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The Time Course of Facial Expression Recognition Using Spatial Frequency Information: Comparing Pain and Core Emotions

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Abstract

We are able to recognise others’ experience of pain from their facial expressions. However, little is known about what makes the recognition of pain possible and whether it is similar or different from core emotions. This study investigated the mechanisms underpinning the recognition of pain expressions, in terms of spatial frequency (SF) information analysis, and compared pain with two core emotions (i.e. fear and happiness). Two experiments using a backward masking paradigm were conducted to examine the time course of low- and high-SF information processing, by manipulating the presentation duration of face stimuli and target-mask onset asynchrony. Overall, we found a temporal advantage of low-SF over high-SF information for expression recognition, including pain. This asynchrony between low- and high-SF happened at a very early stage of information extraction, which indicates that the decoding of low-SF expression information is not only faster but possibly occurs before the processing of high-SF information. Interestingly, the recognition of pain was also found to be slower and more difficult than core emotions. It is suggested that more complex decoding process may be involved in the successful recognition of pain from facial expressions, possibly due to the multidimensional nature of pain experiences.

Perspective: Two studies explore the perceptual and temporal properties of the decoding of pain facial expressions. At very early stages of attention, the recognition of pain was found to be more difficult than fear and happiness. It suggests that pain is a complex expression, and requires additional time to detect and process.

Keywords: pain; facial expression; recognition; spatial frequency; time course

Introduction

Accurately detecting and interpreting nonverbal expressions of pain is important for caregiving. Although not conceptualised as an emotion, pain can also be communicated through facial expressions [19,32,38]. The main method used to explore this takes a component approach, measuring movements of facial muscles during pain [12]. However, this may be different to how we process facial expressions in naturalistic environments, where challenging visual conditions mean that specific details are difficult to see, e.g., brief exposure, limited visibility [10,34,43,44]. Alternatively, a holistic analysis of available information may be required [5,25,33].

One approach to global processing is to consider faces as visual stimulus that contains different types of perceptual information. Spatial frequency (SF) is one of the most basic visual perceptual features that encodes the level of detailed information in a visual representation *and* determines the appearance of a visual display [40]. Low-SF encodes the large-scale facial configuration and coarse structures, whereas high-SF encodes the fine-detailed facial features and abrupt changes. In a clear and intact visual representation, the full spectrum of SF information is available (i.e. broad-SF). Of relevance, is that SF information is relevant for the perception of affective material, including facial expressions [8], where a processing advantage for low-SF over high-SF is found, i.e., greater accuracy or speed. Whilst not often explored, emerging evidence suggests a similar low-SF advantage occurs for pain expression recognition [34,43,44]. This is important as it cannot be automatically assumed that the decoding of pain and emotion expressions occurs in a similar way.

Differences in the processing of low- and high-SF information are also thought to reflect separate neural pathways, with faster routes for processing low-SF information [42]. The holistic decoding of different types of pain expression information may, therefore, also occur through these different routes. If so, then we might expect that temporal changes in the visual percept impacts on facial expression decoding [18]. However, temporal dynamics of SF information processing for pain expressions have not been explored. Neuroimaging and electrophysiological approaches do, however, show more pronounced brain activity for negative emotions (e.g. fear), compared to positive or neutral expressions, during early processing of low-SF stimuli [26,41,42,45]. However, the tasks (e.g. discrimination of sex) used in these studies only provide indirect support, as they do not necessarily require explicit attention to the emotional content of facial expressions. Since responses to facial expressions vary according to purpose [37] and instructions [11], it is not possible to assume that low-SF information plays an early role in the perception of pain. Alternative, more direct, approaches are required. The aim of this study was to investigate the temporal dynamics of SF information processing for the recognition of pain facial expressions.

Two experiments are reported. Both used a backward masking paradigm and directly manipulated the presentation duration of face stimuli. Predictions were informed by the coarse-to-fine processing theory [1,18], which accounts for the role that temporal dynamics have on object recognition in context (e.g. scenes). It suggests that the processing of global scenes represented by low-SF information is faster than object identities represented by fine-detailed information. Therefore, an advantage of low-SF information over high-SF was hypothesised at early stages of processing. As well as pain, fear and happiness expressions were also included. We predicted that pain would be more difficult to recognise based on (a) previous findings that the recognition of pain is slower and less accurate than core emotions [20,34,38,44], (b) pain expressions encoding both sensory and affective qualities of painful experiences, and so being arguably more complex [22], and (c) pain expressions being less frequently encountered in daily life than core emotions, and so less familiar [6].

Experiment 1

Experiment 1 consisted of two tasks: a backward masking task and a simple recognition task without masking. The backward masking paradigm interrupts the processing of a target facial expression with a mask at various time points, allowing one to examine the corresponding visual percept of the expression using different types of SF information. Different time points of processing could be accessed by manipulating the target and mask stimuli onset asynchrony (SOA). In this task, the target face images were masked immediately after the presentation; therefore, the target-mask SOA was equal to the target face presentation duration. We hypothesised that the low-SF information would show an advantage over high-SF in the recognition of facial expressions when the SOA was brief. The simple recognition task was used to examine the role of SF information without any time constraints. According to the coarse-to-fine processing hypothesis, we expected that with sufficient presentation duration and processing, high-SF information would exhibit an advantage over low-SF. The recognition of pain was also expected to be more difficult/less accurate compared to core emotions.

Method

Participants

Forty-three healthy adult participants (22 females and 21 males) were recruited from the University of Bath (mean age=24.92, *SD*=6.70) by advertising through posters, flyers and noticeboard advertisements on campus. G-Power [15] calculated that 26 participants were needed given the study design and the expectation of a large effect size, which was found in previous studies of a similar type [43,44] (power level = 0.95). The majority of the participants were from the student and staff population of the university. However, we did not collect data about participants' social-economic status. The recruitment method and exclusion criteria were the same for both experiments. All participants had normal or corrected to normal vision and reported being pain-free and free from any psychiatric or neurological conditions. Ethics committee approval was granted by the Department of Psychology Ethics Committee (Ref. 13-161) and Department of Health Ethics Committee (Ref. EP 13/14 33a) of the University of Bath for both experiments. Informed consent was obtained from all participants prior to taking part in the experiments. All the participants were financially compensated for their time (£5 for 30 minutes).

Design

Both tasks used a within-groups design[1]. For the backward masking task, the independent variables were the SOA of the target expression (i.e. 17, 33, 67, 150 and 300 ms), the type of SF information (i.e. broad-SF, low-SF and high-SF) and expression (i.e. pain, fear, happiness and neutral). For the simple recognition task, the variables were the type of SF information and expression. Participants' recognition accuracy was

[1] The current study was a discrete part of a larger PhD thesis by the first author, in which participants' sex was also considered as a between-subjects factor. However, in terms of sex-related effects, none of the main effects or interactions were significant in either Experiment 1 (all *F*s < 2.13, *p*s > .13) or Experiment 2 (all *F*s < 2.45, *p*s > .09). Detailed analyses are not reported here, but are available from the corresponding author.

the dependent variable for both tasks.

Stimuli and apparatus

We used the static stimulus set (images) from the STOIC database [35]. The basic stimuli were 40 images and are comprised of 10 actors (five females and five males), each displaying the following four expressions: pain, fear, happiness and neutral. These images were the same as those used in our previous studies [43,44]. Fear and happiness were included as comparison expressions with pain, as we previously found to be the most similar to, and different from, pain in terms of valence and arousal [44]. Neutral expressions were also included as a low-expressive baseline.

The image SF manipulation procedure was the same as described in our previous research [44]. All images were filtered by low- and high-pass Gaussian filters with cut-off values of 8 and 32 cycle per frame, respectively. The manipulation was completed using MATLAB 2012b. Please see **Figure 1** for sample stimuli of pain facial expressions at each SF level. All the original broad-SF images were included as controls to compare with low- and high-SF stimuli. As a result, a total of 120 face images were used as stimuli in this experiment (10 actors × 4 expressions × 3 SF-levels). A validation based on the observers' categorisation of expression types and their subjective ratings of the valence and arousal levels were conducted and reported previously [44].

------ Figure 1 ------

The experiment was designed and controlled using E-Prime Professional 2.0. Stimuli were 256×256 pixels and displayed in their original size of 7.62×7.62 cm on a 19'' LCD screen with a resolution of 1280×1024 pixels and refresh rate of 60 HZ (i.e. refresh duration of 16.67 ms). Participants' viewing distance was about 60 cm in a visual angle of 7.26° for each face image. The same images and apparatus were used throughout.

All participants were given the backward masking task first, and then the simple categorisation task, to avoid any potential priming effect.

Backward masking task

The target stimuli were 96 face images of 8 actors (4 females and 4 males) displaying pain, fear, happiness and neutral at 3 SF-levels. The masks were 6 neutral faces displayed by the other 2 actors (1 female and 1 male) at the 3 SF-levels. The neutral faces were used as masks because they have previously been found to be effective in masking faces and facial expressions [9,27]. The presentation durations of a target face stimulus in this task were 17, 33, 67, 150 and 300 ms.

For each trial (see **Figure 2**), participants were shown a fixation cross at the centre of the screen for 500 ms followed by a blank screen for 50 ms prior to the target face onset, in order to reduce any priming effect of the fixation cross. A target face was presented for a given time length and was immediately replaced by a neutral face mask. Thus, in this task, the target-mask SOA was identical to the presentation duration of the target face. The duration of the mask was fixed at 300 ms, which is sufficient to effectively mask the target [14,23]. In each trial, the gender of the actor and the SF condition of the mask matched with the target face, but the identities were always different.

------ Figure 2 ------

Participants were asked to determine whether the target face was expressing fear, happiness, pain or neutral, by pressing the corresponding key labelled on a keyboard (D = fear, F = happiness, J = pain, K = neutral). Participants were instructed to rest the fingers on the keys and respond as quickly and as accurately as possible. The allocation of the keys was not counterbalanced across participants. A response could be made within 2000 ms since the onset of the target stimulus. After this, with or without a response, the trial terminated and moved onto the next one. There was an interval of 1000 ms between each trial. Participants were instructed that there would always be two faces in each trial (presented consecutively), and the target face was always the first, which could sometimes be presented extremely quickly. They were asked to respond to the expression of the first face they saw. In this task, each participant completed 960 trials (i.e. 96 target stimuli, 5 SOAs, and each repeated twice) with a break after every 192 trials. There was a practice of 20 trials preceding the main task. The target face stimuli in practice were randomly selected for each participant.

Simple recognition task

In each trial, participants viewed one face image at the centre of the screen and were asked to determine the expression by pressing the corresponding key. The face image was maintained on the screen until a valid response was given, and there was no time constraint for making a response. Participants were instructed to “take their time and respond as accurately as possible”. Each participant completed 120 trials with each stimulus image appearing once. No feedback was given in both tasks.

Data preparation and analysis

Data from the backward masking task and the simple recognition task were analysed separately. Participants’ recognition accuracy was measured using signal detection estimates of sensitivity (*d’*) to reduce the effect of possible response bias [17,24]. For the backward masking task, data were entered into a 5×3×4 (SOA [17, 33, 67, 150, 300 ms] × SF Information [broad-SF, low-SF, high-SF] × Expression [fear, happiness, neutral, pain]) ANOVA. The simple recognition task data were entered into a 3×4 (SF Information × Expression) ANOVA. Simple effect analyses were applied when significant interactions were found. *Post hoc* analyses with Bonferroni-type correction were conducted when necessary, and the corrected cut-off point for each analysis was calculated following 0.05/the number of comparison rule (e.g., when there are 3 comparisons, the corrected cut-off point is 0.05/3 = 0.0167). The exact p values after correction and the effect sizes are reported. The data was analysed using SPSS 22.

Data were first screened for invalid responses made within 200 ms since stimulus onset, and no responses were made after 2000 ms since stimulus onset due to the setting of response window. One participant (female) was excluded from further analysis due to making too few valid responses (less than 50%) in multiple conditions. Final data for this analysis were from a sample of 42 participants. For completeness, after removal of invalid trials (2.39% of all trials), the simple hit rates were calculated and are reported in supplementary materials. The *d’* was calculated for each participant. The data were normally distributed with z-scores of skewness and kurtosis between -1.96 and 1.96.

The large number of trials (960) could have resulted in fatigue or boredom. To check for a decline in performance, average RT for the first and second half of trials was calculated for each participant, and a split-half reliability analysis conducted. The Spearman-Brown correlation was .90, indicating good internal consistency across the testing phases. We also compared the average RT for the first half and the second half of the trials. No significant difference was found ($t(41) = 1.62$, $p = .11$, Cohen’s $d = .24$).

Results

Backward masking task

Means and *SDs* of *d'* in each condition are presented in **Table 1**.

------ Table 1 ------

Significant main effects were found for SOA ($F(2.76,113.07)=559.15$, $p<.001$, $\eta^2_p=.93$) and SF information ($F(2,82)=86.36$, $p<.001$, $\eta^2_p=.68$), but not expression type ($F(2.41,98.97)=2.81$, $p=.055$). However, these should be interpreted in light of significant interactions.

The interaction between SOA and SF information was significant (**Figure 3**), $F(5.95,243.97)=6.13$, $p<.001$, $\eta^2_p=.13$. We examined the effect of SOA on each SF, and the SF difference at each level of SOA, separately. The effect of SOA was significant for each SF (all *F*s>240.35, *p*s<.001, η^2_ps>.96), where the *d'* increased as SOA increased, continuously from 17 to 300 ms (all *p*s<.017). A significant SF difference was also found at each level of SOA (*F*s>11.63, *p*s<.001, η^2_ps>.36), except for 17 ms ($F(2,40)=2.80$, $p=.073$). A similar pattern was revealed for SOAs of 33, 67, 150 and 300 ms, in that the *d'* for broad-SF and low-SF was higher than that for high-SF (all *p*s<.001), but no difference between broad- and low-SF (all *p*s>.702).

------ Figure 3 ------

The interaction between SF information and expression type was also significant (**Figure 4**), $F(6,246)=4.27$, $p<.001$, $\eta^2_p=.10$. The effect of SF information was significant for all expression types (all *F*s>19.23, *p*s<.001, η^2_ps>.49), with a similar pattern found. The broad-SF and low-SF expressions were better recognised than the high-SF (all *p*s<.001), but no significant difference was found between broad- and low-SF (all *p*s>.243). The effect of expression type was, however, significant for broad- and low-SF (both *F*s>5.01, *p*s<.005, η^2_ps>.27), where higher *d'* was found for happiness than pain (both *p*s<.010), but not other expressions. The effect of expression type was not significant for high-SF, *F*(3,39)=1.97, *p*=.134. None of the other interactions were significant, both *F*s<1.78, *p*s>.074.

These results support our hypothesis that the presentation duration affected the processing of SF information, and there was an advantage of low-SF information over high-SF at early stages of processing. However, this effect was not pain-specific.

------ Figure 4 ------

Simple recognition task

The simple hit rates and *d'* were calculated and are reported in **Table 1**. No outlier was found. Data from all the participants were included.

A significant main effect of SF information was found, *F*(2,84)=4.14, *p*=.019, η^2_p=.09. Higher *d'* was found for broad-SF expressions than that for high-SF (*p*=.041), but the difference between low- and high-SF, and the difference between broad- and low-SF, was not significant (both *p*s>.090). None of the other main effect or interactions were significant, all *F*s<1.87, *p*s>.156.

The results for this task did not support our hypothesis – with sufficient presentation duration and processing, high-SF information did not exhibit an advantage over low-SF.

Discussion

In Experiment 1, the backward masking task, enabling very brief SOAs, found an advantage of low-SF over high-SF information, which supports our hypothesis that the high-SF filtered expressions required more time to be reliably recognised than those presented by low-SF or broad-SF information. This pattern was found for both pain and core emotions. Expression differences were also found, however, in that facial expressions of pain were recognised less accurately than happiness when using low-SF information. This suggests a less pronounced low-SF advantage for pain than happiness when presented briefly. However, the simple recognition task showed that, without any time constraints, low- and high-SF information was equally informative for expression recognition, and pain was recognised as accurately as core expressions. Differences among other expressions (e.g. fear and neutral) were not observed.

Together, these findings suggest that the low-SF advantage could stem from the temporal aspect. However, it is unclear whether the low-SF information is processed *faster* or *earlier* than high-SF information, as Experiment 1 was not directly designed to explore this. Thus, a second experiment was conducted, where we sought to consider the temporal dynamics of SF information using a potentially more nuanced approach to carefully unpick the early processing stages – information extraction and decoding – in the recognition of facial expression. Experiment 2 examined the stage at which low-SF information precedes high-SF, and the point at which low-SF information loses its advantage. Moreover, since Experiment 1 found pain expressions might be more difficult to recognise than core emotions, Experiment 2 also explored further whether pain is indeed more difficult to recognise.

Experiment 2

Early visual processing involves extracting information from a stimulus and decoding of specific visual input [13,34,39]. Based on Experiment 1, pain-related information might be more difficult to extract from facial expressions or more difficult to decode than core emotions, such as happiness. We adopted an analytical approach to unpacking the early perception and considered these processes separately. Two modified backward masking tasks were employed, aimed to consider the extraction and the decoding process of pain-related information and compare with core emotions.

To achieve this, target presentation durations and the target-mask SOAs were manipulated. In this experiment, the target-mask SOAs were no longer identical to the target presentation durations. Instead, they consist of two parts: the presentation duration of a target face and a gap between the target offset and the mask onset (see **Figure 4**). In this way, the presentation duration of targets allows observers to view the image and extract available information, and the SOA between the target and the mask determines the uninterrupted latencies required by decoding (i.e. perceptual analysis) of the visual input [4,29]. The multiple SOAs within each task allowed the disruption of the decoding of the target expression at various time points and examined the corresponding visual percept while keeping the target stimulus presentation duration unchanged. By comparing the two tasks, it is possible to directly examine the temporal dynamics of the processing of SF information at an early stage. This could also help to reveal the possible mechanisms underlying why the recognition of pain was more difficult than core emotions, i.e., is pain-related information more difficult to extract or decode? We hypothesised that low-SF information would require less time to extract and decode than high-SF in the recognition of facial expressions of pain and core emotions. In addition, we expected to observe that the recognition of pain would be less accurate than core emotions during early processing.

Method

Participants

An additional forty healthy adult participants (24 females and 16 males) were recruited (mean age=27.79, SD=5.55) from the University of Bath. The recruitment methods and exclusion criteria were the same as for Experiment 1. Ethics committee approval was granted, and informed consent was obtained from each participant. All the participants were financially compensated for their time.

Design

Two modified backward masking tasks (i.e. Task A and Task B) were conducted, both of which used a within-groups design. In both tasks, the independent variables were the target-mask SOA (which varied depending on the task, see below for details), the type of SF information (i.e. broad-, low- and high-SF), and expression (i.e. pain, fear, happiness and neutral). The dependent variable was the recognition accuracy.

Tasks

Tasks A and B employed the same backward masking paradigm but used different parameters of the target presentation duration and target-mask SOA. To ensure that the target presentation duration corresponds to information extraction and allows minimal decoding, extremely brief presentation durations were used [18,29,36]. The target face presentation duration was 17 ms in Task A and 33 ms in Task B. In both tasks, the target-mask SOAs were 33, 67, 150, 300 and 1000 ms. In this way, a gap of varied time lengths occurred between target and mask faces in the two tasks (Task A: 17, 50, 133, 283 and 983 ms; Task B: 0, 33, 117, 267 and 967 ms). Both tasks required participants to recognise the target face expression. We used 1000 ms as the largest SOA in both tasks because results from Experiment 1 suggest that adequate processing of SF information requires more than 300 ms, and previous studies indicate that some neural responses to emotional faces can take up to 1000 ms or more from stimulus onset [3].

Both tasks (A and B) followed a similar procedure to that used in Experiment 1 (see **Figure 5**), including the same stimuli for the target and the mask. In both tasks, each participant completed 960 trials (i.e. 96 target stimuli, 5 different SOAs, each repeated twice) with a break after every 192 trials. The stimuli were presented in a random order in both tasks. The order of the tasks was counterbalanced between participants. Since each task took 40-50 minutes to complete, participants completed the tasks on two separate occasions (same time on two consecutive days). Practice sessions were completed prior to each task (i.e., both testing days), and consisted of 10 trials. The target face stimuli in practice were randomly selected from the stimulus set for each participant.

------ Figure 5 ------

Data preparation and analysis

The estimated sensitivity (*d'*) was calculated for both tasks, and served as the dependent variable. Data from Task A and B were analysed together. The data of *d'* were entered into a 2 × 5 × 3 × 4 (Target Presentation Duration [17, 33 ms] × SOA [33, 67, 150, 300, 1000 ms] × SF Information [broad-, low-, high-SF] × Expression [fear, happiness, neutral, pain]) ANOVA.

Two participants (one female and one male) did not complete both tasks in this experiment, and so were excluded. Final data for this analysis were from a sample of 38 participants. Data were first screened for invalid responses made within 200 ms since the stimulus onset. For completeness, after removal of invalid trials (2.68% of all trials), the simple hit rates were calculated and are reported in the Supplement. The data were normally distributed with z-scores of skewness and kurtosis between -1.96 and 1.96. A large number of trials were also included in both Task A and Task B. We, therefore, calculated average RT for the first and second half of trials. The Spearman-Brown correlation was .92 and .89 for Task A and Task B, respectively, indicating good internal consistency across the testing phases. No significant difference was found between the average RT for the first and second half of trials for both tasks (Task A: $t(37) = 1.10$, $p = .28$, Cohen's $d = .18$; Task B: $t(37) = -1.56$, $p = .13$, Cohen's $d = -.25$). In addition, no difference was in RT performance between tasks completed on each testing day ($t(37) = -1.05$, $p = .30$, Cohen's $d = -.17$).

Results

Means and *SDs* of *d'* in each condition of Task A and B are presented in **Table 2 and 3**, respectively.

------ Table 2 and 3 ------

Statistical analysis revealed significant main effects for all variables: Target Presentation Duration ($F(1,37)=15.10$, $p<.001$, $\eta^2_p=.29$), SOA ($F(2.59,95.66)=523.76$, $p<.001$, $\eta^2_p=.93$), SF Information ($F(1.36,50.26)=674.72$, $p<.001$, $\eta^2_p=.95$) and Expression ($F(3,111)=16.43$, $p<.001$, $\eta^2_p=.31$).

Significant two-way interactions were also found: Target Presentation Duration × SF Information ($F(1.26,46.77)=29.39$, $p<.001$, $\eta^2_p=.44$) and SOA × SF Information ($F(4.61,170.58)=38.30$, $p<.001$, $\eta^2_p=.51$). However, these should be interpreted in light of a significant 3-way interaction between Target Presentation Duration × SOA × SF Information ($F(7.12,263.28)=7.88$, $p<.001$, $\eta^2_p=.18$; see **Figure 6**). To explore this three-way interaction, separate analysis was conducted for each type of SF information. The interaction between Presentation Duration × SOA was significant for high-SF ($F(4,148)=10.35$, $p<.001$, $\eta^2_p=.22$). When presented for 17 ms, *d*' increased with SOAs from 33 to 150 ms (all *p*s<.007), whereas when presented for 33 ms, *d*' increased SOA was found from 67 to 300 ms (all ps<.006). These two-way interactions were not significant for broad- and low-SF (all Fs<2.38, ps>.13).

------ Figure 6 ------

Significant interactions were also found for Expression × SOA (F(12,444)=5.62, p<.001, η^2_p=.13) and Expression × SF Information (F(4.50,166.45)=7.89, p<.001, η^2_p=.18). Again, these should be interpreted in light of an additional 3-way interaction between Expression × SOA × SF Information (F(13.34,493.59)=1.85, p=.033, η^2_p=.05; see **Figure 7**). To explore this three-way interaction, separate analyses were conducted for each type of SF information. The interaction of Expression × SOA was significant for broad-SF and low-SF (both Fs>3.92, ps<.001, η^2_ps>.09), but not high-SF (F(12,456)=1.18, p=.299). The patterns were somewhat variable but seemed to suggest that pain was less accurately recognised. Specifically, when presented by broad-SF, pain was recognised less accurately when the SOA was 33 (pain<fear and neutral, both ps<.024), 67 (pain<fear, happiness and neutral, all ps<.015) and 1000 ms (pain<happiness, p=.020). When presented by low-SF, recognition of pain, and later fear, was less accurate, in particular for SOAs of 67 (pain<fear, happiness and neutral, all ps<.001), 150 (pain and fear < happiness and neutral, all ps<.038) and 1000 ms (pain and fear < happiness, both ps<.001). When presented by high-SF information, neutral was recognised more accurately than other expressions (all ps<.001), although this did not vary by SOA.

------ Figure 7 ------

No other interactions were significant (all Fs<2.85, ps>.058).

The results of this experiment support our hypothesis that low-SF information required less time to extract and decode than high-SF. Whilst this effect is not pain-specific, the recognition of pain was shown to be less accurate than core emotions, in particular during early processing, which also supports our hypothesis.

Discussion

Experiment 2 showed that increasing the presentation duration facilitated the recognition of facial expressions presented by high-SF information, but not those presented by broad- or low-SF information. This suggests that even an extremely short exposure of 17 ms is time adequate enough to extract useful information from broad- and low-SF. As expected, information extraction from high-SF required more time. Whilst this pattern was found for both pain and core emotions, a significant pain-related effect was also found. Specifically, pain was recognised less accurately than core emotions, in particular at early stages of processing, and when presented by broad- and low-SF information. Since this effect did not depend on presentation duration, it suggests that pain expressions may require more time to decode than core emotions.

General Discussion

The time course of SF information processing in the recognition of facial expressions of pain, along with emotional expressions, was explored using a backward masking paradigm. Low-SF information had a dominant role in early expression perception, which is in line with previous findings of a low-SF advantage for pain-related information [44]. This suggests a potential advantage in naturally degraded visual conditions for pain expressions, as faces viewed at distance or in the periphery lack fine-detailed high-SF information [36]. Moreover, we found that low-SF and high-SF information were equally informative for pain expression perception when no time constraint was applied (Experiment 1 Simple recognition task). This suggests that the advantage of low-SF information indwells in the temporal aspect of processing. Indeed, in our second experiment, where the temporal dynamics of SF information processing in expression recognition was explored, the lack of synchronisation of SF started from a very early stage of information extraction – the extraction of characteristic information from high-SF elements was slower than that from low-SF. Thus, the decoding of high-SF input may not only take more time to accomplish but also happen at a relatively later stage of processing than low-SF.

This asynchrony between low- and high-SF supports the coarse-to-fine hypothesis that the overall affective quality takes precedence over the fine-details in expression perception. And that this extends to the expressions of pain. This low-SF prioritisation could have a social advantage, especially in environments where vision is constantly changing. Expressions may be viewed as a fleeting glance, because faces can be hidden by competing visual inputs (e.g., objects, scenes, other expressions). It would, therefore, be beneficial for the coarse overall affective quality of facial expressions to be fed-forward, to enable the rapid detection of threat. Fine-detailed high-SF analysis is more complex, and understandably takes longer to process. Like other core emotions, it seems that pain expressions share this feature, and that coarse information about pain is prioritised over fine details.

Whilst the coarse features of pain expressions are prioritised, and in a similar way to core emotions, the current study also suggests that there are differences between pain and core emotion expressions. Our two experiments illustrate that the facial expressions of pain (i.e. broad-SF intact face stimuli) could be successfully decoded within 150 ms, even when the presentation duration was as brief as 17 ms. However, when compared to fear, happiness and neutral expressions, the presentation duration and SOA required for successful recognition of pain appeared to be more difficult to achieve. This finding extends the results reported in previous studies, that the recognition of pain might not be as accurate as found for core emotions (hit rates around 70% vs. 80%, respectively) [20,32,38,44]. It confirms previously reported absolute times required for recognition of core emotions (i.e. fear, happiness) [7,14,28], but also suggests that pain expressions are not processed as fast as core emotions. Interestingly, this study suggests this may be due to a difference in early expression detection, as in the absence of time constraints pain was recognised as accurately as core emotions, and regardless of SF information. Moreover, since this pain-related difference was not affected by the presentation duration but target-mask SOA, this suggests pain information is not more difficult to extract, but instead requires more time to decode. Whilst it remains unclear why, one possible reason could be that facial pain expressions encode both sensory and affective components [22], and so are more complex, thus requiring extra processing time. Another possibility is that pain expressions are less frequently observed in social encounters comparing to core emotions (e.g. happiness or smile face). According to the frequency-of-occurrence hypothesis [6], the corresponding mental representation of less frequently encountered expressions would be less accessible, and the recognition more difficult.

Some unexpected results were also found. For example, the low-SF advantage was found for all expressions, which contradicts what we found previously [44], i.e. the low-SF advantage was pain specific and only found for one other core emotion, namely disgust. This may be because the influence of SF information on expression perception is dependent on the task being performed. In our previous study, expressions (pain, neutral, and six core emotions) were presented for a fixed time length (300 ms) without using any mask, whereas the current study focused on the time course of SF exposure and used critical presentation duration and/or the SOA, which involved different activities. Another counter-intuitive outcome was the failure to find a strong happiness advantage, despite previous studies generally reporting that happiness is easier to recognise [e.g., 31,38]. Although various reasons for the happiness advantage have been proposed [7], it remains unclear how robust this effect is, when it is most likely to occur, and what function it would serve. The current study suggests that one reason could be linked to a disruption in the recurrent processing of target expressions, which might lead to the happiness advantage. Indeed, such disruption could occur both in the backward masking task [25], or when recurrent processing was not crucial for success (i.e., Experiment 1 simple recognition task), leading to no advantage for happiness. Future studies could consider whether the representation of a happy or smiling face forms differently from other expressions, and whether the happiness representation is better retained in short term memory and/or used to make inferences about the emotional content.

There are also some limitations to be considered. The experimental lab-based methodology used here to investigate the dynamics of pain recognition is artificial, and so translation to natural setting is limited. For example, we used posed, prototypical facial expressions of pain and core emotions as stimuli. Although the recognition of posed expressions has been found to reveal comparable performance and accuracy with genuine facial expressions [7], there is evidence that actors' representations of pain differ in some configurations and dynamic features from spontaneous expressions [2]. A related issue is that the visual percept of facial expressions is much more complex in natural conditions, and affected by context. It is also rare for individuals to view expressions in isolation, e.g. pain is often accompanied by fear. Indeed, the difference between pain and fear was only found in Experiment 2, at a very early stage of processing. Although this study considered how our visual percept of facial pain expressions changes in time, the expression itself remained unchanged – they were static, rather than dynamic images. In reality, both our visual percept and the expressions change dynamically. It would be interesting to explore whether similar patterns would emerge for dynamic stimuli. Despite these limitations, there are strengths with the experimental behavioural approach adopted here, including the high degree of precision and control that is not possible within naturalistic settings. The current study highlights that in addition to the component approach to expression encoding, we should also consider other types of perceptual information available.

Whilst there is clearly a need to be cautious about generalisation, it is possible to consider potential implications, including relevance to clinical practice. Basic experimental investigation such as this can help inform the development of automated expressions detection systems, where the processing of such detail is possible. To date, pain detection studies often consider specific facial codes – however, correct identification of such codes requires detailed processing, which may not be possible in a rapidly changing environment. Similarly, this focus has proved difficult when using such system within older age groups, as facial features make identification more difficult [16]. This could potentially be overcome by focussing on low-SF information, where such details are less relevant. It would be interesting to consider how SF information processing contributes to the estimation of pain intensity. Decoding of facial expressions of pain consists of multiple processes that serve different functions, such as pain recognition, severity estimation and authenticity detection. One of the key issues in clinical practice is the underestimation of suffers' pain intensity from their facial expressions [21,30]. It would be interesting to discover how we visually perceive the pain intensity in terms of SF analysis, and how different SF information could inform the underestimation of pain intensity. Such knowledge may, therefore, help facilitate the identification of pain, and reduce errors in expression decoding.

In summary, our results demonstrated that the low-SF information plays a key role in the early perception of facial expressions of pain that is refined as the high-SF information integrates gradually. The low-SF provides early, quickly accessible information, and the high-SF slower information is accessed later. Moreover, this is not specific for the recognition of pain, but also for core emotions (i.e. fear, happiness) and neutral expressions. This suggests that, in terms of SF analysis, the facial expressions of pain share similar visual perceptual properties with these core emotions. However, it also appears that pain expressions are slower and more difficult to decode, which may be due to the multidimensional nature of facial pain expressions. The current study highlights the benefits of taking a global approach to the exploration of pain expression recognition, and in particular, identify the way different types of perceptual information are used in the communication of pain.

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Figure legends:

Figure 1. Sample stimuli of facial expression images of pain at each SF level (from left to right: broad-SF, low-SF and high-SF) It should be noted that the size of the image, viewing distance, printing quality and monitor contrast would influence the appearance and perception of SF information. During experiments, we have controlled for these factors. The original images are obtained from the STOIC database [35], and the SF-filtered images are reproduced with permission.

Figure 2. Illustration of trial procedure for the backward masking task used in Experiment 1

Figure 3. Experiment 1 – Mean sensitivity (*d'*) for backward masked expressions at each SF level with each SOA (error bars represent *SEM*)

Figure 4. Mean sensitivity (*d'*) for fear, happiness, neutral and pain at each SF level in Experiment 1 (error bars represent *SEM*)

Figure 5. Details of trial procedure of the modified backward masking tasks used in Experiment 2

Figure 6. Experiment 2 – Mean sensitivity (*d'*) to expressions presented by each type of SF information in Task A (17 ms presentation) and Task B (33 ms presentation) with each SOA (error bars represent *SEM*)

Figure 7. Mean sensitivity (*d'*) to each expression presented by each type of SF information with each SOA in Experiment 2 (error bars represent *SEM*) * indicates significant differences between expressions; for High-SF, the main effect of Expression

revealed higher *d’* for neutral compared to other expressions, and the interaction Expression × SOA was not significant for high-SF

Table legends:

Table 1 Experiment 1: Mean (SD) of the *d'* for each expression at each SF level with each SOA in the backward masking task and the simple recognition task.

Table 2 Experiment 2 – Task A: Mean (SD) of the *d'* for expressions at each SF level with each SOA.

Table 3 Experiment 2 – Task B: Mean (SD) of the *d'* for expressions at each SF level with each SOA.

Table 2 Experiment 1: Mean (SD) of the *d'* for each expression at each SF level with each SOA in the backward masking task and the simple recognition task.

	17 ms	33 ms	67 ms	150 ms	300 ms	Simple Recognition
Fear						
Broad-SF	0.47 (0.62)	0.97 (0.73)	1.79 (0.92)	2.68 (0.69)	2.85 (0.56)	3.03 (0.41)
Low-SF	0.38 (0.56)	1.05 (0.74)	1.78 (0.88)	2.66 (0.80)	2.88 (0.58)	3.01 (0.53)
High-SF	0.23 (0.45)	0.48 (0.53)	1.04 (0.82)	2.11 (0.94)	2.55 (0.71)	2.86 (0.49)
Happiness						
Broad-SF	0.52 (0.51)	1.01 (0.81)	2.01 (0.95)	2.88 (0.57)	3.07 (0.41)	3.12 (0.58)
Low-SF	0.57 (0.51)	0.75 (0.64)	1.81 (0.76)	2.84 (0.61)	3.06 (0.43)	3.14 (0.39)
High-SF	0.17 (0.59)	0.41 (0.57)	1.14 (0.68)	2.27 (0.62)	2.71 (0.55)	3.00 (0.59)
Neutral						
Broad-SF	0.42 (0.49)	0.78 (0.75)	1.77 (0.91)	2.68 (0.71)	3.02 (0.51)	3.17 (0.45)
Low-SF	0.37 (0.61)	0.80 (0.94)	1.76 (0.80)	2.68 (0.71)	2.90 (0.50)	3.07 (0.51)
High-SF	0.52 (0.66)	0.72 (0.75)	1.15 (0.77)	2.14 (0.83)	2.54 (0.71)	2.97 (0.63)
Pain						
Broad-SF	0.43 (0.49)	0.83 (0.73)	1.71 (0.92)	2.62 (0.73)	2.87 (0.52)	3.03 (0.38)
Low-SF	0.31 (0.54)	0.62 (0.68)	1.69 (0.79)	2.53 (0.86)	2.90 (0.49)	3.06 (0.44)
High-SF	0.28 (0.48)	0.64 (0.59)	1.08 (0.74)	2.17 (0.77)	2.59 (0.68)	2.87 (0.47)

Table 2 Experiment 2 – Task A: Mean (SD) of the *d'* for expressions at each SF level with each SOA.

		33 ms	67 ms	150 ms	300 ms	1000 ms
Fear	Broad-SF	0.97 (0.69)	1.81 (0.99)	2.58 (0.76)	2.76 (0.58)	2.78 (0.63)
	Low-SF	0.81 (0.61)	1.74 (0.75)	2.19 (0.71)	2.66 (0.66)	2.62 (0.60)
	High-SF	0.18 (0.47)	0.33 (0.47)	0.57 (0.46)	0.57 (0.63)	0.77 (0.68)
Happiness	Broad-SF	0.83 (0.75)	1.84 (0.88)	2.69 (0.70)	2.79 (0.65)	2.96 (0.56)
	Low-SF	0.73 (0.53)	1.92 (0.81)	2.50 (0.71)	2.79 (0.65)	2.95 (0.54)
	High-SF	0.04 (0.53)	0.17 (0.47)	0.49 (0.48)	0.60 (0.71)	0.67 (0.74)
Neutral	Broad-SF	1.08 (0.96)	1.85 (1.00)	2.66 (0.76)	2.84 (0.78)	2.92 (0.72)
	Low-SF	0.76 (0.69)	1.89 (0.92)	2.48 (0.86)	2.82 (0.76)	2.75 (0.78)
	High-SF	0.18 (0.49)	0.55 (0.62)	0.87 (0.76)	1.03 (0.85)	1.03 (0.85)
Pain	Broad-SF	0.71 (0.72)	1.35 (0.86)	2.46 (0.63)	2.68 (0.52)	2.83 (0.47)
	Low-SF	0.70 (0.73)	1.21 (0.82)	2.24 (0.78)	2.54 (0.58)	2.68 (0.57)
	High-SF	0.06 (0.56)	0.09 (0.69)	0.40 (0.53)	0.44 (0.67)	0.74 (0.79)

Table 3 Experiment 2 – Task B: Mean (SD) of the *d'* for expressions at each SF level with each SOA.

		33 ms	67 ms	150 ms	300 ms	1000 ms
Fear	Broad-SF	1.19 (0.79)	1.97 (0.83)	2.53 (0.70)	2.63 (0.64)	2.96 (0.54)
	Low-SF	1.18 (0.40)	1.80 (0.92)	2.53 (0.72)	2.70 (0.64)	2.62 (0.62)
	High-SF	0.42 (0.40)	0.55 (0.50)	0.95 (0.70)	1.38 (0.78)	1.53 (0.83)
Happiness	Broad-SF	0.95 (0.71)	2.17 (0.76)	2.75 (0.70)	2.93 (0.56)	3.07 (0.48)
	Low-SF	0.99 (0.82)	1.88 (0.82)	2.77 (0.65)	2.88 (0.62)	2.94 (0.55)
	High-SF	0.40 (0.45)	0.39 (0.65)	1.13 (0.85)	1.53 (0.85)	1.73 (0.79)
Neutral	Broad-SF	1.12 (0.76)	1.98 (0.84)	2.50 (0.89)	2.80 (0.82)	2.89 (0.82)
	Low-SF	0.99 (0.66)	1.89 (1.08)	2.74 (0.76)	2.82 (0.85)	2.76 (0.79)
	High-SF	0.77 (0.59)	0.70 (0.72)	1.48 (1.02)	1.60 (0.92)	1.71 (0.93)
Pain	Broad-SF	0.86 (0.59)	1.79 (0.77)	2.65 (0.60)	2.80 (0.41)	2.92 (0.51)
	Low-SF	0.80 (0.67)	1.54 (0.83)	2.43 (0.70)	2.80 (0.62)	2.73 (0.49)
	High-SF	0.40 (0.56)	0.61 (0.63)	1.21 (0.76)	1.45 (0.69)	1.65 (0.82)

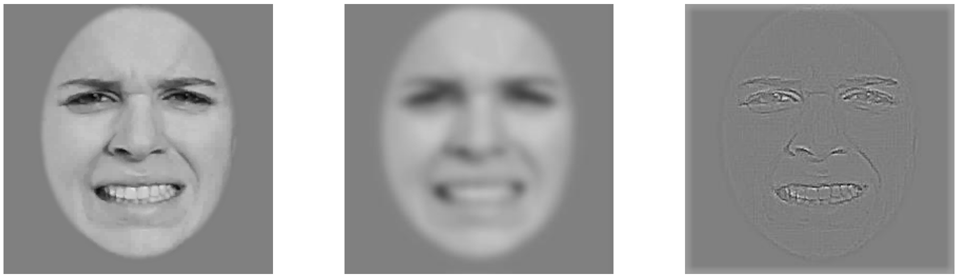

Figure 1. Sample stimuli of facial expression images of pain at each SF level (from left to right: broad-SF, low-SF and high-SF) It should be noted that the size of the image, viewing distance, printing quality and monitor contrast would influence the appearance and perception of SF information. During experiments, we have controlled for these factors. The original images are obtained from the STOIC database [35], and the SF-filtered images are reproduced with permission.

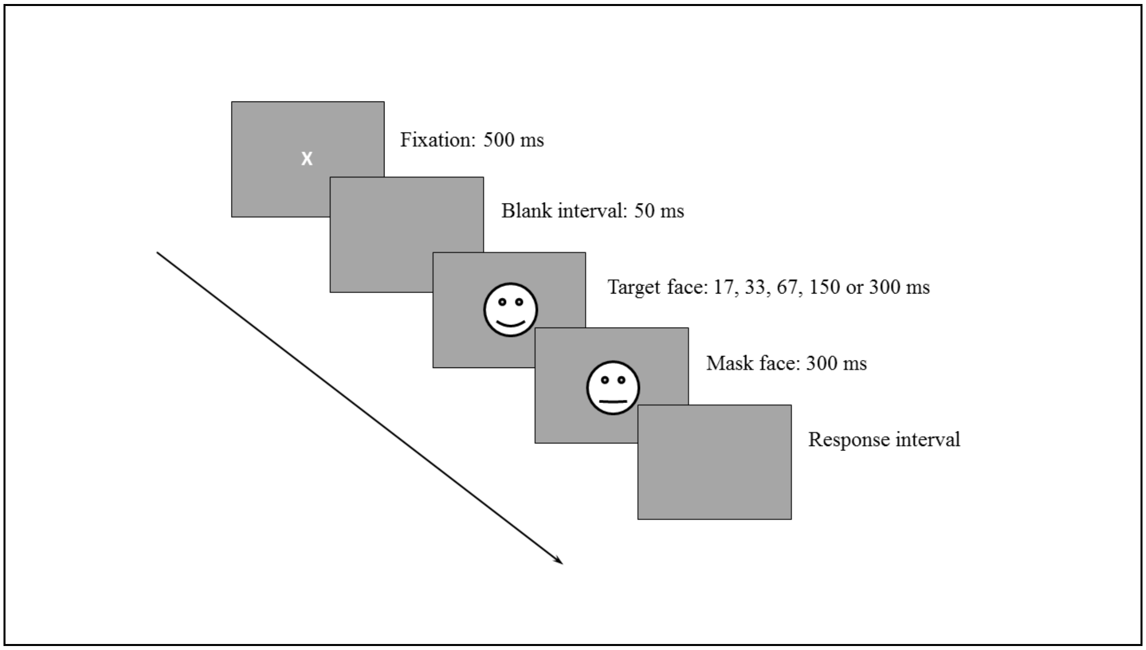

Figure 2. Illustration of trial procedure for the backward masking task used in Experiment 1.

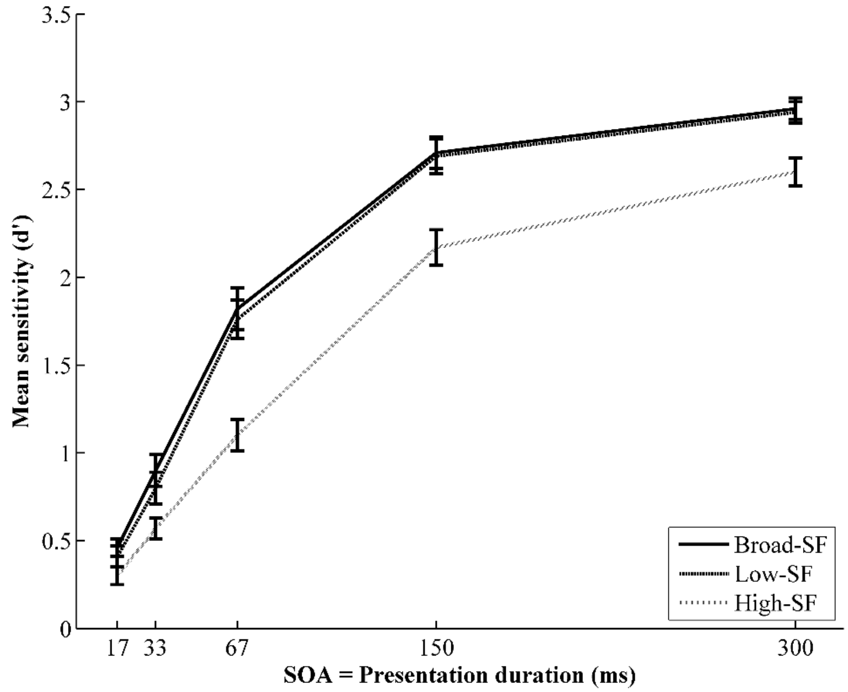

Figure 3. Experiment 1 – Mean sensitivity (*d'*) for backward masked expressions at each SF level with each SOA (error bars represent *SEM*)

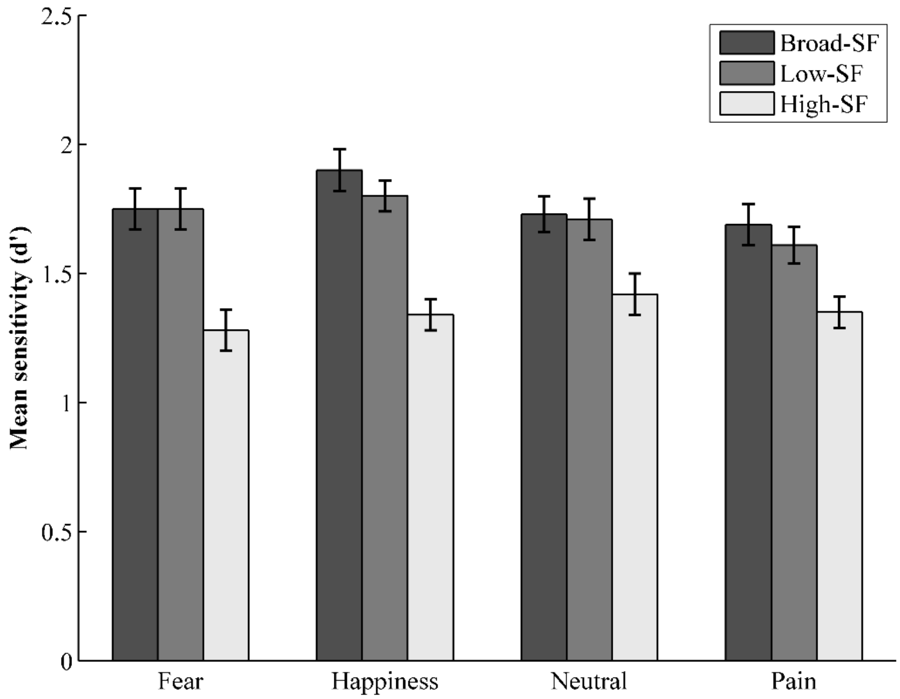

Figure 4. Mean sensitivity (*d'*) for fear, happiness, neutral and pain at each SF level in Experiment 1 (error bars represent *SEM*).

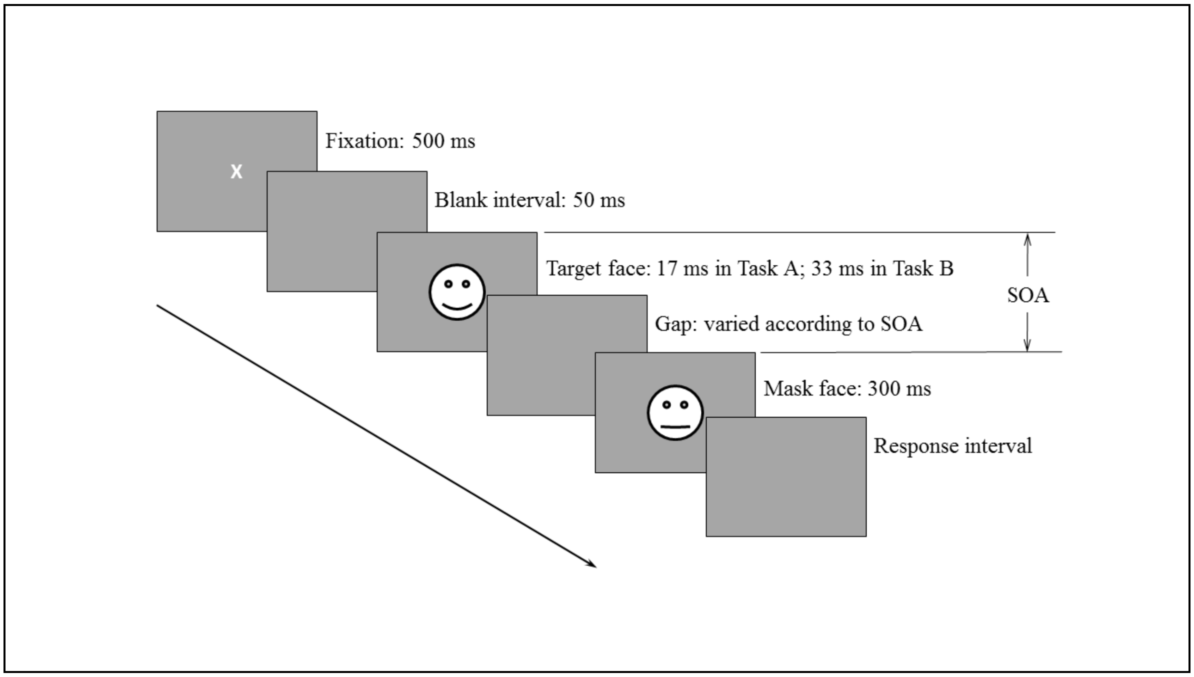

Figure 5. Details of trial procedure of the modified backward masking tasks used in Experiment 2

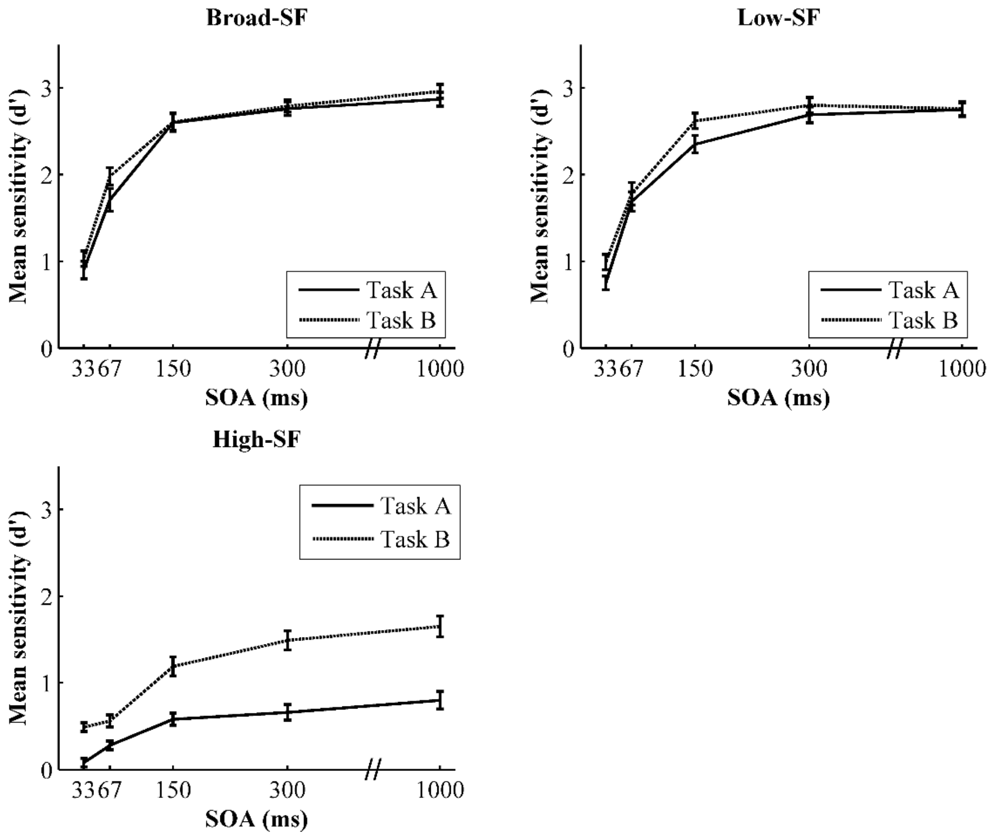

Figure 6. Experiment 2 – Mean sensitivity (*d'*) to all the expressions presented by each type of SF information in Task A (17 ms presentation) and Task B (33 ms presentation) with each SOA (error bars represent *SEM*)

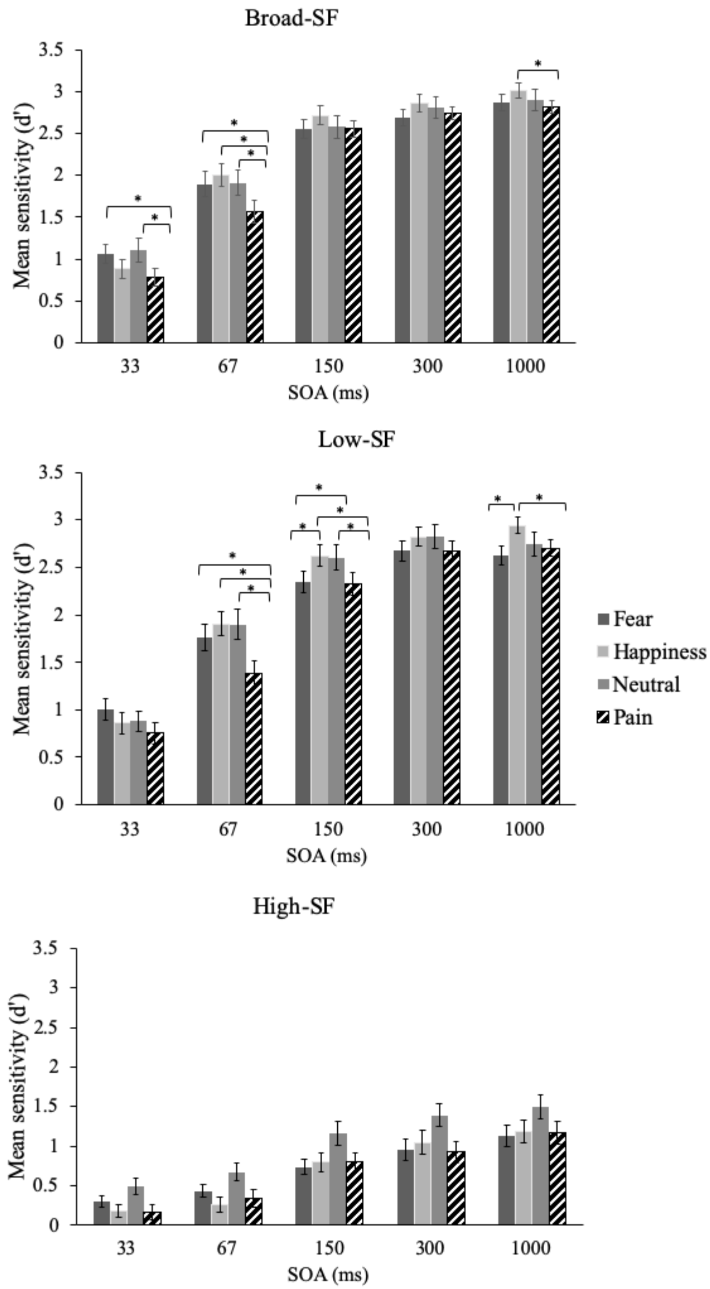

Figure 7. Mean sensitivity (*d'*) to each expression presented by each type of SF information with each SOA in Experiment 2 (error bars represent *SEM*) * indicates significant differences between expressions; for High-SF, the main effect of Expression revealed higher *d'* for neutral compared to other expressions, and the interaction Expression × SOA was not significant for high-SF