voluntary regulation of facial responses (see below). The subjects were debriefed about the goal of the study at the end of the experiment. The study protocol was approved by the ethics committee of the University of Bamberg.

Materials and Procedures

All subjects were carefully familiarized with the methods to be used before the start of the experiment. During the whole session, which lasted for approximately 2 hours, the subjects sat in a comfortable reclining armchair and were facing a computer screen that was positioned 1 m in front of the subject at face level. The testing procedure included the assessment of pain sensitivity (e.g. pain threshold), three test blocks (baseline, up-conditioning, and down-conditioning), and two conditioning/training phases (up-conditioning and down-conditioning). The order of the testing procedure is illustrated in Figure 1. Based on ethical considerations, we decided to always finish with the down-conditioning procedures to prevent the hypothesized pain amplification of the up-regulation to persist after the end of the experiment (a yoked control group was included to control for order effects; see below). To reduce the subjects' awareness of the response-reinforcement contingency, the subjects were told

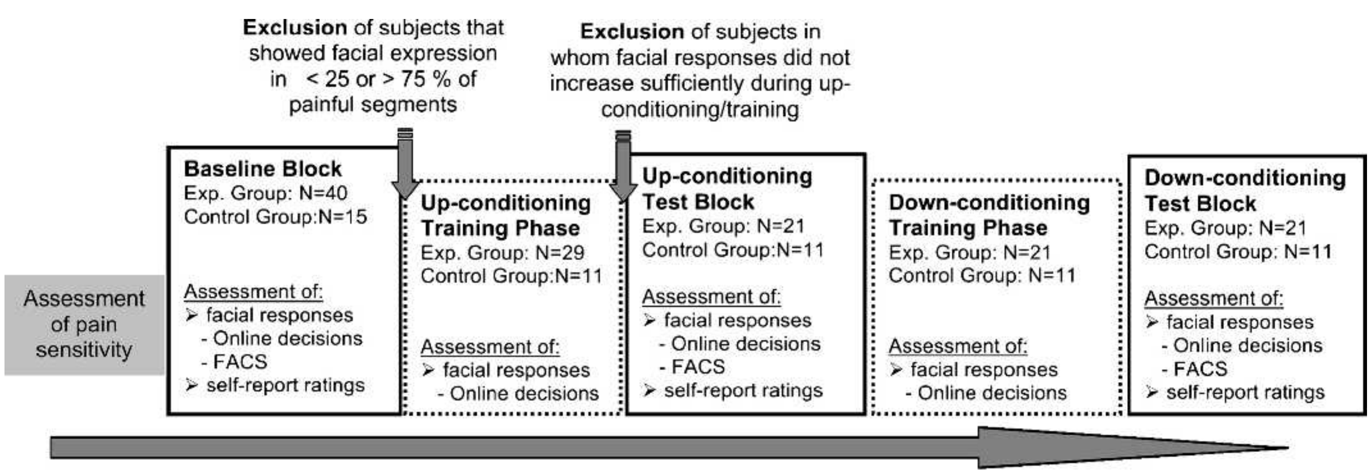

Figure 1. Testing procedure including the assessment of pain sensitivity, the baseline block, the up- and down-conditioning phases, and the corresponding test blocks with the number of subjects tested in each block.

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upon entering the laboratory that the purpose of the study was to determine whether healthy individuals are able to learn to change their heart rate variability in response to noxious stimulation. A short explanation about heart rate variability and its association with pain was given, and fake EKG electrodes were placed on the subjects' right and left wrists and on the right ankle (standard three-lead montage). Pain was induced experimentally by the use of a Peltier-based, computerized thermal stimulator with a 3×3-cm^2 contact probe (Medoc TSA-2001; Medoc Ltd, Ramat Yishai, Israel). The contact probe was attached to the left lower leg. The baseline temperature was always set to 38°C.

Assessment of Pain Sensitivity

Pain sensitivity was assessed individually before the experimental tests to determine the stimulus level required to produce moderate pain in each participant. *Heat pain threshold* was assessed first using the method of adjustment (Step 1), which has been described in detail before (26). After threshold assessment, we conducted *psychophysical intensity estimations* to determine the temperature that was perceived as moderately painful (Step 2). This was done using a protocol that has been described in detail before (26). In short, heat stimuli with temperatures ranging between −2°C and 3°C below/above the individual pain threshold were applied in a random order and rated using a 100-mm visual analogue scale (VAS). The scale was labeled with a verbal anchor of "faintly painful" in the center (50 mm), and the subjects were instructed that all nonpainful sensations should be rated less than 50 mm and all painful ones more than 50 mm. Ratings were then plotted against temperature to create the subject's psychophysical intensity curve (27). The temperature at a psychophysical intensity score of 75 to 80 mm on the VAS was selected to induce moderate pain. We selected these painful intensities to insure that painful stimulation would be sufficiently strong to evoke facial responses in most subjects, without reaching the subject's tolerance. In addition, a nonpainful control temperature rated as 40 mm on the VAS was selected as a reference to assess baseline facial expression unrelated to pain and also to allow us to test whether operantly learned changes in facial pain behavior are pain-specific and thus should not affect facial behavior in response to nonpainful intensities.

Baseline Block

In the baseline block, eight nonpainful and eight painful thermal stimuli were applied in the same random order for all subjects. The temperature increased from baseline to the preset temperatures (4°C/s), remained at a plateau for 5 seconds and returned to baseline (4°C/s). Interstimulus intervals varied between 20 and 25 seconds. After each stimulus, the subjects were asked to rate the intensity and unpleasantness of their sensation on the VAS that appeared on the computer screen immediately after each stimulus. The facial expressions of the subjects were videotaped and analyzed off-line using the Facial Action Coding System (FACS (28)). The experimenter (a certified FACS coder) had to decide online how often subjects displayed pain-indicative facial expressions in response to the painful stimuli. This was necessary a) to exclude all those subjects who responded in less than two or more than six of the eight painful thermal trials with pain-indicative facial responses; b) to register the baseline facial expressiveness of the experimental group that was needed to determine the individual learning criteria for the up- and down-conditioning phases; and c) to match control subjects to experimental partners based on their facial expressiveness. Therefore, the experimenter observed the facial expression of the subjects during the baseline block on a separate computer screen that was connected to a camera that captured the face of the subjects. The experimenter had to make online decisions of whether the subjects displayed pain-indicative facial responses or not. In accordance with previous findings (25,29), four key facial movements were classified as pain-indicative, namely, brow lowering, tightening of the orbital muscles surrounding the eyes, nose wrinkling/upper-lip raising, and closing of the eyes more than 0.5 second. On average, the selected subjects of the experimental and control group displayed pain-indicative responses in four of the eight painful trials in the baseline block (group difference: $p = .818$; Fig. 2). To test the accuracy of these online decisions of whether any pain-indicative responses were shown or not (which is also of enormous relevance for the conditioning phases), these online decisions of the experimenter were compared with the later conducted fine-grained analyses using the FACS. Ninety-three percent of all online decisions matched the FACS-coded results, and thus, the reliability of the online decisions seems to be satisfactory.

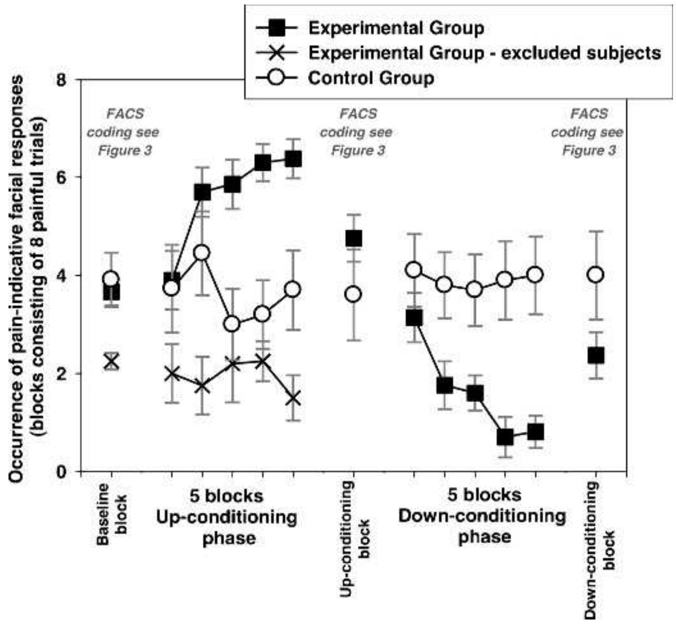

Figure 2. Online decisions (mean values and standard error) of whether any of the four pain-indicative AUs were shown in response to painful stimulations across test blocks and conditioning phases in the experimental and control groups. Painful stimuli are organized in blocks of eight painful stimuli each.

Up-Conditioning and Down-Conditioning Test Blocks

The same eight nonpainful and eight painful thermal intensities as in the baseline block were applied during the up- and down-conditioning test blocks. Furthermore, as in the baseline block, the subjects were asked to rate the intensity and unpleasantness of their sensation (using VAS) immediately after each stimulus. Moreover, the facial expressions of the subjects were again evaluated online and videotaped and analyzed off-line using FACS (28).

Conditioning/Training Phases (Up- and Down-Conditioning)

The operant learning design of Flor et al. (2) was applied in the conditioning phase using a smiley (☺) shown as a reinforcer on the computer screen facing the subject. The background color of the computer screen (blue or green) was used to signal the conditions of up- and down-conditioning to the subject. The subjects were instructed that their heart rate variability would be monitored by the experimenter on a separate computer screen and that, each time it would change in the intended direction, they would receive a positive feedback (smiley would appear on the computer screen). It would be their task to try to make the smiley appear as often as possible. The subjects were further informed that the learning phase would last until they had managed to change their heart rate variability or until 80 painful stimuli had been applied. Moreover, the subjects were informed that there would be two training phases that each aimed at changing heart rate variability in different directions.

In each of the two conditioning/training phases, the subjects received only the moderately painful thermal stimuli. To prevent sensitization, interstimulus intervals of 15 to 20 seconds were used, and the thermode was moved to a different site after every eighth stimulus (the stimuli were organized in blocks of eight painful stimuli). During the stimulation, the experimenter (who had no eye contact to the subject) observed the facial expression of the subjects on a separate computer screen and detected online whether the subjects did or did not display one or more of the four pain-indicative facial muscle movements (25,29). During the up-conditioning phase, the subjects in the experimental group were given positive feedback when they displayed one or more of the four pain-indicative facial responses during the 5-second painful stimulation. During the down-conditioning phase, the subjects received positive feedback when they showed a neutral facial expression during stimulation (defined as "no visible facial movements"). The positive feedback was always given at the offset of the 5-second painful stimulation, to keep it stable between up- and down-conditioning phases. The exact delay between the occurrence of facial expressions

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(up-conditioning) and the feedback lay between 2 and 4 seconds in most cases. Up- and down-conditioning was repeated until the subject reached the learning criterion. This criterion was defined as a 25% increase/decrease in facial pain displays (compared with the subject's baseline performance) observed in two successive segments of eight painful stimuli[1]. The subjects who did not reach the criterion after 10 segments of eight painful stimulation were classified as "unconditionable" and were excluded from further participation in the study (n = 8). The yoked control subjects received positive feedback in the same sequence and for the same number of trials as their experimental counterparts[2], however without consideration of their actual facial expressions of pain.

Facial Expression of Pain: Detailed Analyses

Besides the online decisions of the experimenter of whether facial pain displays were shown or not, facial responses during the three test blocks were further analyzed in more details (Fig. 1). To do this, the face of the subject was videotaped throughout the testing session. The camera was placed in front of the subject on top of a computer screen at a distance of approximately 1 m. The subjects were instructed not to talk during thermal stimulation and to always focus on the computer screen to await the appearance of the VAS scales or the smileys, respectively. A light-emitting diode visible to the camera, but not to the subject, was lighted concurrently with the thermal stimuli to mark the onset of stimulation. A software designed for the analysis of observational data (The Observer XT; Noldus Information Technology, Wageningen, Netherlands) was used to segment the videos and to enter the FACS codes into a time-related database. Time epochs of 5 seconds beginning just after the stimulus had reached the target temperature were analyzed off-line. In total, 48 trials of thermal stimulation recorded in the baseline and test blocks were analyzed in each subject ([eight nonpainful + eight painful trials] × three blocks [baseline, up-conditioning, and down-conditioning]). All coding of facial expression was blind to whether the subjects belonged to the experimental or control group.

Facial responses occurring during the baseline and two test blocks were quantified using the FACS (28), a fine-grained anatomically based system that is considered the criterion standard when decoding facial expressions, including the facial expression of pain (6). The FACS is based on the anatomical analysis of facial movements and distinguishes 44 different action units (AUs). We focused on the four pain-indicative AUs that were up- or down-regulated during the conditioning phase (brow lowering [AU 4], tightening of the orbital muscles surrounding the eye [AUs 6/7], nose wrinkling/upper-lip raising [AUs 9/10], and eye closure [AU 43]). As pointed out before, these four AUs have been found to represent a common facial response to pain and have also been shown to be pain-indicative for thermal heat pain (26). The intensity for each AU was rated on a 5-point scale (A–E). The intensity and frequency of these four AUs were rated by two coders, one being a certified FACS coder and the other one having been trained by an official FACS coder. Ten percent of the video segments were coded by both observers. Interrater reliability, as calculated using the Ekman-Friesen formula (28), was 0.89, which compares favorably with other research in the FACS literature. For further analyses, a composite score was calculated, by multiplying intensity and frequency values for each AU.

Subjective Ratings

The subjects were asked to provide self-report ratings to the painful and nonpainful stimuli only in the three test blocks (Fig. 1). Self-report was obtained using electronic 100-mm VAS of sensory intensity and unpleasantness. Scales successively appeared horizontally on a computer screen with a cursor that could be moved laterally. Scales were labeled with a verbal anchor (faintly painful) in the center, and the subjects were instructed to rate nonpainful sensations less than 50 mm and all painful ones more than 50 mm.

[1] For example, in order to reach the learning criterion for the up-conditioning training, a subject that showed pain-indicative facial responses in four of eight painful trials during the baseline block had to show pain-indicative responses at least six times in a segment of eight painful trials, in two consecutive segments.
[2] Yoked control subjects were paired with subjects from the experimental group depending on their facial expressiveness during the baseline block. For example, a control subject who showed pain-indicative responses in four of eight painful trials in the baseline block received the same reinforcement sequence as a subject from the experimental group that also showed facial expressions in four of eight painful trials.

Statistical Analysis

To investigate the impact of conditioning on pain-indicative facial responses (Hypothesis 1), we conducted two separate analyses. a) The first analysis compared facial responsiveness during the conditioning phases between the experimental and control groups. This analysis was based on the experimenters' online decisions of whether any of the four pain-indicative AUs were shown in response to a painful stimulus (the stimuli were organized in blocks of eight stimuli each). More precisely, analysis of variance (ANOVA) with repeated measurements was conducted with two within-subject factors (type of conditioning: up- and down-conditioning phases and learning curve: blocks 1–3 and the last two blocks) and one between-subject factor (group: experimental and control). b) Based on the fine-grained analyses of facial responses (FACS coding), facial responses (AU 4, AU 6/7, AU 9/10, and AU 43) during the three test blocks were analyzed by the use of multivariate analyses of variance with repeated measurements with one within-subject factor (block: baseline, up-conditioning, and down-conditioning) and one between-subject factor (group: experimental and control). Analyses were conducted separately for nonpainful and painful stimulus intensities.

Two statistical approaches were used to test Hypothesis 2. a) As a first approach, multivariate analyses of variance with repeated measurements were used to investigate the impact of conditioning on self-report ratings (VAS intensity and unpleasantness) during the three test blocks, with one within-subject factors (block: baseline, up-conditioning, and down-conditioning) and one between-subject factor (group: experimental and control group). Again, analyses were conducted separately for nonpainful and painful stimulus intensities. b) As a second statistical approach, the relation between the amount of change in facial pain behavior and the amount of change in pain ratings was evaluated. To do this, difference scores (baseline versus up-conditioning; baseline versus down-conditioning, and up-conditioning versus down-conditioning blocks) were calculated for those pain-indicative facial responses that varied significantly between blocks as well as for self-report ratings. These difference scores were then entered into regression analyses (facial responses were entered as predictors, and self-report were entered as criteria). The findings were considered to be statistically significant at $\alpha < 0.05$.

RESULTS

Temperatures

The pain threshold did not differ between the subjects of the experimental (45.1°C [SD, 1.5°C]) and control group (45.4°C [SD, 1.8°C]; p = .596). The groups also did not differ on the selected stimulation temperatures for nonpainful intensities (experimental group: 44.5°C [SD, 1.6°C]; control group: 45.0°C [SD, 1.9°C]; p = .325) and painful intensities (experimental group: 47.7°C [SD, 1.2°C]; control group: 48.2°C [SD, 1.3°C]; p = .205).

Manipulation Check

When participants were asked at the end of the session, what they thought they did during the conditioning phases to make the smiley appear more often (open question), most participants answered that they did not know (81%). A small percentage (10%) said that they felt the smiley appeared more often when they concentrated on the stimulus or on how the stimulus felt in the first learning phase (up-conditioning) Thirteen percent said that the smiley appeared more often in the second phase (down-conditioning) when they tried to relax or not think about the stimulation; one subject (3%) said that he felt it had something to do with his breathing, and another one (3%) said that meditation in the last learning phase helped to make the smiley appear more often.

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Facial Expression of Pain (Hypothesis 1)

Conditioning Phases: Online Decisions of the Experimenter

During the up-conditioning phase, we succeeded in substantially increasing facial pain behavior in 21 of the 29 subjects of the experimental group (conditioning criterion: 25% increase of facial pain displays compared with the baseline block). The eight unconditionable subjects were excluded after the up-conditioning phase and thus excluded from further analyses; however, their descriptive data are included in Figure 2. As can be seen, being unconditionable was associated with lower facial responsiveness to the painful stimulus. The most important result of the ANOVA was a significant interaction between the factors: group, type of conditioning, and learning curve ($F[4,120] = 11.910$, $p < .0001$). As post hoc comparisons revealed, this interaction effect was due to facial responsiveness increasing during up-conditioning ($p < .001$) and decreasing during down-conditioning ($p < .001$) in the experimental group, whereas no systematic changes could be observed in the control group ($p = .136$ and $p = .407$, respectively; Fig. 2). This clearly demonstrates that facial pain displays can be brought under operant control. Furthermore, a significant main effect was found for the factor type of conditioning ($F[1,30] = 26.705$, $p < .001$), and significant interactions between the factors type of conditioning and group ($F[1,30] = 39.537$, $p < .001$) and between the factors type of conditioning and learning curve ($F[4,120] = 8.967$, $p < .001$) were also found. All other effects or interactions did not reach significance (all $p > .443$). For the sake of completeness, facial responsiveness during the test blocks (based on experimenters' online decisions) is also displayed in Figure 2.

Test Blocks: FACS Analyses

Nonpainful stimuli

As expected, the mean pain-indicative facial responses to nonpainful intensities were negligible (Table 1; also for univariate results) and did not reveal any significant effects of the group or the condition (all p values > .05). Thus, the conditioning procedures did not have any significant effects on facial responses to nonpainful heat intensities. However, given these floor effects with relatively low variances, one has to be cautious when interpreting the statistical findings.

Painful stimuli

Pain-indicative facial responses during painful heat stimulation differed significantly between the experimental group and the control group ($F[4,27] = 4.225$, $p = .009$). The factor block had no significant effect on pain-indicative responses ($F[8,23] = 1.152$, $p = .370$), thus suggesting that, overall, facial responses of both groups did not change between test blocks. Most importantly, we found a trend for a significant interaction between the factors block and group ($F[8,23] = 2.104$, $p = .08$). As can be seen in Figure 3, facial responses in the experimental group tended to increase between baseline and up-conditioning blocks and to decrease between the up- and down-conditioning blocks, whereas facial responses in the control group did not vary systematically between the three blocks. Because the multivariate interaction came so close to reach significance, we decided to conduct exploratory univariate analyses. These revealed that an interaction effect was most pronounced for AU 4 ($F[2,59] = 3.588$, $p = .034$) and for AU 6/7 ($F[2,59] = 3.199$, $p = .048$), whereas no significant interaction was observed for AU 9/10 ($F[2,59] = 1.242$, $p = .296$) and AU 43 ($F[2,59] = 0.491$). Based on these findings, we computed effect sizes (Cohen d for two dependent groups) to verify that the significant interaction effects found for AU 4 (brow lowering) and AU 6/7 (tightening of the orbital muscles surrounding the eyes) were caused by systematic changes across the three test blocks in the experimental group and no differences in the control group. Effect sizes yielding medium or strong effects ($d > 0.50$) are displayed in Figure 3 (upper panels). As can be seen, medium or strong effects were only found between blocks for AU 4 and for AU 6/7 in the

TABLE 1. The Effect of Up- and Down-Conditioning on Facial Responses and Subjective Responses to Nonpainful Thermal Intensities

		Descriptive Statistics, Mean (SD)			MANOVA Univariate Results, *p*		
Response	Group	Baseline Block	Up-Conditioning Block	Down-Conditioning Block	Block	Group	Block by Group
AU 4	E	1.3 (2.8)	0.7 (1.3)	1.1 (1.6)	.809	.057	.708
	C	0.2 (0.6)	0.3 (0.6)	0.4 (1.2)			
AU 6/7	E	1.2 (2.3)	0.4 (0.9)	0.4 (0.7)	.194	.411	.641
	C	0.6 (1.6)	0.1 (0.3)	0.6 (1.2)			
AU 9/10	E	0	0	0.1 (0.4)	.079	.089	.209
	C	0	0.4 (0.9)	0.4 (0.8)			
AU 43	E	0.1 (0.4)	0	0.1 (0.4)	.321	.051	.190
	C	0.1 (0.3)	0.7 (1.8)	1.2 (0.4)			
VAS intensity	E	27.4 (12.3)	24.9 (16.8)	23.6 (13.3)	.393	.910	.549
	C	26.6 (10.2)	21.5 (19.9)	26.3 (16.0)			
VAS unpleasantness	E	18.5 (12.7)	18.1 (17.4)	15.4 (15.4)	.876	.809	.535
	C	19.0 (11.2)	16.8 (21.1)	20.0 (20.0)			

SD = standard deviation; MANOVA = multivariate analysis of variance; E = experimental group; C = control group; AU = action unit; VAS = visual analogue scale.

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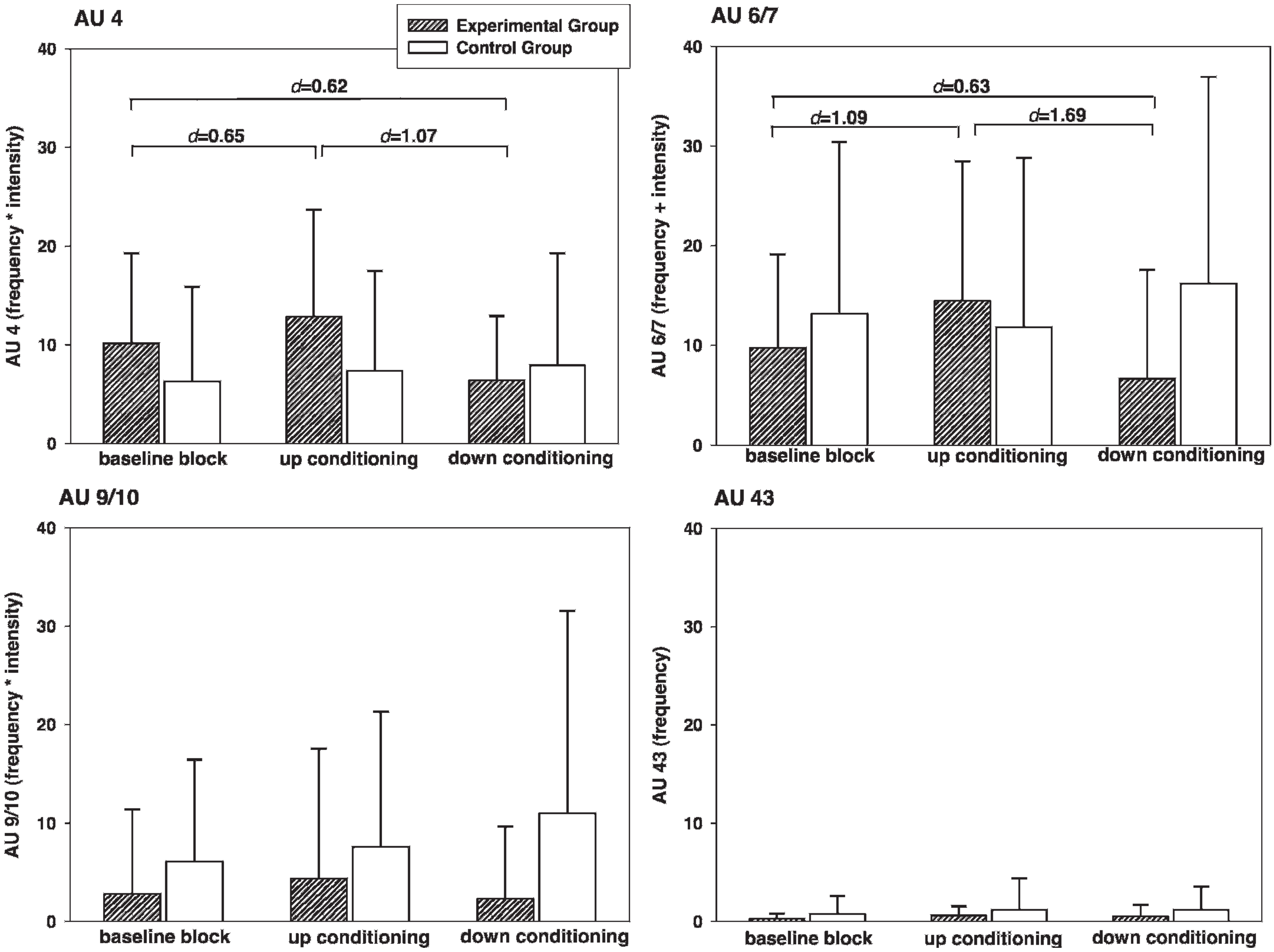

Figure 3. FACS-coded facial responses to painful heat stimulation (mean values (standard deviation)) during the baseline, up-conditioning, and down-conditioning blocks in the experimental group and in the yoked control group.

experimental group but not in the control group (effect sizes were $d < 0.5$).

Subjective Ratings (Hypothesis 2)

First Statistical Approach (ANOVAs)

Nonpainful stimuli

The ratings of the nonpainful intensities did not reveal any significant effects of the group or the condition (all p values > .05).

Painful stimuli

As intended, the subjects rated the painful stimuli as moderately painful (Fig. 4), with no difference in ratings between the experimental and control groups ($F[2,29] = 1.455$, $p = .250$). VAS ratings tended to be lower during the down-conditioning block (Fig. 4), which is supported by a trend toward a significant effect for the factor block ($F[4,27] = 2.470$, $p = .069$). In contrast to our expectations, no significant interaction between the factors group and block occurred ($F[4,27] = 1.350$, $p = .277$), thus suggesting that VAS ratings of the experimental group were not significantly affected by the conditioning procedures.

Second Statistical Approach (Regression Analyses)

Although the aforementioned results suggest that mean pain report was not affected by changes in facial responses, we further investigated the relation between facial responses and subjective ratings. Based on our observation that up- and down-conditioning was only successful for some of the four facial responses, we tested whether the magnitude of changes in facial responses might be correlated to the magnitude of changes in VAS ratings. To this aim, difference scores were calculated separately for AU 4 and AU 6/7 (frequency-by-intensity scores of each AU per test block were used to calculate the difference between baseline versus up-conditioning, baseline versus down-conditioning, and up- versus down-conditioning blocks) because these two AUs changed significantly between test blocks. Difference scores were also calculated separately for VAS intensity and unpleasantness ratings (the mean values per block were used to calculate the difference between baseline

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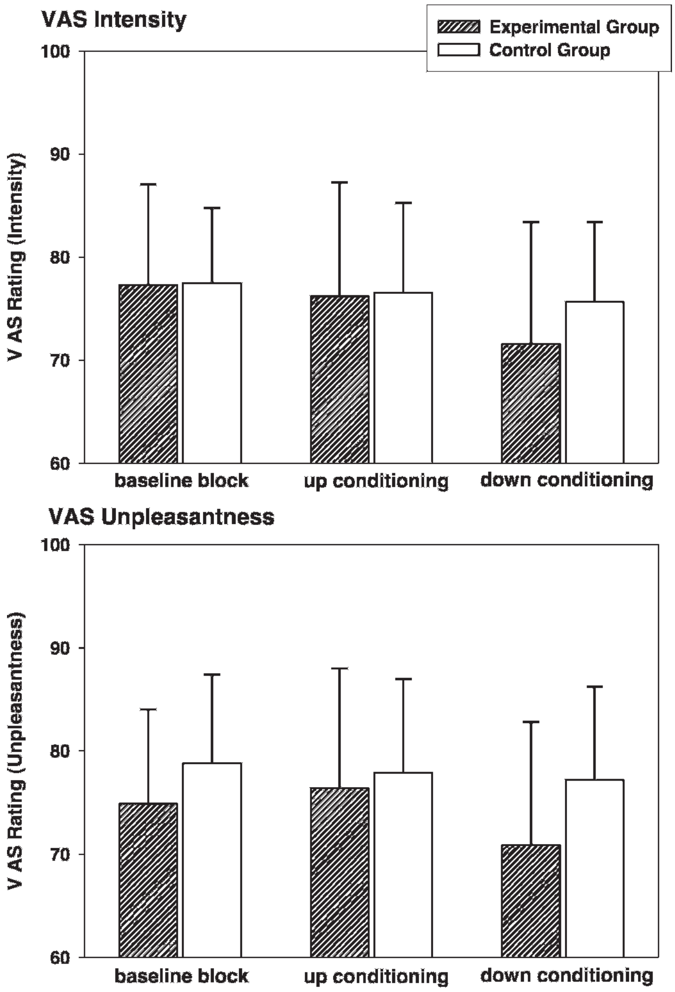

Figure 4. Visual analogue scale (VAS) ratings (mean values (standard deviation)) during the baseline, up-conditioning, and down-conditioning blocks in the experimental group and in the yoked control group.

versus up-conditioning, baseline versus down-conditioning, and up- versus down-conditioning blocks). These difference scores were then entered into a regression analyses. As reported in Table 2, we found highly significant regression coefficients between changes in facial responses and changes in self-report ratings (intensity and unpleasantness ratings) between baseline versus down-conditioning and between up-conditioning versus down-conditioning blocks.

DISCUSSION

The study was designed primarily to investigate whether facial pain behavior can be brought lastingly under operant control using a discriminative reinforcement schedule and to what extent these changes produce parallel effects on subjective pain behavior. Our main findings are that facial pain behavior can be brought under operant control (see conditioning phases); however, of the four key facial movements classified as being pain-indicative, only brow lowering and tightening of the orbital muscles surrounding the eyes seemed to have been sensitive to the operant conditioning procedures and changed more lastingly among baseline, up-conditioning, and down-conditioning blocks. Moreover, operant conditioning of facial pain behavior had no significant effect on verbal pain ratings during test blocks, according to ANOVAs. However, regression analyses revealed that changes in brow lowering and tightening of the orbital muscles surrounding the eyes strongly predicted most changes in self-report ratings and thus pointing to a link between changes in facial and verbal pain behavior. We discuss these findings in this order.

Operant Conditioning of Facial Pain Behavior (Hypothesis 1)

In accordance with our hypothesis, we found that facial pain behavior can be brought under operant control. The first evidence supporting our hypothesis was provided by the substantial changes in facial pain behavior observed online during

TABLE 2. Regression Analyses to Investigate Whether Changes in Pain-Indicative Facial Responses AU 4 and AU 6/7 Can Predict Changes in VAS Ratings (Criterion)[a]

VAS Ratings (Criterion)	R	R^2	p	Standardized β Coefficient AU 4	Standardized β Coefficient AU 6/7
Difference scores between baseline versus up-conditioning blocks					
VAS intensity	0.154	0.024	.714	0.129	0.048
VAS unpleasantness	0.112	0.013	.838	0.022	0.102
Difference scores between baseline versus down-conditioning blocks					
VAS intensity	**0.688**	**0.473**	<**.001**	0.802	–0.257
VAS unpleasantness	**0.710**	**0.503**	<**.001**	0.843	–0.322
Difference scores between up-conditioning versus down-conditioning blocks					
VAS intensity	**0.573**	**0.329**	**.004**	0.605	–0.081
VAS unpleasantness	**0.716**	**0.513**	<**.001**	0.775	–0.173

[a] Responses that changed significantly between test blocks AU 4 and AU 6/7 were entered as two separate predictors. Difference scores were calculated between all three test blocks. Significant results are marked as bold.
AU 4 = brow lowering; AU 6/7 = tightening of the orbital muscles surrounding the eyes; VAS = visual analog scale.

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the conditioning/learning phases in most of the experimental group (72%), whereas facial pain behavior of the yoked control group remained unchanged across conditioning procedures (Fig. 2). Furthermore, the more precise analyses of facial behavior during the test blocks using the FACS (28) revealed that two of the four pain-indicative muscle movements, namely, brow lowering and tightening of the orbital muscles surrounding the eyes, showed more lasting changes that remained significant during up- and down-conditioning blocks (early extinction phases) in the experimental group. Again, facial pain displays did not differ between blocks in the yoked control group. The idea that facial pain behavior, among other pain behaviors, is sensitive to operant conditioning is rather old and can be found in the operant model of chronic pain postulated by Fordyce (1). Several clinical studies have supported this assumption by showing that pain behavior and pain reports diminish in pain patients following operant behavior therapy (e.g. Thieme et al. (30,31)). However, clear experimental evidence on whether facial expressions of pain can be brought under operant control had been lacking so far.

Despite our success in demonstrating that facial pain displays can indeed be brought under operant control, we only succeeded in modifying two of the four pain-indicative facial muscle movements (brow lowering, tightening of the orbital muscles surrounding the eye, nose wrinkling/upper-lip raising, and eye closure). Our selection of the four pain-indicative muscle movements was based on previous findings that could demonstrate that these four muscle movements are the core set of key facial muscle movements that are displayed across groups of individuals and across different pain modalities (25,29). However, although these four facial muscle movements have been found in numerous studies to occur in the context of pain, frequency of occurrence varies substantially among these muscle movements (32–34). As can also be seen in the present study (Fig. 3), those muscle movements that changed significantly following the operant conditioning procedures were those that occurred most often at baseline. Because occurrence of any of the four pain-indicative muscle movements was reinforced during the conditioning phases, it can be expected that we mostly reinforced the two most frequent and most intense ones. This would explain why we only found changes in two of the four pain-indicative muscle movements. The prominent role of the AUs brow lowering and tightening of the orbital muscles surrounding the eyes in the context of experimental heat pain was already evident in previous studies of ours (26,35). Therefore, to investigate, whether the two nonresponsive muscle movements (nose wrinkling/upper-lip raising and eye closure) can also be brought under operant control, future studies are needed that might use other pain induction methods that might elicit higher frequency of occurrence for these muscle movements (e.g. cold pressure pain (25)).

Our results further suggest that it is easier or at least of longer duration to down-condition than it is to up-condition facial pain expressions because three of the four significant changes in facial pain behavior that we found during the test blocks (early extinction phases) were due to changes that occurred during the down-conditioning block (Fig. 2). Because the control group showed no decline in facial pain displays during the last test block, we can rule out that this decline in the experimental group is simply due to habituation effects. Finding down-conditioning to have longer lasting effects is interesting because it stresses that it might be easier for individuals to learn to suppress their facial pain expression than it is to increase or exaggerate their expression following reinforcements and thus operant conditioning might play a more influential role in reducing pain behavior than in exaggerating it. This conclusion would be in accordance with findings of Larochette et al. (36) showing that children can learn more easily to successfully hide their pain than to simulate or exaggerate it.

The sensitivity of facial pain behavior to operant conditioning does not contradict the assumption that facial pain displays are to a great extent hard-wired and inborn as pointed out by Williams (37). Finding similar pain-indicative muscle movements in newborns (38) and across various age groups (33) suggests a universal set of pain-indicative facial muscle movements. However, variations also occur between individuals, between social situations, between pain induction methods, and so on, with regard to different subsets of pain-indicative facial responses and with regard to differences in facial expressiveness (6). Importantly, the degree of facial expressiveness of pain seems particularly sensitive to social reinforcement.

Impact of Operant Conditioning of Facial Pain Behavior on Verbal Pain Reports (Hypothesis 2)

In contrast to our Hypothesis 2, the between-group approach revealed that self-report ratings were not significantly affected by operant conditioning of facial pain behavior. Although the descriptive data (Fig. 4) suggest a slight decrease in pain ratings of the experimental group in the down-conditioning block, this tendency did not reach significance. The hypothesis that manipulation of facial pain behavior will be accompanied by changes in pain ratings was based on the facial feedback hypothesis. This hypothesis suggests that enhanced emotional facial expression amplifies the corresponding affective experience, whereas the inhibition of facial expression leads to diminished affective experience (18–22). Experimental evidence supporting this hypothesis stems mainly from research of voluntary smiling and perceived amusement, with individuals that are voluntarily moving their musculus zygomaticus upward (e.g. due to holding a pen between their teeth) while watching cartoons rate these as more amusing compared with the control groups (39). With regard to influences of facial pain expressions on pain experience, experimental evidence has been scarce and contradictory. In the few studies conducted so far, the participants were either asked to voluntarily exaggerate their facial expression of pain in response to noxious stimulation or to voluntarily perform discrete muscle movements during pain stimulation (that were either pain-indicative or not). Whereas, in one of the studies, exaggerated facial pain displays did not lead to an increase in self-report ratings (24); the two other studies did find evidence for increased pain ratings in

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those participants who exaggerated their facial expression of pain (23) or who voluntary performed pain-indicative muscle movements (12). There are several factors that might explain differences between studies. First, the voluntary manipulation of facial expression might allow for a stronger modulation of the facial response leading to more robust changes compared with the present study. However, using the voluntary approach, the participants are made explicitly aware of the manipulation of facial movements and might draw interference about the hypothesis of the study and in consequence act accordingly that could explain the positive results obtained in two of the studies (12,23). Compared with the previous studies, our operant conditioning approach relied on mostly involuntary changes in facial behavior. Indeed, when we asked the participants at the end of the session whether they had any hypotheses of what kind of response we tried to reinforce, the participants never suspected their facial expression (see the results reported under Manipulation Check).

Our findings that self-report ratings were not affected by up- and down-conditioning of facial pain behavior do not necessarily contradict the facial feedback hypothesis. As pointed out previously, we observed that the success of lasting up- and down-conditioning varied substantially between subjects and between muscle movements and was relatively small in magnitude at the group level. Most likely, our effects would have been stronger if we assessed self-report ratings during the conditioning phases where changes in facial responses were much greater (Fig. 2). We refrained from doing so because it was neither possible to assess self-report right after the stimulus (this would have prolonged the time between facial response and reinforcement) nor after the reinforcement (because ratings would have been influenced by the reinforcement). However, during the test blocks (which represent early extinction phases) not all participants modified all four pain-indicative facial responses, and thus, it seems important to take into consideration the actual rate of change in facial pain displays when trying to answer the question of whether changes in facial pain behavior lead to changes in pain ratings. Therefore, we decided to also use a regression approach as a second statistical method and analyze whether the degree of actual changes in facial responses can predict changes in self-report ratings between test blocks. As hypothesized (Hypothesis 2), we did find significant associations between changes in facial expressions and changes in verbal pain behavior. More precisely, we found moderate-to-strong positive associations between changes in brow lowering and tightening of the orbital muscles surrounding the eye and changes in self-report ratings (β coefficients suggest the strongest associations between brow lowering and VAS ratings). The greater the decrease in the facial responses during the down-conditioning block (compared with baseline and up-conditioning), the greater was the decrease in VAS intensity and unpleasantness ratings. These findings clearly support the facial feedback hypothesis. However, because we could only find significant predictions for changes during the down-conditioning block, it seems that not all changes in facial movements influence pain ratings in the same way, and thus, the facial feedback hypothesis might be refined by determining the relative contribution of specific somatomotor changes to the subjective experience of pain and emotions.

Limitations

Our study has several limitations that are important to take under consideration when trying to interpret and generalize our findings. First of all, the sample size was relatively small (n = 21, in the experimental group; n = 11, in the yoked control group). Although we recruited 55 healthy subjects, a considerable number of participants had to be excluded because they showed very low (the most frequent reason) or very high rates of facial responses to the moderately painful stimulation at baseline or because their facial pain behavior was unconditionable. However, given that it takes at least at least 30 to 40 minutes of testing to decide whether an individual's facial pain behavior is suitable for operant conditioning procedures and at least 60 minutes to find out whether that facial behavior is conditionable, the effort of selecting a greater number of subjects, especially a greater number of yoked control subjects (who have to show the same expressiveness as experimental partners) is significant. The most frequent reason for exclusion was facial nonresponsiveness to pain stimulation. However, we also excluded some subjects (n = 8) who were unconditionable during the up-conditioning phase. We did this because our main focus lay on the fine-grained analysis of facial responses during the test block (after the successful completion of the conditioning phase). This might have biased our findings. Another important limitation of our study is that we tried to use operant conditioning techniques to increase and decrease facial pain behavior in one single session. It can be expected that conditioning phases that are repeated across two or three testing sessions conducted on different days would have resulted in more stable conditioning effects. Moreover, more testing sessions would have also allowed testing the effect of the discriminative stimulus. We had planned to use the discriminative stimulus to change between up- and down-conditioning more often within a test block, once successful up- and down-conditioning was achieved. However, because the successful conditioning procedures took approximately 25 minutes each and entailed a considerable amount of painful stimuli, we were only able to have pure up-conditioning and down-conditioning test blocks. Another limitation arose from choosing a smiley as a reinforcer. We did this, following a protocol of Flor et al. (2), which succeeded in operant conditioning of verbal pain ratings. However, because the smiley image itself represents a facial expression, that might have had an influence on the facial expression of pain, especially in the up-regulation condition. In future studies that try to bring facial pain behavior under operant control, a different reinforcer should be used (e.g. money counter). A final limitation arises from the complexity and dynamics of facial displays. Reinforcement was defined as being contingent on one or more of the four pain-indicative muscle movements. Because these four pain-indicative movements can partly also be observed in other affective states (e.g. tightening of the eyebrows is also

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typical for anger), we cannot fully exclude that other affective states were additionally reinforced. However, given that we only elicited the affective state *pain* and given that non–pain-indicative facial responses were very rare (non–pain-indicative AUs were also FACS coded but only occurred on average in 3% of all painful trials), we believe that we primarily reinforced facial expressions of pain. Moreover, it might be criticized that individuals were reinforced if any of the four pain-indicative responses occurred and thus might have been reinforced for different responses. However, these four responses are not independent from each other, but in this setting, they all represent manifestations of the same behavior (namely facial pain displays). Furthermore, individuals tend to show reaction stereotypes and respond with a very similar pattern of facial expressions, at least across the same type of painful stimulus; thus, the subjects were most likely reinforced for very similar responses.

In summary, we could demonstrate that facial pain behavior can be brought under operant control. Interestingly, down-conditioning of facial pain behavior showed slightly longer lasting effects compared with up-conditioning attempts, thus suggesting that operant learning might play a promising role in down-regulating of facial expressions of pain. Moreover, although the effect of changes in facial pain displays on subjective pain report was inconsistent, we did find a strong relationship between a decrease in the pain-indicative responses and a decrease in pain intensity and unpleasantness ratings, supporting the idea that changes in facial pain behavior can indeed lead to changes in verbal pain ratings and thus giving support for the facial feedback hypothesis.

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