Impact of visual learning on facial expressions of physical distress: A study on voluntary and evoked expressions of pain in congenitally blind and sighted individuals

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ABSTRACT

The ability to facially communicate physical distress (e.g. pain) can be essential to ensure help, support and clinical treatment for the individual experiencing physical distress. So far, it is not known to which degree this ability represents innate and biologically prepared programs or whether it requires visual learning. Here, we address this question by studying evoked and voluntary facial expressions of pain in congenitally blind (N = 21) and sighted (N = 42) individuals. The repertoire of evoked facial expressions was comparable in congenitally blind and sighted individuals; however, blind individuals were less capable of facially encoding different intensities of experimental pain. Moreover, blind individuals were less capable of voluntarily modulating their pain expression. We conclude that the repertoire of facial muscles being activated during pain is biologically prepared. However, visual learning is a prerequisite in order to encode different intensities of physical distress as well as for up- and down-regulation of one’s facial expression.

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1. Introduction

Facial expressions play a key role in communication and social interactions (e.g. Darwin, 1872; Ekman, 1999). Amongst the large variety of inner states being communicated via facial displays, biologically the most relevant one’s seem to be facial expressions of physical and psychological distress. Especially the communication of physical distress (e.g. pain) via facial expressions has been shown to be a powerful tool that can rapidly warn onlookers of potential danger as well as elicit attention, empathetic reactions and caring behaviour in the observer (Botvinick et al., 2005; Williams, 2002; Saarela et al., 2007); thereby ensuring help and social support for the person experiencing physical distress. Consequently, the ability to facially communicate physical distress can be vital to guarantee one’s physical and psychological well-being.

Although the interest in studying facial expressions has a long and rich scientific history, which even dates back the mid 19th century (Darwin, 1872), it is still controversially discussed to which degree this ability to distinctively encode internal states via facial expressions is a learned behaviour or whether it originates from innate and biologically prepared programs (e.g. Mesquita et al., 1997; Ekman, 1992). In the effort to answer this question, several studies investigated congenitally blind individuals. Given that congenitally blind individuals have had no access to visual feedback; it is possible to investigate facial expressions that have not been shaped by visual learning.1 First attempts to study facial expressions in blind individuals have already been conducted by Darwin (1872) who reported – based on single case observations – that facial expressions do not differ between blind and sighted individuals. Succeeding Darwin’s rather descriptive approach, observational study designs, selection of sample, sample size and maybe most importantly the standardization of methods used for facial expression analyses have vastly improved over the decades. Whereas in older studies (e.g. Thompson, 1941; Freedman, 1964; Eibl-Eibesfeldt, 1973) the analysis of facial expressions in blind individuals was solely based on unstandardized observations by the experimenter, more recent studies used standardized tools like Ekman and Friesen’s (1978) anatomically based Facial Action Coding System (FACS) (e.g. Galati et al., 2003; Tracy and Matsumoto, 2008; Matsumoto and Willingham, 2009), which is considered the gold-standard in facial expression research (Ekman and Rosenberg, 1997). Up to now, studies have investigated voluntary (e.g. Galati et al., 1997; Rinn, 1991) as well as spontaneous/evoked facial

1 Other forms of learning (e.g. learning through touch, learning by reinforcement), however, cannot be excluded.
expressions of various inner states (joy, anger, sadness, surprise, interest, pride, shame) in congenitally blind individuals (e.g. Galati et al., 2003; Tracy and Matsumoto, 2008; Matsumoto and Willingham, 2009). It was found that spontaneous facial expressions are very similar in blind and sighted individuals, although blind individuals tended to display more extraneous facial muscle movements; like closing of the eyes (Galati et al., 2003; Galati et al., 2001; Tracy and Matsumoto, 2008; Matsumoto and Willingham, 2009). In contrast, when asked to voluntarily display various facial expressions, congenitally blind individuals had more difficulties posing these expressions compared to sighted individuals (e.g. Galati et al., 1997; Rinn, 1991). Based on these findings, it was concluded that the ability to show spontaneous facial expressions does not require learning through visual feedback, whereas visual feedback seems important for specific voluntary facial displays (Rinn, 1991; Galati et al., 1997).

1.1. Spontaneous/evoked facial expression of physical distress

Surprisingly, none of the studies listed above has focused on the role visual learning plays in shaping facial expressions of physical distress, but focused mainly on classical emotions like anger, joy or surprise. The only evidence that the encoding of physical distress via facial expressions might be unchanged in congenitally blind individuals stems from Thompson (1941) and Eibl-Eibesfeldt (1973) who reported that blind children cried, pulled down the corners of the mouth or shouted with pain when they accidently hurt themselves. However, no standardized method was used to analyse facial expressions, the physical distress was not experimentally controlled and no subjective self-report was assessed which could indicate the degree of physical distress experienced. Thus, it still remains uncertain to which degree the ability to facially express physical distress requires visual learning or whether it is mostly an innate behaviour. In order to answer this question, the present study aims to induce the experience of physical distress in congenitally blind and sighted individuals by applying experimental pain stimuli and to assess subjects’ spontaneous/evoked facial expressions. Experimental pain intensities will be adjusted to individuals’ pain sensitivity to ensure that participants are experiencing comparable levels of physical distress. Moreover, relatively long pain induction times will be used to elicit a physical distress whose quality, intensity, temporal pattern and underlying physiological mechanisms resemble those of clinical pain more closely compared to phasic pain stimulation (Lautenbacher et al., 1995).

Additionally, different intensities of physical distress (close-to-painful, slightly and moderately painful) will be induced. In sighted individuals, it has been shown that the magnitude of facial expression changes in parallel to the intensity of pain being experienced (e.g. Kunz et al., 2006; Craig et al., 2001). It has, however, never been investigated whether congenitally blind individuals are also capable of differentially encoding different affective intensities via their facial expression.

Based on these considerations, our first hypothesis is that the ability to facially express the experience of physical distress (evoked expressions of pain) is not dependent on learning through visual feedback as evidenced by no group differences between congenitally blind and sighted individuals with regard to (i) the repertoire of facial muscle movements displayed in response to physical distress (descriptive statistics) and (ii) the ability to distinctively encode different intensities of pain via one’s facial expression (inferential statistics).

2. Materials and methods

2.1. Subjects

Twenty-one congenitally blind (female: N = 11, male: N = 10; mean age: 31.5 (SD: 8.7) years) and forty-two sighted age matched control subjects (female: N = 22, male: N = 20; mean age: 28.9 (SD: 5.3) years) participated in this study. Congenitally blind subjects were recruited with the help of the Bavarian Association for the Blind (Bayrischer Blindenbund). Sighted controls were recruited via advertisement in local newspapers. Causes of blindness were: congenital glaucoma (N = 3), retinopathy of prematurity (N = 15), and congenital optic atrophy (N = 1). Seventeen blind subjects reported having no light perception since birth; four subjects reported formless diffuse perception to bright light. Besides blindness, subjects reported no physical or other types of impairments. Congenitally blind and sighted control subjects had not

2 Given that we are investigating facial expressions evoked by experimental pain stimuli, we prefer the term “evoked expressions” instead of “spontaneous expressions” in the present experimental context.

1.2. Voluntary facial expression of physical distress

Given that facial expressions in adults are often a combination of spontaneous/evoked as well as voluntary components, we also want to investigate whether visual learning is an essential prerequisite to develop the ability to exert voluntary control over one’s facial expression of pain. Since it is difficult to distinguish which part of a facial expression is “truly” evoked and which part is voluntarily controlled, most studies asked subjects to pose facial expressions as an indication of an individual’s underlying ability to exert voluntary control over their facial expression. As stated above, most studies found posed facial expressions to be severely reduced in congenitally blind individuals (Ortega et al., 1983; Rinn, 1991; Webb, 1977). However, in a more recent study by Galati et al. (1997), almost no differences in voluntary facial expressions (surprise, anger, joy, disgust, sadness, fear) were observed between sighted and congenitally blind individuals. Galati et al. (1997) argue that in contrast to previous studies, that used more abstract instructions for voluntary expressions (e.g. verbal labels (“show a facial expression of disgust”)), they used instructions that blind individuals could better relate to. Subjects were asked to imagine different affective scenarios, which had been selected before by blind individuals, and display a facial expression likely to occur during the scenario (Galati et al., 1997). We aim to further investigate into this issue by using two different types of instructions for voluntary expressions of pain. Following the approach by Galati and colleagues, we will use instructions that both congenitally blind and sighted individuals can well relate to; by instructing participants to voluntarily repeat the facial expressions, which they thought to have shown spontaneously in response to the tonic heat stimulation (instruction a “repeat condition”). Furthermore, participants will be instructed to optimize their voluntary facial expression of physical distress in a way that an onlooker would clearly understand what kind of affective state they are trying to express (instruction b “optimal condition”). This second instruction to optimize one’s voluntary facial expression is a task that blind individuals can be expected to have more difficulties with. Sighted individuals on the other hand can use visually stored patterns to optimize their voluntary expression (e.g. what does a typical facial expression of pain look like, how can I make the expression more clear) and thus, have an advantage during the “optimal condition”.

Based on these considerations, our second hypothesis is that visual learning is not an essential prerequisite for voluntary facial expressions of physical distress as long as individuals can relate to the task instructions; however visual learning is necessary in order to effectively modulate (in this context exaggerate) one’s voluntary expression. This would be evidenced by (i) no significant group differences in voluntary facial expressions when subjects are asked to voluntarily reproduce their facial expressions shown during physical distress (“repeat condition”); whereas (ii) congenitally blind individuals show less marked voluntary expressions compared to sighted individuals when subjects are asked to optimize their facial expression (“optimal condition”).
taken any analgesic medication or alcohol for at least 24h prior to the test session. Furthermore, no subject was taking any psychotropic medication. All subjects provided written informed consent and were paid for their participation. The study protocol was approved by the ethics committee of the University of Fribourg.

2.2. Materials and procedure

Subjects were carefully familiarized with the methods to be used before the start of the assessment. During the whole session, which lasted for approximately 1.5 h, subjects sat upright in a comfortable armchair. The testing procedure (see Fig. 1) included the assessment of evoked facial responses to tonic heat stimulation of different intensities (6 min each; Part 1). In order to minimize attention to, and voluntary regulation of, facial responses during part 1, subjects were told upon arriving at the laboratory that the purpose of the study was to determine whether congenitally blind and sighted individuals differ in their perception and responses to painful heat stimulation. Following part 1, we revealed that our main interest lies in facial expressions and subjects were asked to voluntary display facial expressions of different pain intensities (Part 2). Following a previous protocol that has been shown to successfully elicit facial expressions of pain (Kunz et al., 2006), pain was induced by use of a Peltier-based, computerized thermal stimulator (Medoc TSA-2001; Medoc Ltd, Ramat Yishai, Israel) with a 3 cm × 3 cm contact probe attached to the ventral surface of the right or left thigh.

2.2.1. Part 1—evoked facial expressions

2.2.1.1. Thermal stimulation (pain induction). Since our aim was to compare facial responses to noxious stimulation in congenitally blind and sighted individuals, we wanted to exclude variations that are simply due to differences in the subjects' pain experience by tailoring the stimulation intensities to the individual pain threshold. Thus, heat pain thresholds were determined first using the method of adjustment. Subjects were asked to adjust a temperature starting from 38 °C, using heating and cooling buttons (rate of change: 0.5 °C/s), until they obtained a level which was barely painful. Following a familiarization trial, there were 5 trials and the average of these trials was used to constitute the threshold estimate. Thresholds were assessed on the right and left body side (see Fig. 1); thresholds did not differ between right and left side ($p > 0.05$). Tonic heat stimuli were administered either at close-to-painful, slightly painful or moderately painful intensities. This was done according to protocol of the Tonic Heat Pain Model (Laubenbacher et al., 1995). Small heat pulses with an amplitude of 1.3 °C were administered at a constant frequency of 30 pulses per minute (sine wave; duration of each pulse was 2 s, rate of rise: 0.5 °C/s). For close-to-painful heat, the pulses were tailored to have a base of 2.3 °C below the individual pain threshold and a peak temperature of 1 °C below it. For slightly and moderately painful heat, the procedure was the same with the exception that the base/peak temperatures were -1.3/+0 °C (slightly painful) and -0.3/+1 °C (moderately painful) below/above the threshold, respectively. Each stimulus intensity was applied twice, first on the right and then on the left thigh, resulting in 6 stimulation blocks (see Fig. 1). Since body side of stimulation has been shown to have no effects on heat pain perception (Sperrual et al., 2003), we did not counterbalance the order of body sides. In each block, the duration of tonic heat stimulation was 6 min. The order of stimulation intensities was randomized across subjects (we did however exclude linear ascending and descending orders). Moreover, the order of stimulation was also changed within subjects by changing the order between body sides (reversed order on the second body side), so that every subject received 2 different orders of stimulation intensities. To avoid local sensitization, the site of stimulation on the ventral surface was changed after each stimulation block. The interval between stimulation blocks was approximately 3 min to avoid carry-over effects (Tousignant-Laflamme et al., 2008).

2.2.1.2. Self-report. The subjects were asked to rate the intensity of the tonic heat stimuli in intervals of one minute during tonic heat stimulation (between seconds 50 and 60 of each 1-min epoch, see Fig. 1). The rating should describe the sensation they felt at the given moment (Laubenbacher et al., 1995). Subjects were asked to give ratings between 0 and 100 on a numerical rating scale (NRS). They were instructed that the number 50 should equal a “faintly painful” sensation so that all non-painful sensations should be rated below 50 and all painful one’s above 50 (Marchand et al., 1991). For further analyses, ratings were averaged across the 6 min and across the left and right body sides; this was done separately for each stimulus intensity. Facial expression.

The face of the subject was videotaped throughout each 6 min block (see Fig. 1). The camera was placed in front of the subject at a distance of approximately 4 m. In order to ensure a frontal view of the face, all subjects wore a soft cervical collar during the testing procedures (see Fig. 2) to stabilize their head position. Subjects were also instructed not to talk during pain induction unless they were asked to provide verbal ratings.

We quantified facial responses using the Facial Action Coding System (FACS, Ekman and Friesen, 1978), a fine-grained anatomically based system that is considered the gold standard when decoding facial expressions. The FACS distinguishes 44 different Action Units (AU) produced by a single muscle or a combination of muscles. The intensity (5-point scale) and duration of these AUs were rated by four coders, one being a certified FACS coder and the other three having been trained by the certified FACS coder. The proportion of blind/sighted participants scored by each of the 4 raters was: 7/12; 5/5; 5/10 and 4/5, respectively. Since the amount of video data recorded in this study is rather extensive compared to previous studies (63 subjects × approx. 36 min of video data), we decided that five percent of the video segments will be a sufficient amount of data points necessary for conducting interrater reliability. Therefore, five percent of the video segments (video segments were taken from excerpts showing facial responses to all three stimulus intensities of 4 sighted controls and 3 blind individuals) were coded by all observers. Interrater reliability, as calculated using the Ekman–Friesen formula (Ekman and Friesen, 1978; number of AUs agreed upon >2 and divided by the overall amount of AUs coded), was 0.81, which compares favourably with other research in the FACS literature. A software designed for the analysis of observational data (the Observer Video-Pro; Noldus Information Technology) was used to segment the videos and to enter the FACS codes into a time-related data-base. Per stimulus intensity, 12 min of video recording were FACS coded (except those time intervals when participants were otherwise engaged).
provided verbal ratings). For further analyses, the duration of each AU was summed up across these 12 min and the mean intensity score of each AU was calculated. Moreover, for purposes of necessary data reduction, we combined those AUs that represent facial movements of the same muscle as has been done in preceding studies without any loss of information (Prkachin, 1992; Kunz et al., 2004, 2007; Hale and Hadjistavropoulos, 1997). Therefore, AUs 1 and 2, AUs 6 and 7, AUs 9 and 10 as well as AUs 25, 26 and 27 were combined to form new variables. For inferential statistics, composite scores were computed by multiplying duration x intensity score of each AU and then averaging those AUs selected to be relevant in the present context (see Table 2).

2.2.2. Part 2—voluntary facial expressions

Following the completion of part 1, subjects were asked to voluntarily show facial expressions (see Fig. 1). They were asked (a) to reproduce their facial expressions from part 1 (repeat condition) or (b) to voluntarily express as optimal as possible what they had been feeling during part 1 of the study (optimal condition).

2.2.2.1. Thermal stimulation—cuing paradigm. To help subjects recollect their evoked facial expressions (repeat condition), we decided to use a cuing paradigm. Therefore, the three thermal intensities from part 1 were applied again immediately after each of the voluntary facial expressions (see Fig. 1). These temperature cues were applied for a period of 30 s each on the right body side. The order of the three stimulation intensities was randomized across subjects. To keep both the “repeat” and “optimal” conditions comparable, the three stimulus intensities were again presented (in the same order) during the “optimal condition” (see Fig. 1).

2.2.2.2. Self-report. Following the 30 s of stimulation, temperature returned to baseline (38 °C) and subjects were asked to rate the intensity of the heat stimuli again on the NRS. This was done to control that the cuing paradigm was valid in so far that stimulus intensities were rated similarly in parts 1 and 2. This temperature rating preceded the instruction for the voluntary facial expression (see Fig. 1). Following the display of a voluntary facial expression, subjects were always asked to rate how well they think they succeeded (a) in repeating their facial expression or (b) in displaying an optimal facial expression (see Fig. 1). They were asked to rate their ability using a NRS, ranging from 0 (I did not succeed at all) to 100 (I succeeded extremely well).

2.2.2.3. Facial expression and voluntary display tasks. After subjects rated the pain intensity of the “cuing” temperature they were asked to voluntarily show a facial expression for 5 s (to mark beginning and end of these 5 s, verbal signals “start” and “stop” were given by the experimenter).

Part 2a “repeat condition” — Subjects were instructed to display the facial expression, which they thought to have shown during part 1 of the experiment, at the given temperature.

Part 2b “optimal condition” — Subjects were instructed to optimize their voluntary facial expression. They were told to imagine, that their facial expression was the only way they could communicate to another individual what they had subjectively experienced before and thus, they should express what they had felt before as optimal or as clearly as possible.

The voluntary facial response of the subject was videotaped and quantified (FACS coding) the same way as during part 1. The only difference was that instead of duration and intensity, only the intensity of each Action Unit was scored, given that the duration was fixed to 5 s and thus held no information.

2.3. Statistical analysis

Part 1 — Self-report: To ensure that group differences in spontaneous facial responses are not explained by group differences in subjective pain ratings, self-report ratings were compared between blind and sighted individuals using analysis of variance with repeated measures (between subject factor: subject group [Blind, Controls]; within subject factor: stimulus intensity [close-to-painful, slightly painful, moderately painful]). In case of group differences, ratings would be used as covariate in the facial expression analyses.

Part 1 — Facial expression: Repertoire of facial movements (descriptive statistics): In a first step, we wanted to assess which facial movements (Action Units) might be relevant in the present experimental context (pain-relevance) for congenitally blind individuals and for sighted controls. In order to do this, we used descriptive statistics and selected those AUs that were displayed more than 1% (this equals on average an occurrence rate of 18 s per subject) during the entire segments of thermal stimulation (close-to-painful, slightly painful and moderately painful intensities). This occurrence rate of 1% might seem very small. However, facial expressions are very dynamic and are of rather short duration (often lasting not longer than a second). Thus, most of the time during tonic stimulation no facial responses occur and these periods of “facial silence” are more or less often interrupted by facial displays (depending on the stimulus intensity and on the facial expressiveness of the individual).
Table 1
Mean values (+SD) of self-report ratings in part 1 and part 2 of the study. Ratings are given separately for each stimulus intensity and separately for sighted controls and blind individuals.

<table>
<thead>
<tr>
<th></th>
<th>Stimulus intensity</th>
<th>Pain ratings</th>
<th></th>
<th>Slightly painful</th>
<th>Moderately painful</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (SD)</td>
<td>Part 1, Controls</td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Blind</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Close-to-painful</td>
<td>38.2 (10.8)</td>
<td>42.9</td>
<td>51.9 (10.2)</td>
<td>53.4 (11.9)</td>
<td>64.3 (11.8)</td>
</tr>
<tr>
<td>Slightly painful</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moderately painful</td>
<td></td>
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</tbody>
</table>

3. Results

3.1. Part 1—spontaneous pain expressions

Pain thresholds were comparable between blind and sighted controls, as indicated by no group differences (blind: 44.1 °C (SD 1.7); controls: 44.4 °C (SD 1.8); p > 0.5; \( \eta^2 = 0.007 \)).

3.1.1. Self-report

Thermal sensation rating: Self-report ratings of the tonic heat stimulation did not differ between groups (no significant effects for the factor subject group or the interaction between subject group and stimulus intensity (\( p > 0.05; \eta^2 = 0.015 \))). As intended, analyses of variance only revealed a significant main effect for the factor stimulus intensity (\( F(2,122) = 88.856; p < 0.001; \eta^2 = 0.593 \)). As can be seen in Table 1, self-report ratings increased across the three intensities and lay in the expected ranges (close-to-painful intensities were rated below 50; and slightly as well as moderately painful intensities were rated above 50). Calculating post hoc t-tests revealed that the increase of self-report ratings was significant between all three temperature intensities (p-values < 0.017 (Bonferroni corrected for multiple comparisons)).

3.1.2. Evoked facial expression

Repertoire of facial movements (descriptive statistics): When selecting – out of the approximately 40 Action Units – those AUs that are pain-relevant in the given experimental context, there was an immense overlap between congenitally blind and sighted individuals. As can be seen in Table 2, with the exception of Action Unit 14 (dimpler), blind and sighted individuals displayed the same repertoire of facial muscle movements during tonic heat

<table>
<thead>
<tr>
<th>Action Units with an occurrence of &gt;1%a</th>
<th>Percentage of occurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sighted control</td>
</tr>
<tr>
<td>Part 1</td>
<td></td>
</tr>
<tr>
<td>AU 12 lifting the eyebrows</td>
<td>3.3%</td>
</tr>
<tr>
<td>AU 4 contracting the eyebrows</td>
<td>5.3%</td>
</tr>
<tr>
<td>AU 67 contracting the muscles surrounding the eyes</td>
<td>5.0%</td>
</tr>
<tr>
<td>AU 14 lifting the lip corners (smile)</td>
<td>1.5%</td>
</tr>
<tr>
<td>AU 14 lip dimpler</td>
<td>2.0%</td>
</tr>
<tr>
<td>AU 25,26,27 opening the mouth</td>
<td>9.9%</td>
</tr>
<tr>
<td>AU 43 closing the eyes (&gt;0.5 s)</td>
<td>1.2%</td>
</tr>
</tbody>
</table>

a An occurrence rate of 1% equals an average duration of 18 s per subject.

b Those Action Units that occur in both subject groups are marked in bold.
stimulation (although the rate of occurrence of these Action Units varied between groups). Moreover, the facial muscle movements listed in Table 2 have been found in numerous previous studies to occur in the context of pain (e.g. Prkachin, 1992; Craig et al., 2001; Prkachin and Solomon, 2008). Thus, in accordance with hypothesis 1, the repertoire of facial muscle movements elicited during physical distress, are very comparable between groups (see also example given in Fig. 2).

Group differences in facial encoding of pain (inferential statistics): Following this first step of selecting pain-relevant AUs, AUs were combined to form composite scores of facial pain displays. As has been done in previous studies (Kunz et al., 2007, 2008, 2009a), those AUs that occurred in both subject groups (marked in bold in Table 2) were averaged to form composite scores. Before we entered these composite scores into the ANOVA, we checked whether they meet the assumptions of parametric statistical tests. Given that the data was neither normally distributed (strongly positively skewed distributions) nor were the variances homogeneous, we decided to transform the data using square-root transformation (Osborne, 2002). The transformed scores were then entered into analysis. There was a main effect for the factor stimulus intensity (F(1,66,101.51) = 3.870, p = 0.034; η²p = 0.061), with facial expressions significantly increasing across stimulus intensities (see Fig. 3). There was also a main effect for the factor subject group (F(1,61) = 5.489; p = 0.022; η²p = 0.082); with congenitally blind individuals being facially more expressive (see Fig. 3). Moreover, the interaction between subject group and stimulus intensity also yielded a significant effect (F(1,66,101.51) = 3.464; p = 0.034; η²p = 0.060). Calculating effect sizes (Cohen’s d) revealed that the increase of facial expressiveness across intensities yielded moderate to strong effect sizes in sighted individuals, whereas mostly small effects were found in congenitally blind individuals (effect sizes are displayed in Fig. 3).

Likewise, post hoc t-tests revealed a very similar picture, with facial expressions significantly increasing across intensities only in sighted individuals (p-values < 0.008 (Bonferroni corrected for multiple comparisons)), whereas facial expressions did not differ between stimulus intensities in congenitally blind individuals (all p-values > 0.008 (Bonferroni corrected for multiple comparisons)). Moreover, running polynomial trend analyses revealed a linear increase of facial pain displays in sighted individuals (F(1,41) = 11.651, p = 0.001; η²p = 0.221) whereas neither a linear (F(1,20) = 0.457, p = 0.507; η²p = 0.022) nor a quadratic trend (F(1,20) = 2.391, p = 0.138; η²p = 0.107) was found in blind individuals across intensities. This indicates that facial expressions of sighted individuals encode the intensity of physical distress notably better than those of blind individuals.

3.2. Part 2—voluntary facial expressions

3.2.1. Self-report ratings

Thermal sensation rating: Analysis of variance revealed that the cueing paradigm was valid in so far that the three temperature intensities were rated in a similar pattern across part 1 and part 2a (p > 0.05; η²p = 0.037) as well as between part 1 and part 2b of the study (p > 0.05; η²p = 0.040). This was true for both subject groups as indicated by a non-significant interactions between the factors subject group and study part (p-values in both ANOVAs > 0.05; η²p-values < 0.006). With the exception of the factor stimulus intensity (p-values in both ANOVAs < 0.05; η²p-values < 0.656), none of the other effects reached the level of significance (p > 0.05; η²p < 0.11). Calculating post hoc t-tests to further explain the significant effect for the factor stimulus intensity, revealed that the increase of self-report ratings was significant between all three temperature intensities (all p-values < 0.008 (Bonferroni corrected for multiple comparisons)). Descriptive statistics (mean values and SD) are given in Table 1.

Ability ratings: Congenitally blind and sighted controls rated their ability to display voluntary facial expressions as similarly successful (factor subject group: p > 0.05; η²p = 0.036). As can be seen in Table 1, both groups rated their ability to display voluntary responses as moderately successful. Interestingly, ability ratings were neither affected by type of instruction ((a) reproduce vs. (b) display an optimal expression), nor by stimulus intensity (all p-values > 0.05; η²p < 0.020). Furthermore, none of the interaction effects reached level of significance (all p-values > 0.05; η²p < 0.016).

3.2.2. Voluntary facial expression

Analysis of variance showed a significant effect for the factor stimulus intensity (F(2,122) = 22.017; p < 0.001; η²p = 0.237). As can be seen in Fig. 4, subjects’ voluntary pain-related facial
expressions significantly increased across intensities. Moreover, this increase did not differ between the two types of instruction (part 2a vs. part 2b) as indicated by a non-significant interaction effect between type of instruction and stimulus intensity ($F(1, 811.103.6) = 1.133$, $p = 0.877$; $\eta^2_p = 0.002$). The second main factor, namely type of instruction also revealed a significant effect ($F(1, 61) = 9.991$, $p = 0.002$; $\eta^2_p = 0.112$). As can be seen in Fig. 4, voluntary displays of pain-related facial muscle movements were more pronounced when subjects were instructed to display an optimal facial expression (2b) compared to being instructed to repeat their facial expressions from part 1 (2a).

With regard to our main interest, namely group differences, analysis of variance revealed a trend towards a significant group effect ($F(1, 61) = 3.458$, $p = 0.068$; $\eta^2_p = 0.055$). Congenitally blind individuals showed less marked voluntary facial expressions compared to sighted individuals (see Fig. 4). Moreover, the increase of voluntary facial expressions across intensities also showed a tendency to differ between subject groups (interaction effect between group and stimulus intensity: $F(2, 122) = 3.039$, $p = 0.052$; $\eta^2_p = 0.045$). Whereas sighted individuals showed steeper increases in voluntary expressions from close-to-painful to painful intensities, blind individuals showed steeper increases from slightly to moderately painful intensities (see Fig. 4). As expected, the factor subject group interacted significantly with the factor type of instruction ($F(1, 61) = 13.904$, $p < 0.001$; $\eta^2_p = 0.249$).

For post hoc analyses, we compared voluntary expressions (i) between blind and sighted individuals as well as (ii) between types of instructions (part 2a and 2b).

- **(i)** Post hoc t-tests revealed no significant differences between subject groups during block 2a (all $p$-values $> 0.008$ (Bonferroni corrected for multiple comparisons)). Likewise, computation of post hoc effect sizes for the comparisons of facial expressiveness in blind and sighted individuals revealed only small effect sizes between groups (Cohen's $d$ ranging between 0.14 and 0.41) when individuals were instructed to repeat their facial expression (block 2a). In contrast, significant group differences were found when comparing facial expressions between subjects during the instruction to optimize one's voluntary facial expression (block 2b) ($p$-values < 0.008 for slight and moderate pain intensities (Bonferroni corrected for multiple comparisons)); with congenitally blind individuals showing markedly reduced facial expressions (see Fig. 4). Likewise, moderate to large effect sizes (Cohen's $d$ ranging between 0.56 and 0.88) were found for group difference in facial pain displays during part 2b.

- **(ii)** Moreover, computing post hoc t-tests to compare facial expressiveness between part 2a and 2b – separately for each subject group – revealed that voluntary facial expressions significantly increased during the optimal condition only in sighted controls (all $p$-values $< 0.008$ (Bonferroni corrected for multiple comparisons)), whereas no significant differences between conditions were found in blind individuals (all $p$-values $> 0.008$ (Bonferroni corrected for multiple comparisons)). Likewise, effect sizes revealed a very similar picture, with facial expressions considerably increasing between part 2a and 2b in sighted individuals (Cohen's $d$ ranging between 0.67 and 1.02), whereas facial expressions did not change between part 2a and 2b in congenitally blind individuals (Cohen's $d$ ranging between 0.06 and 0.24). This means that sighted individuals were able to voluntarily increase their expressiveness when asked to express as clearly as possible what they had experienced at each stimulus intensity; whereas congenitally blind individuals were not able to do this. Examples of voluntary facial expressions of moderate painful intensities are displayed in Fig. 2.

### 4. Discussion

Our main aim was to investigate to which degree the ability to express physical distress (pain) via one's facial expression is dependent on the possibility of visual learning. Our main findings were that congenitally blind and sighted individuals displayed the same pattern of facial movements in response to painful heat stimulation. However, although congenitally blind individuals were facially more expressive compared to sighted controls, they were less capable of encoding different pain intensities using their facial expression. In contrast to the more marked evoked facial expressions of pain in blind individuals, they showed rather reduced voluntary facial expressions. Whereas sighted individuals were able to voluntarily increase their facial expressions of distress when asked to pose and "optimal expression", blind individuals were not able to voluntarily optimize their facial expression. We will discuss these findings in more detail below.

#### 4.1. Evoked facial expressions

As hypothesized, congenitally blind individuals displayed a very similar repertoire of facial movements in response to tonic heat stimulation of close-to-painful and painful intensities (see Fig. 2). With the exception of the buccinator muscle (lip dimpler), which was only activated by sighted individuals in response to the tonic heat stimulation, both subject groups displayed the same types of facial movements. These expressions included contraction or relaxation of 6 facial muscle groups, namely: the frontalis muscle (lifting the eyebrows), the corrugator muscle (contracting the eyebrows), the orbicularis oculi muscle (contracting the muscles surrounding the eyes), the zygomatic major muscle (smile), mentalis/temporalis muscles (opening the mouth) and the levator palpebrae superioris muscle (closing the eyes $> 0.5$ $\mathrm{s}$). These 6 facial movements have repeatedly been reported in the context of clinical as well as of experimental pain conditions (e.g., Craig et al., 2001; Prkachin, 1992; Prkachin and Solomon, 2008; Kunz et al., 2004, 2006, 2009b; Williams, 2002). Thus, the possibility of visual learning does not seem necessary in order to display a pain-related set of facial expressions in response to painful (or close-to-painful) stimulation. This finding is in accordance with findings on facial expressions of pain in neonates, who have been found to display similar facial expressions in response to noxious procedures (e.g. heel lance) as adults do, despite having had a very limited learning experience (e.g., Galati and Craig, 1987). Moreover, the finding also fits well with previous reports on spontaneous/evoked facial expressions of other affective states. It has been shown that congenitally blind and sighted individuals display very similar facial expressions when experiencing disgust, joy, surprise, interest, sadness, anger or fear (e.g. Eibl-Eibesfeldt, 1973; Ortega et al., 1983; Galati et al., 2003; Matsumoto and Willingham, 2009) as well during the experience of pride and shame (Tracy and Matsumoto, 2008). Accordingly, our study further supports the assumption that the patterns or the repertoire of facial muscles being activated during specific affective states are biologically prepared.

However, despite the evidence for an innate biological preparedness, visual learning, which probably occurs in early childhood, nevertheless seems to be crucial in order to use one's facial expression to distinctively encode different intensities of physical distress. In numerous studies it has been shown that the magnitude of facial expressions in sighted individuals increases proportionally to the physical distress being experienced (e.g., Hadjistavropoulos et al., 2000; Kunz et al., 2004, 2006). In accordance with this, facial expressions of the sighted individuals showed a significant linear increase across the three stimulus intensities in the present study. In contrast, no linear or quadratic increase in facial expressiveness was found for congenitally blind
individuals. This is the first study to ever investigate the ability of congenitally blind individuals to facially encode different affective intensities. Our findings suggest that the facial encoding of small to moderate differences in affective states seems to require learning through visual feedback. The ability to encode even small to moderate differences in affective states can however be of crucial relevance in social communication as well as, in the case of pain, for clinical pain treatment.

Moreover, congenitally blind individuals showed augmented facial expressiveness during tonic heat stimulation compared to sighted controls. We could recently demonstrate that the degree of facial expressiveness in response to painful heat stimulation is associated with activity in fronto-striatal areas (Kunz et al., 2011). Using functional Magnet Resonance Imaging, we found that low expressive individuals showed higher activations in these areas, consistent with an inhibitory process involved in the active suppression of facial expressiveness. This tendency to suppress is a very common phenomenon that has been discussed in the context of learned display rules regulating when and how one should express specific affective states (Matsumoto, 1991). These display rules are believed to be learned during childhood, with peers and parents in general discouraging the strong expression of emotions (Izard, 1971). Larachotte et al. (2006) demonstrated that children between the ages of 8 and 12 years are able to successfully suppress their facial expression of pain and that these children reported to suppress their pain expression in everyday life in order to avoid embarrassment in front of peers or to avoid worrying their parents (Larachotte et al., 2006). In line with this, brain pathologies leading to frontal degeneration, loss of inhibitory functioning and implementation of social rules – like dementia – have been shown to result in increased facial expressiveness in response to pain (Kunz et al., 2006).

Considering these previous findings, the augmented facial expressiveness in blind individuals seems to be the “default” value that sighted individuals learn to inhibit to a socially desirable level through visual feedback. Similarly, visual – and social – feedback seems necessary in order to learn about the situations in which it is appropriate to show painful facial expressions and in which it is more appropriate to inhibit them.

In addition to these main findings on evoked facial expression, we also want to comment on a couple of other interesting observations. In accordance with previous findings on facial expressions of various inner states (e.g. anger, interest, joy; Galati et al., 2003; Matsumoto and Willingham, 2009), we found evoked facial expressions to be more marked in blind compared to sighted individuals. This increase in facial activity was mostly due to increased raising of the eyebrows (AU1,2) and longer periods of closed eyes (AU43) (see Table 2). Very similar findings were reported by Galati et al. (2003), who also observed that congenitally blind children more frequently raised their eyebrows and closed their eyes in response to various affective situations (e.g. during the experience of anger, surprise, interest). This suggests, that congenitally blind individuals respond to painful stimuli with a set of facial muscle movements that do not seem to be specific to pain but instead seem to be a “basic expression” that is typically shown during emotional experiences in congenitally blind individuals. It remains to be investigated to which degree this “basic expression” of raised eyebrows and closed eyes overrides the more pain-specific facial expressions, like contracting the eyebrows and the muscles surrounding the eyes. It is possible that this “basic expression” makes it more difficult for an observer to recognize pain-indicative muscle movements in blind individuals. Another interesting finding was that sighted individuals as well as congenitally blind individuals displayed oblique lip raise (smiling) during tonic heat stimulation. Although smiling might seem an unexpected accompaniment of pain, it has been reported in numerous studies (for an overview see Kunz et al., 2009b). The “smile of pain” has been hypothesized to occur as a self-regulatory strategy that helps to dissociate from the threatening and plaguing aspects of physical distress. Moreover, it could also be a social-regulatory strategy that serves to mask one’s physical distress from others (Kunz et al., 2009b). The occurrence of the “smile of pain” in congenitally blind individuals suggests that the ability to use facial expressions for social- or self-regulatory strategies does not require visual learning. Matsumoto and Willingham (2009) came to a similar conclusion as they observed congenitally blind athletes displaying social smiles after being defeated in a judo match.

4.2. Voluntary expressions

Whereas congenitally blind individuals displayed more marked spontaneous expressions, their voluntary facial expressions tended to be diminished compared to sighted controls. Interestingly, this reduction in voluntary facial expressions in blind individuals was only observable when instructed to display an optimal facial expression, whereas no group differences occurred when subjects were instructed to repeat their facial expressions shown during part 1 of the study. This finding is in accordance with previous studies that also reported a reduction in voluntary facial expressions in blind individuals (e.g. Fulcher, 1942; Rinn, 1991) when instructions were more difficult to relate to, whereas no differences were found when instructions for voluntary facial expressions were used that were adjusted to match blind individuals experiences (Galati et al., 1997). These findings seem to suggest that memory traces of one’s own spontaneous/evoked expressions are sufficient in order to learn to voluntarily activate one’s facial muscles in patterns that are specific for different affective states. Given that voluntary and evoked facial expressions have been shown to be regulated by different cerebral networks, this finding is very interesting. Voluntary facial expressions are mainly regulated by cortical regions (especially the primary motor cortex) whereas evoked facial expressions are regulated by a cerebral network of both subcortical (e.g. basal ganglia, brainstem) and cortical regions (e.g. primary motor cortex, prefrontal areas) (Blair, 2003; Wild et al., 2006; Kunz et al., 2011). Despite these neuro-functional differences between voluntary and evoked facial expressions, visual learning does not seem necessary in order to voluntarily activate emotion-specific muscle patterns.

However, visual learning seems necessary in order to sufficiently customize or change one’s voluntary facial expressions. Whereas sighted individuals showed increased pain-indicative facial expressions when asked to more clearly express the physical distress they had experienced, blind individuals level of expressiveness remained unchanged compared to the instruction to simply repeat their expression. The regulation of facial expressiveness by social display rules does not only encompass down regulation but also up-regulation of expressiveness (Matsumoto, 1991). The ability to up-regulate one’s facial expressiveness is believed to also develop in early childhood (Josephs, 1994), with children being able to voluntarily exaggerate their facial expression of pain if instructed to do so (Larochette et al., 2006). This is in line with our findings, namely that sighted individuals were well capable of voluntarily up-regulating their facial expressions when asked to express more clearly what they had experienced before (see also examples given in Fig. 2). This ability was reduced in blind individuals. Thus, visual learning seems to be a prerequisite in order to develop strategies to successfully up-regulate facial expressions of physical distress.

Surprisingly, congenitally blind individuals were able to voluntarily express different pain intensities, although they were not able to encode different intensities of physical distress with their evoked facial expressions. This suggests that congenitally blind individuals are able to facially express different affective intensities, however, only under voluntary control.
Despite the reduced ability of congenitally blind individuals to “optimize” their voluntary facial expression (part 2b), blind and sighted individuals rated their ability to reproduce and to pose an optimal expression as similarly successful. Regardless of type of instruction and regardless of stimulus intensity, subjects reported that they were moderately successful in producing voluntary facial expressions. Given that congenitally blind individuals were less able to optimize their voluntary facial expression, these findings might seem surprising. It is possible that visual feedback helps to develop awareness of how adequate one’s facial expression can convey specific affective states. However, misjudgment of the communication adequacy of one’s facial expression has also been found for sighted individuals who have had access to visual feedback throughout their lives (Barr and Kleck, 1995). Therefore, lack of visual feedback might only make it more difficult to estimate how well one can communicate affective states via one’s facial displays.

As one limitation of the present cuing design chosen to investigate voluntary facial expressions of pain we have to mention that we cannot exclude that participants showed spontaneous facial expressions of those spontaneous expressions elicited in the previous 30 s (during the cuing of the different temperatures). Facial responses during cuing were not video-taped and thus, we cannot exclude this possibility. However, we wanted to keep the task difficulty for voluntary expressions not too high and therefore, it was important to provide a frame of reference for the subjects to help them show voluntary expressions of the three different pain intensities.

4.3. Conclusion

Our data suggest that some basic algorithms of facial displays are biologically prepared. These algorithms do – for example – determine which repertoire of facial muscles is activated in specific affective states. This activation of emotion-specific muscle patterns is crucial in order to successfully communicate one’s affective state. However, these biologically prepared algorithms have to be customized. Because only the customization, which seems to require visual learning in the early childhood, allows producing differential facial expressions that are adjusted to the social or situational requirements. In our context, this customization allowed sighted individuals to spontaneously encode different intensities of pain and to up- and down-regulate their facial expressions.

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