Target meta-awareness is a necessary condition for physiological responses to masked emotional faces: evidence from combined skin conductance and heart rate assessment.

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Abstract

Much heated debate surrounds the extent to which we can process emotional stimuli without awareness. In particular the extent to which masked emotional faces can elicit changes in physiology measurements, such as heart rate and skin conductance responses, has produced controversial findings. In the present study, we aimed to determine whether briefly presented faces can elicit physiological changes and, specifically, whether this is due to unconscious processing. We measured and adjusted for individual differences in the detection threshold using both receiver operating characteristics and hit rates. For this we also used a strict Bayesian assessment of participant thresholds. We then measured physiological responses to threshold adjusted emotional faces and for hits, misses and post-binary subdivisions of target meta-awareness. Our findings based on receiver operating characteristics revealed that, when faces were successfully masked there were no significant physiological differences in response to stimuli with different emotional connotations. In contrast, when targets were masked based on hit rates we did find physiological responses to masked emotional faces. With further analysis we found that this effect was specific to correct detection of angry and fearful faces and that increases in experienced arousal were associated with higher confidence ratings for correct detection of these stimuli. Collectively, our results do not support the notion of unconscious processing when using markers of physiological processes. Rather they suggest that target meta-awareness is a necessary condition for -- and possibly determined by -- physiological changes in response to masked emotional faces.

Introduction

Can emotional responses be experienced without awareness? Is it possible that we can be scared, happy, sad, or simply aroused without being consciously aware of what has triggered this experience? These questions are as tantalizing in modern psychological research today (Pessoa, 2017) as they were in psychoanalytic theory almost one hundred years ago (Freud, 1923/1962). In the last thirty years, psychologists have devoted significant resources in providing an answer (Brooks et al., 2012). The method typically employed in the area (van der Ploeg et al., 2017) is to present very brief (6.25 to 83.33 ms) emotional stimuli preceded (forward masking) and/or followed (backward masking) by non-emotional stimuli used in order to mask - i.e., make *invisible* - the emotional targets (Bachmann & Francis, 2013). Neural, physiological or behavioural responses to these masked targets are suggested as evidence for unconscious processing (Pessoa & Adolphs, 2010).

This field of research has produced extensive (Brooks et al., 2012), though theoretically controversial, findings (Pessoa, 2005a; 2005b). For example, fMRI activation in emotion processing areas such as the amygdala has been reported in response to masked angry (Nomura et al., 2004), fearful (Liddell et al., 2006) and happy faces (Duan et al., 2010) among other masked stimuli types (Brooks et al., 2012). Masked emotional faces have also been shown to elicit specific markers of bioelectric activity recorded from cortical brain regions (Lu et al., 2011). They have been shown to induce liking and dislike to subsequently presented targets (Winkielman & Berridge, 2004; 2005; Lapate et al., 2014) and direct our attention as visual cues processed without explicit awareness (Yiend, 2010).

The biological preparedness model that has been put forth to explain these neural and behavioural responses suggests that unaware emotional targets can induce changes in physiological processes (van der Ploeg et al., 2017) that enable us to make automatic and involuntary responses to environmental stimuli (LeDoux, 2003). This model suggests that when stimuli confer survival value (Liddell et al., 2006) and social communication value (Hess & Fischer, 2013) and require an instant reaction they do not rely on slow-cortical pathways that enable awareness of the presented visual stimuli to produce a response. Instead they recruit a fast-subcortical pathway to the amygdala that disseminates automatic nervous system arousal and allows us to respond and adapt to our environment without conscious awareness (Pessoa & Adolphs, 2010).

When this theoretical notion was put to the test using physiological assessment such as sweating (skin conductance response) and cardiovascular changes (heart rate and blood pressure) there was evidence of an effect (van der Ploeg et al., 2017) such as higher physiological changes for masked fearful faces (Williams et al., 2004; 2006; Lapate et al., 2014) and threatening pictures (Najstrom & Jannson, 2007) compared to masked neutral stimuli. Nevertheless, the extent to which these findings represent unconscious processing has been extensively debated in the relevant literature. The main critical themes include the presentation of a set duration threshold for masked faces that is assumed “to remain consistently below the detection threshold on all trials and across all participants” (Lähteenmäki et al., 2015; p. 341), the assessment of detection performance using hit rates (Pessoa et al., 2005a; 2005b) and the assertion of unawareness using non-significance (Dienes, 2015).

For example, previous studies presented masked emotional faces for durations spanning from 6.25 to 83.33 ms and compared the concomitant physiological effects to the effects caused by masked neutral faces (presented for the same duration). Signal detection research has suggested that masked emotional faces are more clearly detected than masked neutral faces for set durations (e.g. 16.67 ms) because they confer emotional incongruence with the neutral mask (Calvo & Lundqvist, 2008; Kim et al., 2010). Previous research has also suggested that some participants are able to reliably discriminate what kind of face was presented at 16.67 and 33.33 ms (Pessoa et al., 2005a; 2005b). This sheds doubt on whether previous studies reported results that were indeed indicative of the response to unseen stimuli and suggest that the duration of the masked targets should be adjusted both for per participant and stimuli type differences to ensure truly unconscious presentation.

Hit rates and non-significance for differences to chance-level meta-awareness have also been used in previous studies to assess and assert target awareness respectively (van der Ploeg et al., 2017). In this context, the consensus in previous research has been that if correct detection rate as assessed usually in a post-experimental task (Lähteenmäki et al., 2015) is not significantly different from chance this is evidence that the participants were guessing and were unaware of the presented target (Stanislaw & Todorov, 1999). The first problem with this approach is that hit rates are a possibly biased measure. It allows participants to reply using different subjective criteria. For example, chance-level performance can be the outcome of conservative or liberal detection strategies such as replying seeing a masked face only when one is completely certain a face was presented or replying yes when one is quite unsure that a face was presented (Pessoa et al., 2005a; 2005b). The inclusion of unbiased signal detection measures such as d' and A' that produce a ratio between hits (correct answers) and false alarms (wrong answers) has been suggested as a more reliable alternative for assessing chance-level performance.

In respect to asserting chance-level awareness previous studies compared participant detection performance to absolute chance (e.g., 50%). If the analysis returned non-significant differences from chance the researchers claimed unconscious perception. The important problem with this approach is that "non-significantly different from chance" -- lack of evidence for the alternative hypothesis - is misinterpreted as significantly at-chance and thus as evidence for the null (Overgaard et al., 2013). Previous research has suggested that instead of the traditional frequentist approach, Bayesian inference should be used to assert if performance is significantly at-chance ($B < 1/3$) and infer unconscious processing (Dienes, 2015).

These possible biases shed some doubt to the extent that emotional signals were adequately masked in previous studies. The primary aim of the current report was, therefore, to address these issues and provide necessary methodological conditions to answer whether we can experience physiological changes in response to unconscious emotional faces. To achieve this goal, we pre-experimentally adjusted for per participant and stimuli type differences in detection performance using both hit rates and signal detection theory and we also assessed target meta-awareness using Bayesian significance for chance-level detection performance; furthermore, we analysed separately correct and incorrect responses and target detection confidence responses to masked angry, fearful, sad and neutral faces using combined skin conductance and heart rate recordings.

Methods

Participants

Twenty-five volunteers (thirteen females) participated in the current study. The mean age for the participants was 33.2 years (S.D. = 8.98). The exclusion criteria for the current study were history of head trauma, current medical treatment, current or previous DSM Axis I or II diagnosis and current or previous alcohol/drug abuse - assessed through self-report. Participants were screened before the experiment with the Somatic and Psychological Health Report Questionnaire; participants with scores at or below 1.0 were included; data from one female participant were excluded. The experiment was approved by the Ethics Committee of the School of Psychology of the University of Nottingham.

Facial Stimuli

The facial stimuli used were taken from the dataset created by Gur and colleagues (2002). They included faces with angry, fearful, sad and neutral facial expressions. The stimuli were adjusted for interpupillary distance, transformed to grey scale and resized to a standard 1024x768 pixels resolution. Their luminescence was averaged in SHINE, Matlab Toolbox and Fourier Painter and finally they were spatially aligned and framed into pure white within a cropped circle (Height: 6 cm, Width: 4 cm).

Pilot Stages: Stimuli Pre-Selection

The processed faces were presented to a separate set of participants (n = 17). Stimuli were presented for one second preceded by a fixation cross for three seconds. Pre-target baseline and maximum deferral skin conductance (3 seconds post stimuli offset; van der Ploeg et al., 2017) and heart rate (4 seconds post stimuli offset; Critchley et al., 2005) were recorded during the presentation. After each trial participants were assigned a stimuli classification, a stimuli intensity and a stimuli ambiguity task. A blank inter-screen interval for eight seconds was presented after the engagement tasks to allow skin conductance and heart rate responses to return to baseline.

After collecting the results for this pilot stage, we selected the angry, fearful, sad and neutral stimuli that produced a significant effect ($p \leq .01$) for correct classification of emotional valence. From this subset, we further chose as the most representative examples for their emotional valence thirty angry, fearful and sad stimuli that produced the highest scores in a self-developed percentage based metric (Appendix 1.1; 1.2):

$$IF\ (\%) = ((\frac{(10 - \text{Amb.}) + (\text{Int.})}{2}) * 50) + (\left(\left(\frac{\text{SCR Maximum Deferral}}{\text{Max}\,\{\text{SCR Maximum Deferral Stimuli Type}\}}\right) * 25\right) + ((\frac{\text{HR Maximum Deferral}}{\text{Max}\,\{\text{HR Maximum Deferral Stimuli Type}\}}) * 25))$$

Pilot Stages: Visual Contrast Discrimination

The selected subset of processed faces and a total of forty non-facial blur patterns matched for cropped spatial alignment and luminance were presented to a different set of participants (n = 17). The stimuli were presented for 33.3 ms with backwards masking produced by neutral faces presented for 116.67 ms. Participants were asked to rate their subjective experience of visual contrast after each presentation using ratings on a scale from one (not at all) to ten (intense). Subjective experience of contrast for the non-facial patterns (M = 2.19, S.D = 1.08) was not rated higher than contrast in the face condition (M = 2.23, S.D. = 1.1; $t(16) = 1.41$, $p = .17$; $d = 0.03$; Appendix 2.1) suggesting that differences of visual contrast between the non-facial patterns and the emotional faces, and the neutral masks would not artefactually impact target detection (Bachmann & Francis, 2013) and physiological responses (Kim et al., 2010) in subsequent experimental stages.

Pilot Stages: Adaptation of the Perceptual Awareness Scale

In a final pilot experimental stage, we implemented and tested an initial post-binary adaptation of the Perceptual Awareness Scale (PAS - Sandberg & Overgaard, 2015). We presented a different set of participants (n = 23) with hit rate threshold adjusted masked angry, sad, neutral and no facial stimuli for per participant and stimulus type durations. We assigned participants with a binary detection task (How many stimuli did you see? 1 or 2). Subsequently, for i being the reply to the binary task we asked them to rate their perceptual experience between unsure, possibly i, most likely i and definitely i. We measured skin conductance during the presentation.

We found that no differences in SCR changes were reported between possibly and most likely for any stimulus type and binary response type (hits, misses, correct rejects, false alarms; $p > .05$). On a follow-up stage, we could contact fifteen participants included in the original pilot and asked them to rate the ambiguity between each item on the four-point scale from one (not at all) to ten (intense). Ambiguity between possibly and most likely (M = 6.8, S.D. = .94) was rated significantly higher than any other category combination (F (2.47, 34.51) = 28.63. $p < .01$; $\eta^2 = .67$; Greenhouse-Geisser corrected; Appendix 3.1; 3.2). Based on these findings and in order to avoid possible linguistic ambiguity between these categories we collapsed the four-point scale into a three-point scale including ‘unsure’, ‘possibly’ and ‘definitely’ as subjective measures.

Main Experiment: Physiological Recording and Analysis

During the main experiment skin conductance and heart rate were used to assess physiological responses. Skin conductance responses were measured from the non-dominant hand (index/first and middle/second fingers; Banks et al, 2012) of each participant using disposable Ag/AgCl gelled electrodes. The signals were received by a BIOPAC System, EDA100C in units of microsiemens and recorded in *AcqKnowledge* (Braithwaite et al, 2014). Heart rate was measured via a double finger cuff from the non-dominant hand (ring/third and little/fourth finger) using an ambulatory CNAP^{TM} MONITOR 500 and responses were recorded in beats per minute (bpm) also in *AcqKnowledge*.

To make our data comparable with previous research we used similar analysis parameters. The presence of a phasic skin conductance response was defined as an increase (> .01 μS) with respect to each pre-target baseline occurring 3 second post stimuli offset (van der Ploeg et al., 2017). The presence of a heart rate response was defined as an event-related heart rate peak in beats per minute with respect to each pre-target baseline occurring 4 seconds post stimuli offset (Critchley et al., 2005). The raw signals for both measures were processed using the Derive Phasic from Tonic and manual Dirac Delta (Δ) functions. The data did not require additional smoothing, filtering or transformations (Braithwaite, 2014; p.

10-12). Non-responders for physiological changes were included in the data analysis (Venables & Mitchell, 1996).

Main Experiment: Presentation Testing

The stimuli were presented on a high frequency LED monitor set at 120 Hz (8.33 ms per frame). A Canon G16 camera with 240 Hz refresh rate (4.17 ms) recorded two pilot runs of the experiment and the stimuli presentation was assessed frame by frame; no instances of dropped frames were detected. A self-developed dropped frame report script with one frame (8.33 ms) tolerance threshold was coded in Python and two pilot experimental diagnostic sessions were run (Peirce, 2016). The presenting monitor operated at 8.33 ms refresh rate for checking dropped framed diagnostics and reported no dropped frames; prognostic dropped frame rate was estimated at 1/5000 trials. Experimental stages were, subsequently, run using dropped frames diagnostics and per stimuli presentation frame rate performance of the stimuli presenting monitor; no instances of dropped frames were detected.

Main Experiment: Detection Threshold

In the first part of the main experiment we defined the detection threshold individually per participant and stimulus type. We presented participants with a fixation cross for 3 (±1) seconds. After the fixation cross an angry or fearful or sad or neutral face or a non-facial blur pattern was presented for 8.33 or 16.67 or 25 ms with backward masking by a neutral face presented for 108.33 ms. Twenty angry, twenty sad, twenty neutral and twenty-six non-facial blur patterns were presented for each duration (8.33, 16.67, and 25 ms); presentation order was randomised. Five seconds after each presentation, an on-screen message asked participants to decide how many stimuli were presented during the trial. Participants were asked to press 1 if they saw one face or 2 if the saw two faces (using the keyboard).

To define the detection threshold per participant and stimulus type non-parametric receiver operating characteristics (Zhang & Mueller, 2005) and hit rate performance were calculated separately. The duration of presentation (8.33 or 16.67 or 25 ms) that marked the smallest negative or positive difference from chance per stimulus type was imported separately for ROC and hit rate performance to the main experiment; [.5. - $P_{threshold}$] closest to .5 (Figures 1 & 2). When participants reported equal differences from chance between two thresholds (e.g., 16 ms: .45; 25 ms: .55) the briefer duration was imported in the main stage. This stage was performed for each participant seven days before and at the same time slot as the skin conductance and heart rate responses stage below.

Main Experiment: Skin Conductance and Heart Rate Responses

In the second part of the main experimental stage we tested if, as assessed per participant and stimulus type, the threshold adjusted faces can elicit changes in physiological processes. Participants were invited to the same laboratory space under identical conditions. They took part in two 15-minute experimental sessions separated by a 5 minutes long break; session order was randomised. In both sessions participants were presented with a fixation cross for 3 (±1) seconds. After the fixation cross an angry or fearful or sad or neutral face or a non-facial blur pattern were presented. In one session, the faces were presented for hit rate adjusted durations and in the other session they were presented for ROC adjusted durations (Figure 1). In both sessions, faces were backward-masked with a neutral face presented for 108.33 milliseconds. Five different angry, sad, fearful, neutral and a total of twenty different non-facial blur patterns were presented in each session (Ray et al, 1977) with order randomized (Wiens et al, 2003).

Five seconds after each presentation an on-screen message asked participants to decide how many stimuli were presented during the trial. Participants were asked to press 1 if they saw one face or 2 if the saw two faces, using the keyboard. After this task, participants were asked to rate their confidence for their decision using the adjusted form of the PAS (Ramsoy & Overgaard, 2004). Using conditional branching for *i* being the participant response during the binary signal detection task participants were asked how they would rate their confidence for their reply between one (unsure), two (possibly i) and three (definitely i). Participants were allowed six seconds to complete each task. A blank screen for eight seconds was presented after the completion of the engagement tasks to allow physiological measures to return to baseline (Cacioppo et al., 2007).

Figure 1: Experimental Conditions during Physiological Assessment

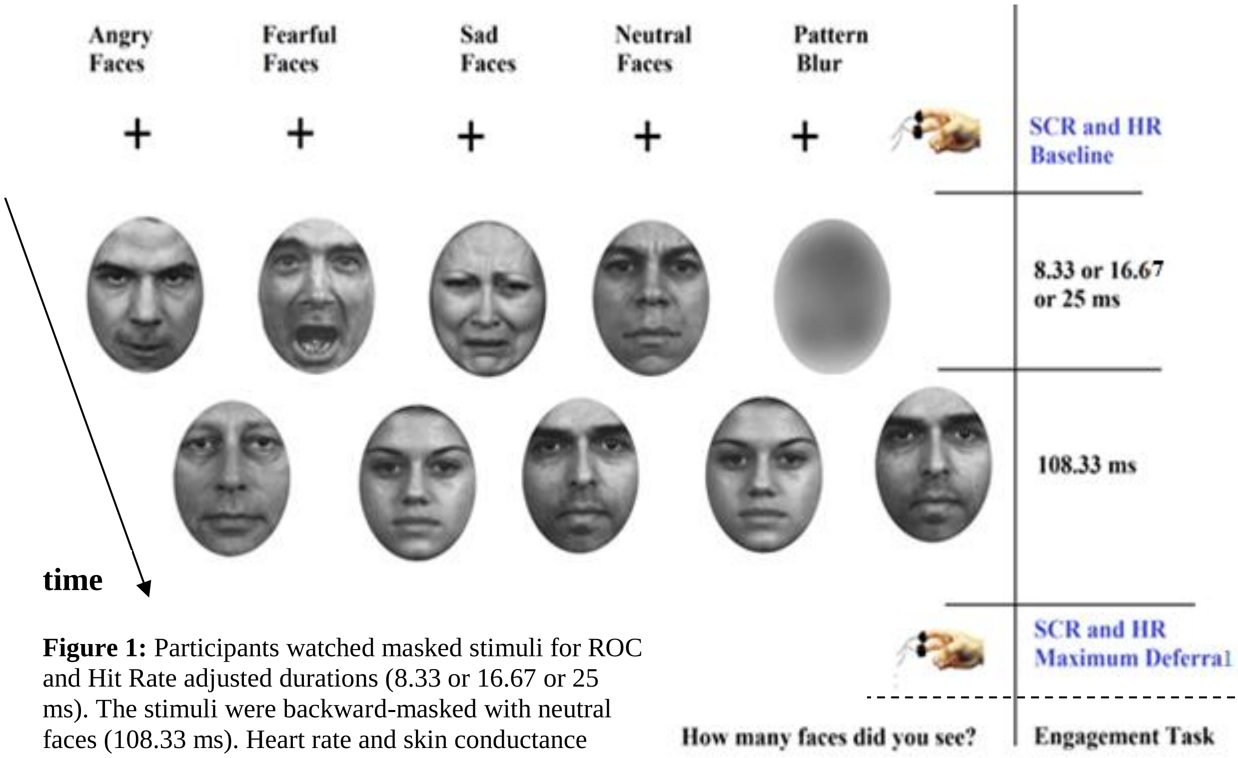

Figure 1: Participants watched masked stimuli for ROC and Hit Rate adjusted durations (8.33 or 16.67 or 25 ms). The stimuli were backward-masked with neutral faces (108.33 ms). Heart rate and skin conductance responses were measured during the presentation.

Results

ROC Threshold Adjusted Faces:

Signal Detection

We wanted to explore if ROC threshold adjusted stimuli were processed significantly at-chance (A = .5). A uniform Bayesian analysis with corrected degrees of freedom (df < 30; SE = (SE x ((1 + $\frac{20}{df x df}$))) (Berry, 1996)) was run using the Dienes calculator (2014; 2015) to assess chance-level processing; B < 1/3. The credible intervals were defined at -.05 (lower bound) and .05 (higher bound) with 0 representing absolute chance-level performance. Detection performance using non-parametric receiver operating characteristics revealed significant evidence for overall chance-level processing (M = .49, S.D. = .03; S.E. = .01 (.01); B = .29). When tested separately, however, individual stimuli types indicated insensitivity to chance-level processing (1/3 > B < 3; Figure 2).

Physiological Responses

The ROC Threshold adjusted faces did not lead to significant differences between different emotions in terms of respective skin conductance (F (4, 92) = 1.51, p = 21; η^2 = .06) or heart rate responses (F (4, 92) = .34, p = .85; η^2 = .02). Angry (SCR: M = .01, S.D. = 01; HR: M = .37, S.D. = .64), fearful (SCR: M = 01, S.D. = 01; HR: M = .39, S.D. = .63), sad (SCR: M = 01, S.D. = 01; HR: M = .36, S.D. = .55) and neutral faces (SCR: M = 01, S.D. = 01; HR: M = .36, S.D. = .51), and pattern blur stimuli (SCR: M = 01, S.D. = 01; HR: M = .53, S.D. = .65) were not processed differently in terms of physiological arousal.

Hit Rate Adjusted Faces:

Signal Detection

To explore if hit rate adjusted faces were processed significantly at chance-level a uniform Bayesian analysis was run using the Dienes calculator and the exact same parameters used for ROC adjusted faces; credible intervals set at - 5% to 5% with standard error corrected for degrees of freedom (df < 30). Detection performance using hit rates showed insensitivity for chance-level processing (M = 49.01%, S.D. = 2.85%; S.E. = .1 (.2); B = .55); sensitivity for individual stimuli can be seen in Figure 2.

Figure 2: Detection Performance (A) and Thresholds (B) for Different Faces

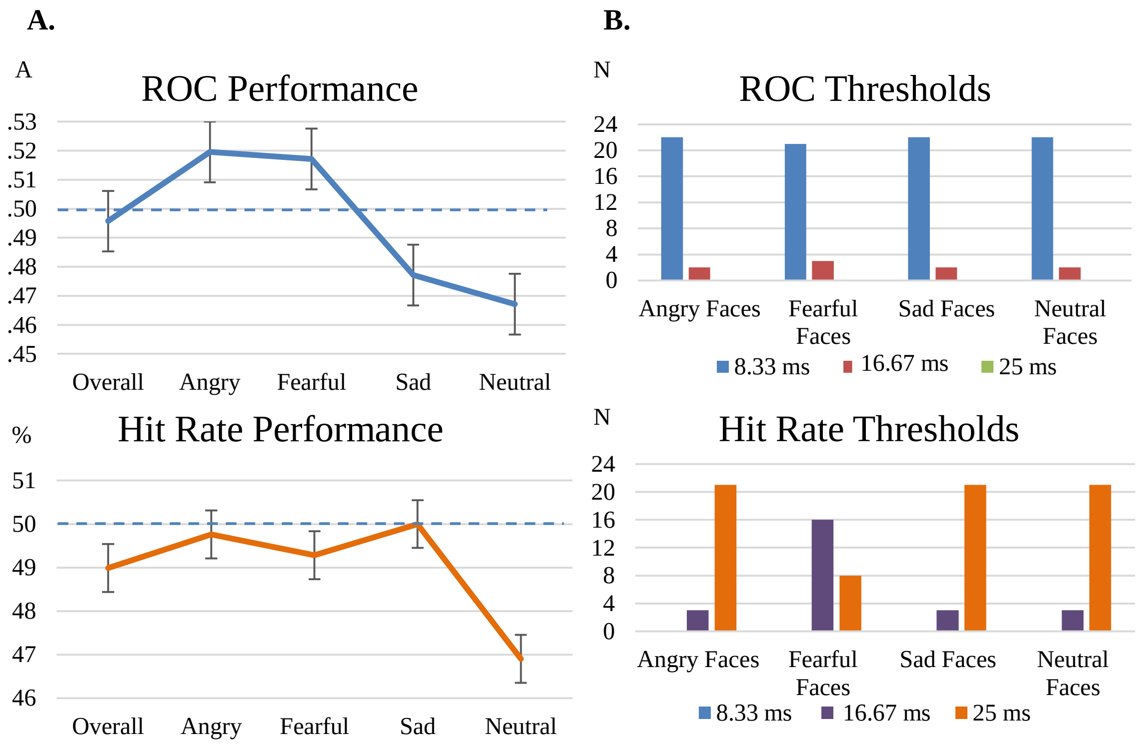

Figure 2: Detection performance for ROC adjusted and Hit Rate adjusted faces and participant count (N) per assessed threshold of presentation (8.33, 16.67 or 25 ms) and stimuli type. Most of the participants were clustered (by ROC) across faces in the lowest available threshold condition (8.33 ms) where correct detection was lowest in comparison to other available durations.

Overall Physiological Responses

The hit rate adjusted faces reported significant differences in SCR changes between different stimuli types (F (2.1, 48.32) = 25.16, $p < .01$; $\eta^2 = .52$; Greenhouse-Geisser corrected). When adjusted using Bonferroni corrections for multiple comparisons our findings revealed that the effect was specific to angry and fearful faces. Angry faces (M = .04, S.D. = .02) elicited higher SCR changes than sad (M = .01, S.D. = .01, p < .01; d = 1.21), neutral (M = .01, S.D. = .01, p < .01; d = 1.38) and pattern blur stimuli (M = .01, S.D. = .01, p < .01; d = 1.37). Similarly, fearful faces (M = .04, S.D. = .02) also elicited higher scores for SCR changes than sad (M = .01, S.D. = .01, p < .01; d = 1.63), neutral (M = .01, S.D. = .01, p < .01; d = 1.83) and pattern blur stimuli (M = .01, S.D. = .01, p < .01; d = 1.76).

Heart rate responses reported a similar effect ($F(2.05, 47.09) = 10.09$, $p < .01$; $\eta^2 = .31$). The effect was again specific to angry and fearful faces. Angry faces (M = 1.46, S.D. = 1.28) elicited higher heart rate changes than sad (M = .57, S.D. = .47, p = .04; d = .92), neutral (M = .5, S.D. = .34, p = .03; d = 1.02) and pattern blur stimuli (M = .63, S.D. = .61, p < .01; d = .82). Fearful faces (M = 1.32, S.D. = .89) also elicited higher heart rate changes than sad (M = .57, S.D. = .47, p = .01; d = 1.05), neutral (M = .5, S.D. = .34, p = .01; d = 1.21) and pattern blur stimuli (M = .63, S.D. = .61, p < .01; d = .9).

Hits and Misses

To further understand this effect, we compared SCR and HR changes per stimuli type (angry, fearful, sad, neutral and pattern blur) and detection response (hits, misses, correct rejects and false alarms). Our findings revealed that there were significant differences for SCR between stimuli ($F(2.36, 54,34) = 20. 37$, $p < .01$; $\eta^2 = .47$; Greenhouse-Geisser corrected). There were also significant differences per detection response type ($F(1, 23) = 35.99$, $p < .01$; $\eta^2 = .61$) and a significant stimuli type by detection response interaction ($F(4, 92) = 19.65$, $p < .01$; $\eta^2 = .46$). When adjusted using Bonferroni corrections this effect revealed that hits for angry (M = .05, S.D. = .04) and fearful faces (M = .06, S.D. = .04) elicited significantly higher SCR than any other response combination and stimulus type (p < .01; Table 1). The same effect was reported for heart rate responses ($F(1.89, 43.57) = 5.93$, $p = .01$; $\eta^2 = .21$; Greenhouse-Geisser corrected). The effect was again specific to hits for angry (M = 1.78, S.D. = 1.33) and fearful faces (M = 1.92, S.D. = 1.29) in comparison to all other stimuli types (p < .01; Table 1) suggesting that the overall effect reported in the previous analysis was specific to correct detection for angry and fearful faces (Table 1; Appendix 4.1)

Table 1: Hits and Misses SCR (μS) and HR (bpm) Changes for different Stimuli

Stimulus Type	Detection Response	SCR Change (μS)	SCR S.D. (μS)	HR Change (bpm)	HR S.D. (bpm)
Angry	Hits*	.05	04	1.78	1.33
	Misses	.01	.02	.89	2.63
Fearful	Hits*	.06	.04	1.92	1.29
	Misses	.01	.01	.67	1.45
Sad	Hits	.02	.01	.72	.75
	Misses	.01	.02	.39	.47
Neutral	Hits	.01	.01	.5	.79
	Misses	.01	.01	.58	.68
Pattern Blur	Correct Rejects	.01	.01	.49	.49
	False Alarms**	.02	.02	.95	1.36

Table 1: SCR and HR per stimulus type and response for meta-awareness. * (asterisk) signifies that the specific subdivision for meta-awareness for the specific stimuli type reported higher physiological changes (SCR and HR) than other stimuli types after adjusting for multiple Bonferroni comparisons. ** show items that were associated with significance trends compared to other non-asterisk types after adjusting for multiple Bonferroni comparisons (Appendix 4.1; 6.1).

Adjusted PAS Scale

We further chased these significant results to explore if hits for angry and fearful faces could be associated with skin conductance and heart rate changes for different categories of the adjusted PAS scale (unsure, possibly and definitely). Our data showed two significant effects. Although there were no overall differences per adjusted PAS scale reply, hits for angry faces demonstrated a significant linear trend for skin conductance ($F(2, 49) = 4.37$, $p = .02$) and heart rate responses ($F(2, 49) = 15.28$, $p < .01$). The same effect was revealed in response to hits for fearful faces for skin conductance ($F(2, 48) = 10$, $p < .01$) and heart rate changes ($F(2, 48) = 25.63$, $p < .01$) suggesting that physiological arousal interacted with confidence ratings for correct detection for angry and fearful faces (Figure 3; Appendix 5.1).

Figure 3: Skin Conductance Changes (µS) for each experimental condition

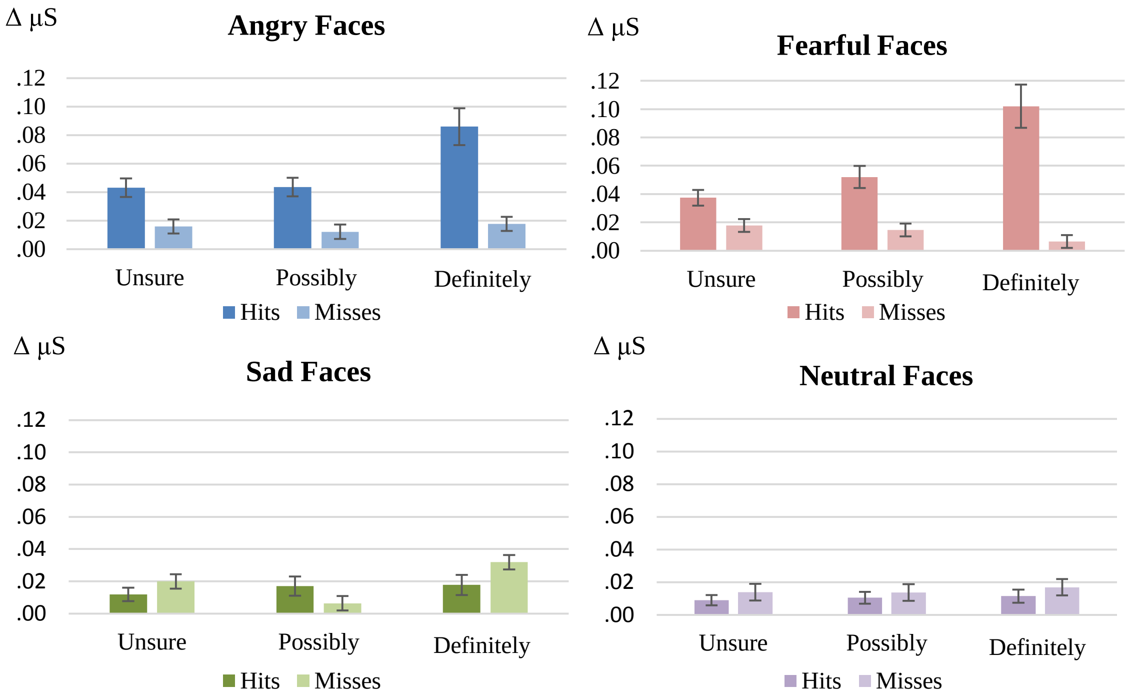

Figure 3: Skin conductance changes for different stimuli types. SCR scores are arranged per signal detection response type (hits, misses) and detection confidence (unsure, possibly, definitely) ratings. Error bars show the standard error of the mean. A Linear trend was reported for skin conductance and detection confidence that suggested higher arousal interacted with confidence for target meta-awareness.

Discussion

In this experimental study, we examined if backward masked emotional faces can elicit physiological changes (Williams et al., 2005; 2006). We also examined whether these changes can be due to unconscious processing (Pessoa, 2005a; 2005b). We implemented several methodological developments to explore this question such as separate ROC and hit rate adjustments in the detection threshold and Bayesian assessment of significance for chance-level detection performance. We found that ROC threshold adjusted faces did not elicit changes in physiological responses. Hit rate threshold adjusted faces elicited physiological changes that further analysis proved to be associated with correct detection for masked angry and fearful faces. We found a significant linear relationship between physiological arousal and detection confidence that was again specific to correct detection for angry and fearful faces.

Previous research has suggested that if a stimulus has biological relevance -- such as survival value (Liddell et al., 2006) --, it can elicit automatic and involuntary changes in physiological processes irrespectively of whether it is consciously perceived (LeDoux, 2003). Our findings support the idea that biologically relevant stimuli can induce changes in skin conductance and heart rate (van der Ploeg et al., 2017) but suggest that target meta-awareness at some sufficient level of confidence is a necessary condition for these changes (Pessoa, 2005a; 2005b). In the current study, only angry and fearful faces produced an effect and only in trials that included correct detection of these stimuli. This result is partly counter to what prevails in topical publications (van der Ploeg et al., 2017). We could not provide evidence for unconscious processing of fully masked emotional faces that we had expected to be indicated using physiological assessment, and we could not support previous findings where fMRI, (Brooks et al., 2012), EEG (Zhang et al., 2011), behavioural responses (Winkielman & Berridge, 2004; 2005) or skin conductance (Lapate et al., 2014) were used – all suggesting that emotional processing can occur without meta-awareness.

We suggest that this discrepancy is due to the substantial methodological differences between the current study and previous research (van der Ploeg et al., 2017). In the current investigation, we utilized previous signal detection findings (Calvo & Lundqvist, 2008; Lähteenmäki et al., 2015) and implemented subjective thresholds for detection performance. This could have been the catalyst for eliminating physiological differences using unbiased criteria for meta-awareness such as receiver operating characteristics (Stanislaw & Todorov, 1999). The alternative implementation of detection threshold durations using traditional detection criteria such as hit rates provided similar results to those obtained in previous studies and is the kind of evidence that has previously been used to conclude that masked angry and fearful faces induce changes in physiology (see also van der Ploeg et al., 2017). However, further analysis of the current data provided support for the Pessoa and colleagues (2005a; 2005b; 2006; 2017) model that suggests that trial-by-trial response analysis reveals that the subset of trials that included correct detection modulates physiological changes to masked emotional content and creates the overall effect (Pessoa et al., 2005b; p. 370). These findings cast doubt on the extent that physiological changes can be elicited without meta-awareness (Pessoa & Adolphs, 2010).

The critical question that the current study sets -- and one that has also been raised by the Pessoa and colleagues group (2005a; 2005b) -- is whether physiological changes influence correctness of target meta-awareness (Pessoa et al., 2017). Previous research has suggested that our behavioural responses to masked stimuli can be influenced by introspective cognitive and emotional criteria (Kouider et al., 2010; Aru et al., 2012). In relation to the current results, this suggests either that arousal could have been higher when target visibility was higher (Adolphs, 2008) or that arousal modulated target meta-awareness and shaped the confidence of the perceptual experience (Anderson, 2005).

For example, Lapate and colleagues (2014) suggested that conscious processing has a regulatory role and disrupts the automatic associations between experienced arousal and evaluative judgement. Arousal elicited by unaware stimuli, on the other hand, decreases likeability for subsequent presented targets because the experience of affect is not subject to executive control (Pessoa & Adolphs, 2010). Evaluative judgement in relation to target presentation could also be regulated by experienced arousal by allowing participants to rely on the experience of affect to respond to the detection task. This would suggest that participant responses did not necessarily indicate whether a stimulus was consciously perceived but whether there was sufficient experienced affect and sufficient awareness of the experienced affect allowing to assume target presentation (Critchley et al., 2004; 2005). In simpler terms, it is possible that participants could have responded in the laboratory in the same way that we respond in real-life when we experience physiological changes and environmental ambiguity: by inferring that “something must have happened”.

This is a promising hypothesis that can nonetheless be quite controversial. Initially, the linear trend effect currently reported was significant only for correct detection of angry and fearful faces. This suggests that it is confidence for meta-awareness and not unawareness that is regulated by fluctuations in the experience of arousal for these faces. On the other hand, if we suggest that physiological changes can regulate meta-awareness and shape perceptual experience can be extended to posit that false alarms for either detection or discrimination performance would also be associated with physiological changes (Pessoa et al., 2005a; 2005b; 2006; 2017). This effect was not significant in the current research (Table 1; Appendix 6.1), although there were trends in the predicted direction. This makes unclear whether it is only post-binary detection confidence or also binary target detection responses that are determined by the experience of arousal during the presentation (Pessoa, et al., 2005a, 2005b).

Finally, a limitation of the current study must be noted. The reported effect was assessed using only measures of autonomic nervous system arousal such as skin conductance and heart rate responses. Our findings cannot answer whether emotional and behavioural reports, neural processing or different methods for the assessment of physiological changes will demonstrate the same linear trend between participants’ responses and confidence for meta-awareness.

Conclusions

The current study suggests that successfully masked emotional faces do not elicit changes in physiological processes. Instead, the current results point to the possibility that autonomic nervous system arousal is specific to trials that include masked target meta-awareness. The current findings allow the hypothesis that arousal could be a possible determinant for target meta-awareness by shaping perceptual experience and influencing confidence reports for the correct detection of angry and fearful faces.

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Appendix

Appendix 1.1: Stimuli Pre-Selection

	Session					
	A (type): Mean (S.D.)		B (experience) Mean (S.D.)			
Accuracy (%)	Group AB	Group BA	Group AB	Group BA	Overall Session A	Overall Session B
Angry*	71.97 (9.97)	80.55 (5.27)	46.35 (11.25)	44.44 (8.07)	76.47 (8.79)	45 .29 (9.43)
Fearful	75 (8.01)	77.22 (6.66)	53.12 (7.98)	57.22 (11.48)	76.17 (7.18)	55.29 (9.91)
Disgusted	73.12 (10.66)	67.77 (8.7)	45 (8.45)	40.55 (7.26)	70.29 (9.75)	42.64 (7.92)
Happy	81.25 (9.54)	81.11 (10.24)	60 (11.95)	66.66 (12.74)	81.17 (9.6)	63.52 (12.47)
Sad	85.62 (5.62)	80 (9.35)	54.37 (8.63)	57.55 (7.94)	82.64 (8.12)	56.17 (8.2)
Neutral	88.75 (4.43)	85.55 (8.45)	66.9 (4.58)	70 (16.95)	87.05 (6.85)	68.52 (12.47)
Intensity (1 - 10)						
Angry	6.3 (.89)	6.02 (1.32)	7.35 (1.09)	7.13 (1.69)	6.15 (1.11)	7.23 (1.4)
Fearful	5.91 (.46)	5.48 (,63)	7.06 (.35)	6.71 (1.14)	5.68 (.58)	6.88 (.86)
Disgusted	5.46 (.34)	5.88 (.67)	6.43 (.26)	6.92 (1.01)	5.68 (.56)	6.69 (.77)
Happy	5.96 (.59)	5.87 (.45)	7.51 (1.01)	7.42 (.64)	5.91 (.5)	7.46 (.81)
Sad	4.88 (,48)	4.81 (.59)	5.06 (1.15)	5.26 (.77)	4.84 (.52)	5.16 (.94)
Ambiguity (1 - 10)**						
Angry	5.62 (1.02)	5.66 (1.34)	4.63 (1.29)	3.5 (1.07)	5.64 (1.16)	4.03 (1.28)
Fearful	5.24 (1.13)	5.16 (.81)	4.19 (.73)	4.05 (1)	5.19 (.94)	4.12 (.86)
Disgusted	6.23 (.58)	5.29 (.51)	4.98 (.85)	4.49 (.32)	5.74 (.71)	4.72 (.65)
Happy	5.28 (.48)	5.2 (.56)	3.69 (.66)	3.61 (.55)	5.24 (.51)	3.64 (.59)
Sad	5.61 (.58)	5.52 (.48)	3.79 (.75)	3.96 (.65)	5.56 (.51)	3.88 (.68)
Neutral	4.38 (.6)	4.93 (.84)	2.93 (.96)	3.26 (.96)	4.67 (.77)	3.1 (.94)
Accuracy Analysis (p values)						
	(AT Task)					
(AE Task)	Angry	Fearful	Disgusted	Happy	Sad	Neutral
Angry*	**.00*****	.138	.365	**.016**	**.005**	**.00**
Fearful	.	**.00*****	**.003**	.65	1	**.007**
Disgusted		.	**.00*****	**.003**	**.00**	**.00**
Happy		.	.	**.00*****	1	1
Sad	.				**.00*****	.001
Neutral		.	.		.	**.00*****

Figure 5: Accuracy, Intensity and Ambiguity Ratings in respect to emotional category for session A (stimuli type) and B (current mood) per participant group; AB (type first), BA (experience first) and overall. In the bottom part Bonferonni **adjusted** ($p \leq .05$) Post Hoc analysis for overall accuracy. Green items signify higher scores for left column; red items for top row. ***** BA > AB, AE order effect; ****** AB > BA, AT order effect. *******

Same stimuli are compared between tasks (task/type interaction); Bonferonni **corrected** ($p \leq .01$) paired samples t - test. Left column refers to **AE task**, top row refers to **AT task**.

Appendix 1.2: Percentage Metric

$$IF\ (\%) = \left(\left(\frac{(10 - \text{Amb.}) + (\text{Int.})}{2}\right) * 50\right) + \left(\left(\left(\frac{\text{SCR Maximum Deferral}}{\text{Max \{SCR Maximum Deferral Stimuli Type\}}}\right) * 25\right)\right.$$
$$\left. + \left(\left(\frac{\text{HR Maximum Deferral}}{\text{Max \{HR Maximum Deferral Stimuli Type\}}}\right) * 25\right)\right)$$

Ambiguity using a one (not at all) to ten (extremely) scale. This item is reversed (10 – x).
Intensity using a one (not at all) to ten (extremely) scale.
Highest unambiguous increase of a phasic skin conductance response three seconds post stimulus offset with respect to pretarget baseline for the specific stimuli.
The score for the stimuli with the highest unambiguous increase in phasic skin conductance response three seconds post stimulus offset with respect to pretarget baseline for the specific emotional stimuli category.
Highest unambiguous increase of a phasic heart rate response four seconds post stimulus offset with respect to pretarget baseline for the specific stimuli.
The score for the stimuli with the highest unambiguous increase in phasic heart rate four seconds post stimulus offset with respect to pretarget baseline for the specific emotional stimuli category.

Appendix 2.1: Visual Contrast

Gender

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Male	8	47,1	47,1	47,1
	Female	9	52,9	52,9	100,0
	Total	17	100,0	100,0	

Descriptive Statistics

	N	Range	Minimum	Maximum	Sum	Mean		Std. Deviation	Variance
	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic
Face	17	3,75	1,10	4,85	38,05	2,2382	,26725	1,10192	1,214
NoFace	17	3,80	1,15	4,95	37,35	2,1971	,26211	1,08072	1,168
Angry	17	4,00	1,20	5,20	38,40	2,2588	,28787	1,18694	1,409
Fear	17	4,00	1,20	5,20	40,40	2,3765	,30384	1,25276	1,569
Sad	17	3,80	1,00	4,80	37,80	2,2235	,26172	1,07908	1,164
Neutral	17	3,20	1,00	4,20	35,00	2,0588	,23374	,96375	,929
Valid N (listwise)	17								

Appendix 3.1: Ambiguity Descriptives

Descriptive Statistics

	Mean	Std. Deviation	N
Unsure_vs_Possibly	3,8000	1,52128	15
Unsure_vs_Most_Likely	2,4667	,74322	15
Unsure_vs_Definetely	2,4000	,82808	15
Possibly_vs_Most_Likely	6,8000	,94112	15
Possibly_vs_Definetely	3,6000	1,63881	15
Definetely_vs_Most_Likely	4,2000	1,08233	15

Appendix 3.2: Ambiguity Pairwise Comparisons

Pairwise Comparisons

Measure: MEASURE_1

(I) factor1	(J) factor1	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
1	2	1,333*	,333	,020	,157	2,510
	3	1,400	,423	,078	-,094	2,894
	4	-3,000*	,338	,000	-4,193	-1,807
	5	,200	,698	1,000	-2,265	2,665
	6	-,400	,423	1,000	-1,894	1,094
2	1	-1,333*	,333	,020	-2,510	-,157
	3	,067	,284	1,000	-,936	1,069
	4	-4,333*	,252	,000	-5,223	-3,444
	5	-1,133	,477	,484	-2,816	,549
	6	-1,733*	,316	,001	-2,848	-,619
3	1	-1,400	,423	,078	-2,894	,094
	2	-,067	,284	1,000	-1,069	,936
	4	-4,400*	,289	,000	-5,422	-3,378
	5	-1,200	,509	,502	-2,996	,596
	6	-1,800*	,312	,001	-2,900	-,700
4	1	3,000*	,338	,000	1,807	4,193
	2	4,333*	,252	,000	3,444	5,223
	3	4,400*	,289	,000	3,378	5,422
	5	3,200*	,595	,001	1,099	5,301
	6	2,600*	,335	,000	1,417	3,783
5	1	-,200	,698	1,000	-2,665	2,265
	2	1,133	,477	,484	-,549	2,816
	3	1,200	,509	,502	-,596	2,996
	4	-3,200*	,595	,001	-5,301	-1,099
	6	-,600	,505	1,000	-2,383	1,183
6	1	,400	,423	1,000	-1,094	1,894

2	1,733*	,316	,001	,619	2,848
3	1,800*	,312	,001	,700	2,900
4	-2,600*	,335	,000	-3,783	-1,417
5	,600	,505	1,000	-1,183	2,383

Appendix 4.1: Comparison between hits and misses per stimuli type

Descriptive Statistics

	Mean	Std. Deviation	N
TPAngry	,0527	,04005	24
FNAngry	,0124	,01632	24
TPFear	,0641	,03669	24
FNFear	,0094	,01443	24
TPSad	,0154	,01368	24
FNSad	,0109	,01929	24
TPNeutral	,0093	,01359	24
FNNeutral	,0120	,01444	24
TNNoFace	,0094	,00673	24
FPNoFace	,0159	,01576	24

Pairwise Comparisons

Measure: MEASURE_1

(I) Stimuli_Type	(J) Stimuli_Type	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
1	2	-,004	,004	1,000	-,016	,008
	3	,019*	,005	,009	,004	,035
	4	,022*	,005	,002	,007	,037
	5	,020*	,005	,003	,005	,035
2	1	,004	,004	1,000	-,008	,016
	3	,024*	,004	,000	,011	,036
	4	,026*	,004	,000	,013	,040
	5	,024*	,004	,000	,013	,035
3	1	-,019*	,005	,009	-,035	-,004
	2	-,024*	,004	,000	-,036	-,011
	4	,003	,002	1,000	-,004	,009
	5	,001	,003	1,000	-,009	,010
4	1	-,022*	,005	,002	-,037	-,007
	2	-,026*	,004	,000	-,040	-,013
	3	-,003	,002	1,000	-,009	,004
	5	-,002	,002	1,000	-,009	,005
5	1	-,020*	,005	,003	-,035	-,005
	2	-,024*	,004	,000	-,035	-,013

3	-,001	,003	1,000	-,010	,009
4	,002	,002	1,000	-,005	,009

Based on estimated marginal means

*. The mean difference is significant at the ,05 level.

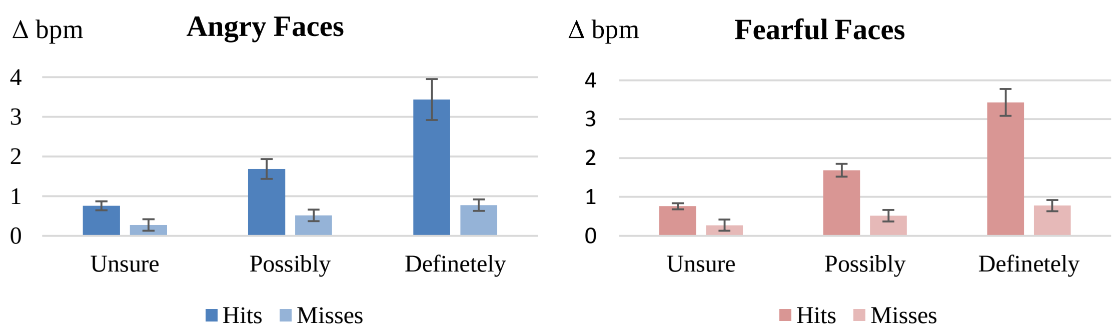
b. Adjustment for multiple comparisons: Bonferroni.

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	TPAngry - TPSad	,03731	,04129	,00843	,01987	,05474	4,427	23	,000
Pair 2	TPAngry - TPNeutral	,04345	,03826	,00781	,02730	,05961	5,564	23	,000
Pair 3	TPAngry - TNNoFace	,04336	,04021	,00821	,02638	,06034	5,283	23	,000
Pair 4	TPFear - TPSad	,04872	,03821	,00780	,03258	,06485	6,246	23	,000
Pair 5	TPFear - TPNeutral	,05486	,03604	,00736	,03964	,07008	7,457	23	,000
Pair 6	TPFear - TNNoFace	,05477	,03843	,00784	,03855	,07100	6,983	23	,000

Appendix 5.1:

Figure 4: Heart Rate Changes (bpm) for each experimental condition



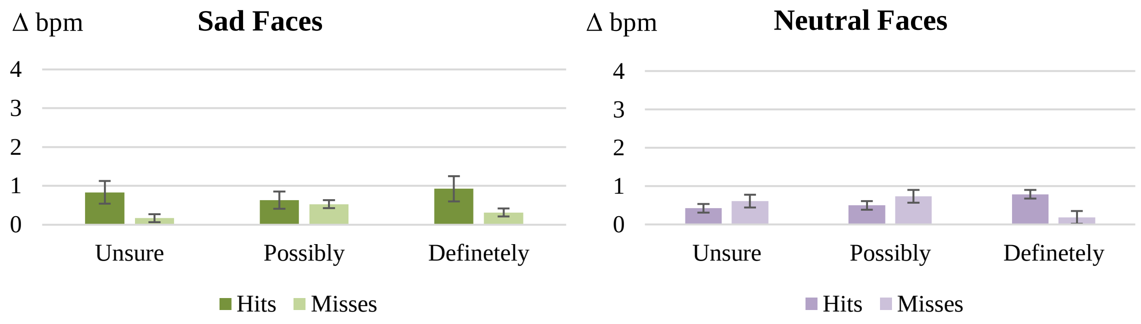


Figure 4: Heart rate changes in beats per minute for different stimuli types arranged for signal detection (hits, misses, correct rejects, false alarms) and detection confidence replies (unsure, possibly, definitely). Error bars how ± 1 standard error of the mean.

Appendix 6.1: Trends for False Alarms

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	TNNoFaceHR	,4988	24	,49545	,10113
	FPNoFaceHR	,9478	24	1,36430	,27849
Pair 2	TNNoFace	,0094	24	,00673	,00137
	FPNoFace	,0159	24	,01576	,00322

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	TNNoFaceHR - FPNoFaceHR	-,44897	1,14660	,23405	-,93313	,03520	-1,918	23	,068
Pair 2	TNNoFace - FPNoFace	-,00654	,01772	,00362	-,01402	,00094	-1,808	23	,084