

Electro-cortical Correlates of Social Cognition in Autism Spectrum Disorder – An Affective
Multisensory Integration Paradigm

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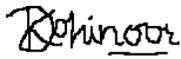
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This dissertation is for everything that got me here, and wherever I go next.

DECLARATION

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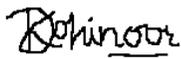
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STATEMENT 1

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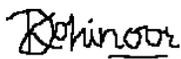
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Abstract

Abnormalities in sensory processing have been reported in individuals with autism spectrum disorder (ASD) in all sensory modalities. Along with unimodal deficits, there is mounting evidence for a deficit in assimilating information across modalities, or multi-sensory integration (MSI), especially in affect perception. Though the original objective of the study was to compare affective MSI in ASD and controls, due to time and technical constraints, only controls were tested. A reaction time, forced choice, categorization paradigm was used: Event-Related Potentials (ERPs) were recorded simultaneously while participants were asked to distinguish between dynamic stimuli depicting fear or disgust emotions; presented either auditorily (non-verbal), visually, or audio-visually. Results demonstrated a visual dominance in processing of emotions. ERPs were more sensitive in identifying neural correlates of affect perception. ERP component amplitudes and latencies correlated with behavioral measures of accuracy and reaction times (RTs). Based on the study, the paradigm was evaluated for its integrity to test MSI effects in ASD and controls, and a modified affective MSI paradigm has been proposed. Further research on MSI in ASD will help understand its etiology and guide intervention.

Keywords: multisensory integration, autism, emotion perception, ERP

Autism: etymology, origin and description

The term “autism” originates from the Greek word “autos,” meaning “self.” Eugen Bleuler (Bleuler, 1911) first used the term autism to mean an “isolated self” as one of the symptoms of schizophrenia (English translation: Bleuler, 1950). However, the inaugural definition of autism as an independent disorder was described by Leo Kanner in 1943, who described 11 children with “autistic disturbances of *affective* contact” (Kanner, 1943). A year after Kanner, Hans Asperger (Asperger, 1944) also used the term for children with similar features but who did not show severe language impairments and had high quotients of non-verbal intelligence; a syndrome which later came to be known as Asperger’s Syndrome (AS). Though clinical definitions of autism as a disorder continue to evolve, the Diagnostic Statistical Manual, Fifth Edition (DSM-V) provides diagnostic criteria for autism including two core deficits: repetitive behaviors and restricted interests, and reciprocal social communication and interaction impairments. The features of autism lie on a spectrum, ranging from severe to mild, termed as Autism Spectrum Disorder (ASD), including the previously separate categories of Asperger’s and Pervasive Developmental Disorder – Not Otherwise Specified (PDD-NOS).

Etiology and diagnostic presentation

The exact causes of ASD are as yet unknown; researchers are now giving up on a single explanation of autism, and believe it to be a complex disorder with a set of features that may have distinct neurological, psychological, genetic and environmental causes (Happé & Ronald, 2008; Happé, Ronald, & Plomin, 2006). Twin-studies have supported a genetic influence (Le Couteur et al., 1996), further implicating the role of genes like MECP2 (Currenti, 2010), and de-novo mutations (Sebat et al., 2007). Certain pre-natal and perinatal environmental factors may also play a role in its pathogenesis (Hultman, Sparen, & Cnattingius, 2002; Kolevzon, Gross, &

Reichenberg, 2007). Increase in total brain volume, aberrant connectivity, abnormal activation of certain brain areas and neuronal disorganization (Minshew & Williams, 2007; Rippon, Brock, Brown, & Boucher, 2007) have also been suggested as causes of the different features of autism. The clinical presentation of ASD varies with age (Shattuck et al., 2007), gender (Rivet & Matson, 2011), presence of associated/comorbid disorders (Gillberg & Billstedt, 2001) and intelligence quotient (IQ) (Burack & Volkmar, 1992).

In spite of the heterogeneity seen in individuals with ASD, what appears to be prevalent across the spectrum in almost all children and adults with ASD, are abnormalities in sensory processing across age and ability (Marco, Leighton, Hill, & Nagarajan, 2011; Tomchek & Dunn, 2007).

Sensory processing in ASD

Sensory processing can be defined as an overarching term for the way in which the Central Nervous System and Peripheral Nervous System manage incoming sensory input, and its utilization in responding to environmental demands (Miller & Lane, 2000). Atypicalities in ASD include hypersensitivity, hyposensitivity, sensory overload and under/over-responsivity, seen not just in one sensory modality, but across auditory, visual, oral, olfactory and tactile domains (Kientz & Dunn, 1997; Watling, Deitz, & White, 2001). Whether or not these improve with age remains controversial (Bennetto, Kuschner, & Hyman, 2007; Kern et al., 2006) as some studies have indicated lifelong sensory impairment (Crane, Goddard, & Pring, 2009). Sensory dysfunction adversely affects an individual with ASD in a variety of domains including academics (Ashburner, Ziviani, & Rodger, 2008), social performance (Hilton, Graver, & LaVesser, 2007), and social learning (Baranek et al., 2013). It increases repetitive behaviors (Chen, Rodgers, & McConachie, 2009) and puts a burden on families (Schaaf, Toth-Cohen,

Johnson, Outten, & Benevides, 2011), impacting social relations, cognition, behavior and language (Bogdashina, 2013).

In the 1970s, sensory processing research burgeoned, with evidence increasing for atypical sensory modulation in individuals with ASD (Hermelin & O'Connor, 1970; Stroh & Buick, 1964). Later, however, domain-specific theories of social cognition took precedence. These included an inability to understand others' feelings and thoughts: "Theory of Mind," (Baron-Cohen, Leslie, & Frith, 1985), impairment in executive functions (Ozonoff, Pennington, & Rogers, 1991), and weak central coherence (Frith & Happe, 1994). Some researchers also implicated dysfunction of the mirror-neuron system. (Oberman & Ramachandran, 2007). While these models drive much of the current research in autism, one of the major drawbacks of these theories is that they fail to explain the non-social symptoms of autism (repetitive behaviors and sensory abnormalities). The sensory perceptual domain thus found renewed interest in autism, research further expedited by the use of questionnaire methods to measure sensory sensitivities and abnormalities (Crane et al., 2009).

Multisensory integration (MSI)

In the last two decades, an emerging theory has been that of atypical multisensory integration (MSI) in individuals with ASD. MSI can be defined as a process of integrating information simultaneously across different sensory modalities (O'Neill & Jones, 1997). MSI dysfunction has been investigated in individuals with ASD across age and ability (Leekam, Nieto, Libby, Wing, & Gould, 2007), though the findings are equivocal and limited. Researchers are suggesting that an MSI dysfunction might underlie some of the core socio-cognitive deficits of autism, as well as the observed unisensory processing abnormalities (Russo et al., 2010). Even with developing sensory integration therapies (Lang et al., 2012), empirical investigations of

MSI in autism remain limited. Most researches have used behavioral measures (for example, Charbonneau et al., 2013) However, these measures assume that behavioral performance are accurate measures of multisensory integration, but disregard confounds of differing task instructions and the allocation of attention. In addition, the link between underlying brain processes and behavioral performance is as yet unclear, and similarities and differences in behavioral performance may not reflect similar corresponding cognitive processes (Russo et al., 2010). The integrity of MSI can be better assessed by electrophysiological methods like Event-Related Potentials (ERPs) as they significantly contribute to the understanding of neural mechanisms, offering better temporal resolutions than other neuroimaging techniques (Banaschewski & Brandeis, 2007). ERPs represent changes in brain activity in response to any sensory, cognitive or motor event (Luck, 2005). They are extracted from ongoing electroencephalogram (EEG), and recorded non-invasively at the scalp surface (Jeste & Nelson III, 2009). ERPs consist of specific components, with early components reflecting basic sensory-processing, and later components reflecting higher-order perceptual and cognitive processing of stimuli (Picton & Hillyard, 1988). They can be recorded in passive paradigms (i.e. in paradigms which do not require the specific allocation of attention or responses from the participants), and thus are not confounded by variables like attention and task instruction.

Multisensory processing allows individuals to bind together information which is spatially and/or temporally coincident, and helps allocate attention to particular objects in noisy environments without being overwhelmed by the separate streams of information arriving from each unisensory channel (Donohue, Darling, & Mitroff, 2012). The bulk of the research in lower-level MSI in ASD indicates that children with ASD have a broader temporal window of integration (Foss-Feig et al., 2010). They also show an absence of a multisensory neural

enhancement (i.e. an enhanced ERP; Russo et al., 2010), as well as abnormal latencies and amplitudes of early ERP components as compared to typically developing (TD) children (Courchesne, Lincoln, Kilman, & Galambos, 1985; Courchesne, Lincoln, Yeung-Courchesne, Elmasian, & Grillon, 1989). Much of the research in higher-order MSI in ASD focuses on the processing of speech. The most common finding is of the McGurk illusion which integrates information from the two unisensory modalities, to form an audiovisual multimodal percept (McGurk & MacDonald, 1976). In this illusion, an individual hears the syllable “ba” and sees the speaker say “ga,” thus perceiving that the speaker said “da.” Individuals with ASD experience this illusion less frequently (Gelder, Vroomen, & Van der Heide, 1991; Stevenson, et al., 2014), and also face difficulties in processing audiovisual speech adequately in noisy environments as compared to controls (Fuxe, et al., 2015).

The multimodality of emotion perception in ASD

In day-to-day life, individuals process emotions in a multisensory context - commonly expressed by the auditory and visual modalities together (de Gelder, et al., 2005; de Gelder & Vroomen, 2000). This ability to “read” emotions from faces and voices is integral to our social behavior and interactions with the social world. In TDs, redundant information i.e. information from multiple modalities usually facilitates performance (as evidenced by shorter reaction times (RTs) and higher accuracy) on tasks of recognition and discrimination (Molholm, Ritter, Javitt, & Fuxe, 2004; Murray, et al., 2005), however individuals with ASD do not appear to benefit as much as controls in the multisensory condition (Charbonneau, et al., 2013; Collignon, et al., 2013). Most research, however, has focused only on one modality (especially the visual modality) to elucidate processing of emotions in ASD (Russo et al., 2010). Most investigations in children with ASD have used static faces/stimuli and have found diminished ability to

recognize facial emotions (Bal, et al., 2010; Celani, Battacchi, & Arcidiacono, 1999) as well as intact performance (Feldman, McGee, Mann, & Strain, 1993). Stimuli consisting of dynamic faces (Charbonneau et al., 2013; Loveland, Steinberg, Pearson, Mansour, & Reddoch, 2008) have been seldom used. Static stimuli have less ecological validity as emotions have a dynamic nature; dynamic movements of the face have shown to improve perception of emotions and increase their salience (Harms, Martin, & Wallace, 2010). Studies with adolescents and adults have also found reduced accuracy in the ASD group, especially for negative emotion recognition (Ashwin, Chapman, Colle, & Baron-Cohen, 2006) as well as subtle or no differences between the ASD group and controls (Loveland et al., 2008). The most common electrophysiological finding in the visual domain has been that of the N170 ERP component. The N170 is a negative deflection at around 150-200 ms post stimulus, sensitive to faces, and thought to be related to the structural encoding of the face (Bentin, Allison, Puce, Perez, & McCarthy, 1996). The N170 has been shown to respond to emotional expressions as well (Blau, Maurer, Tottenham, & McCandliss, 2007). An absence of right hemisphere lateralization in the ASD group as compared to controls (Dawson et al., 2002), higher latencies (O'Connor, Hamm, & Kirk, 2007) and smaller amplitudes in Asperger's (O'Connor, Hamm, & Kirk, 2005) of the N170 component have also been demonstrated. Atypical latencies and amplitudes for the P1 component i.e. the first positive deflection (between 100 – 200 ms) reflecting basic sensory processing, for the ASD group have also been identified (Jeste & Nelson III, 2009). A few studies have also studied affective vocalization processing in ASD (Hall, Szechtman, & Nahmias, 2003). However, they were limited by language-related confounds (Lindner & Rosén, 2007). Interestingly, ERP components P2 (i.e. the second positive deflection after stimulus onset, thought to reflect integration of prosodic cues, occurring at around 200 ms, usually generated in frontal/frontal-temporal sites)

and N300 (reflecting early evaluation of emotion, a negative deflection occurring at around 300ms) have shown atypical latencies and amplitudes in the ASD group as compared to controls (Lerner, McPartland, & Morris, 2013; Paulmann, Jessen, & Kotz, 2009). Behavioral findings of the multimodality of emotion perception and recognition in ASD have revealed deficits in the MSI of emotions (for example, Charbonneau et al., 2013) with reduced behavioral facilitation for the ASD group in the bimodal/audiovisual redundant condition as compared to the unisensory conditions. However, in contrast, Jones et al. (2010) found no multisensory integration deficit in the recognition of emotions. Collignon et al. (2008) demonstrated a visual dominance for normative individuals while discriminating between emotions of fear and disgust, while another study found that individuals with ASD relied on the auditory modality for emotion discrimination (Stevenson et al., 2014).

In a number of studies exploring lower-level affective MSI, the electrophysiological responses for both unisensory and redundant conditions are recorded, and the ERPs for the redundant condition are subtracted from the sum of the ERPs for the unimodal conditions, known as the Additive Model (Giard & Peronnet, 1999). This difference wave is thought to reflect lower order MSI processes. However, this model has been criticized due to common responses: the sum ERP contains two motor responses while the bimodal ERP contains only one, thus leading to erroneous interpretations (Cappe, Thut, Romei, & Murray, 2010). Different levels of attention are also confounding for the additive model (Besle, Fort, Delpuech, & Giard, 2004). In spite of these limitations, studies have used the additive model and have found differences in affective MSI in ASD and controls (Russo et al., 2010) indicating less intensive MSI in ASD, while some have found intact lower- and higher-order MSI in individuals with autism (Magnee, 2008). Differences in MSI effects between ASD and TDs have been demonstrated at different

time points, as early as 100 ms post stimulus onset (Brandwein et al., 2012), with the ASD group using different cortical networks for the integration of information. In a study by (Wong, Fung, Chua, & McAlonan, 2008) normal ERP responses (P1, P2 and N170) were evidenced in the ASD group as compared to controls; however, dipole source modeling revealed aberrant activity in children with ASD. Individuals with ASD also show atypical responses to different emotions. Charbonneau et al. (2013) found higher accuracy for the emotion of disgust as compared to fear in the auditory modality. However, emotion recognition ability was impaired significantly in individuals with ASD as compared to controls for the emotion of surprise but not for recognition of happiness, sadness, fear, anger and disgust (Jones et al., 2010). Children with ASD may also interpret ambiguous emotions as negative (like fear or anger) more often than controls (Kuusikko et al., 2009). In a study using fearful and happy stimuli, increased Visual P1 and N170 and Auditory P2 amplitudes for the emotion of fear as compared to happiness were evidenced in adult individuals with Pervasive Developmental Disorder (PDD) (Magnée, de Gelder, van Engeland, & Kemner, 2008).

The discrepancy in the differences found in the visual, auditory and bimodal modalities between individuals with ASD and controls may be due to IQ levels, age, and the dependent variables measured, as well as due to the heterogeneity found within the spectrum of autism, including Asperger's and PDD-NOS (Harms et al., 2010). Whether individuals with ASD possess a specific deficit in emotion processing in a particular modality or a more generalized deficit irrespective of the modality is still unclear. In addition, the question whether emotion perception and recognition abnormalities in ASD are primary, or secondary to the more fundamental socio-cognitive deficits remains unanswered.

MSI in typically developing individuals (TDs)

For emotion processing, TDs showed enhanced processing in the bimodal condition as compared to the unisensory conditions (Collignon, et al., 2008), and are more fluent at processing female faces than male faces (Ramsey-Rennels, 2006). This was further validated by the fact that RTs in the bimodal condition violated the race model prediction (Miller, 1982; see methods), providing evidence for multisensory integration. Women showed better facilitation from the multisensory integration of emotions as compared to men (Collignon, et al., 2010). A visual dominance in emotion processing was also evidenced (Collignon et al., 2008; Latinus, VanRullen, & Taylor, 2010). MSI effects have been demonstrated electrophysiologically as early as 50 ms (Russo et al., 2010), and even later (between 250 – 600 ms; Schweinberger, Kloth, & Robertson, 2011). Even in TDs, the Additive Model has demonstrated MSI effects (Giard & Peronnet, 1999; Murray et al., 2005). An increase in N170 amplitudes in the bimodal condition as compared to the unisensory conditions was also found (Schweinberger et al., 2011). Visual objects presented at the same place as auditory ones were thought to occur earlier in time by TDs, and this was accompanied by an increase in P1 amplitude (Van der Burg, Talsma, Oliver, Hickey, & Theeuwes, 2011). Many studies have also shown an enhanced P2 amplitude in the bimodal as compared to the unisensory condition (Giard & Peronnet, 1999; Stekelenburg & Vroomen, 2007). Significant correlations between the behavioral and electrophysiological measures of MSI have indicated that underlying neural mechanisms play a role in the facilitation of behavior in the redundant condition (Brandwein et al., 2011).

Aims and hypotheses

In accordance with the above findings, the main aim of the present study was to elucidate the differences in affective multisensory integration on a forced choice emotion categorization task, using both behavioral and electrophysiological measures in individuals with ASD and TDs.

To overcome the limitations of static stimuli and lexical confounds, we used ecologically valid dynamic stimuli and non-verbal affective vocalizations, adopted from Charbonneau et al. (2013). The emotions of fear and disgust were presented auditorily, visually, and audiovisually. Even though fear and disgust are both negative emotions, they can be clearly differentiated from one another, allowing clarity for research purposes (Ekman & Friesen, 1976; Simon et al., 2007). The present exploratory pilot can be called a conceptual replication of the study by Charbonneau et al. (2013), further extended by the use of electrophysiological measures. Thus, the first aim of the present exploratory pilot study was to behaviorally and electrophysiologically evaluate performance across modalities. Given the apparent limits of the additive model, we extracted peaks of ERP visual components N170, P1, P2 and the auditory P2. It was hypothesized that the bimodal modality would show better overall performance as compared to both unisensory modalities. Significant differences in ERP components were also predicted across modalities. Multisensory processing was tested by evaluating Miller's (1982) Race Model Inequality (See Methods). Further, the study aimed to explore differences in accuracy and reaction times across emotions and gender of the actor depicting the emotion. The study also sought to elucidate the relationship between behavioral performance and ERP components. It was predicted that within-modality amplitudes and latencies of ERP components would correlate with performance in the corresponding modality. The paradigm used in the present study was also evaluated in order to assess whether it can reliably test for multisensory integration differences in ASD and TDs.

2. Methods

The aim of the study was to compare the behavioral performance and electro-cortical correlates of multisensory integration of emotions in typically developing individuals and individuals with ASD. The study received full ethical approval from the Ethics Committee of the

Albert Ludwig University of Freiburg. However, due to time and technical constraints, we were unable to test with a clinical sample. Hence, only controls were tested for the present study.

2.1. Participants

Nineteen healthy individuals (8 males; mean age = 25.21 years, age range 20-29 years) were recruited from the University of Freiburg in the present study through opportunity sampling. No participants had neurological or audiological problems, and had normal or corrected-to-normal vision. All participants were right-handed and participated in the study after giving informed written consent. Two participants were unable to complete the task. The final sample used for the behavioral data analysis was $N = 17$. For EEG processing, one participant was excluded due to excessive muscle and sweat artefacts. Thus, the data of 16 participants ($N = 16$) was used for EEG data analysis.

2.2. Stimuli

The stimuli used in the present study were adopted from Charbonneau et al. (2013). Fear and disgust expressions were used, and were chosen from a set of standardized dynamic stimuli, expressed by one male and one female actor. Each actor portrayed both the emotions. The original clips were all processed through Adobe Premiere (Adobe Systems Inc., San Jose, US) in order to obtain stimuli for the three stimulus conditions i.e. auditory only, visual only, and audiovisual/bimodal. Each clip was 500 milliseconds in length.

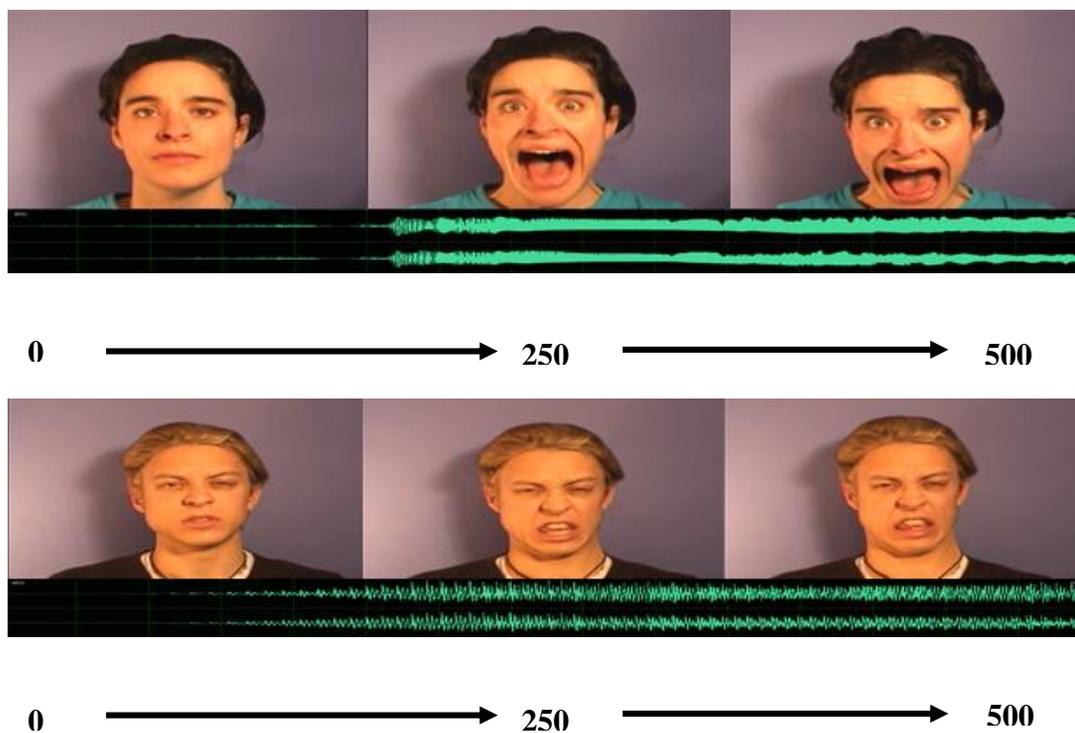


Figure 1. Female Fear and Male Disgust stimuli. Participants were asked to distinguish between emotions of fear and disgust, both presented by one male actor and one female actor. Stimuli were presented auditorily, visually, and audio-visually.

The *audiovisual* clips were congruent i.e. both the auditory and visual modalities depicted the same emotion. The *visual* clips represented natural, day-to-day facial expressions (Simon, Craig, Gosselin, Belin, & Rainville, 2008) as validated by the Facial Action Coding System (FACS) (Ekman & Friesen, 1976). The clip gradually evolved from a neutral face into a full expression (either fear or disgust) (see Fig. 1). The stimuli had a size of 350 x 430 pixels. The sound from the visual clip was unlinked, and then deleted from the sequence. The *auditory* clips, expressing fear and disgust by one male and one female actor, were extracted from the

audiovisual clip obtained from Charbonneau et al. (2013) (see Fig. 1). Each condition consisted of the following four stimuli:

Female Fear. A female actor expressing the emotion of fear.

Male Fear. A male actor expressing the emotion of fear.

Female Disgust. A female actor expressing the emotion of disgust.

Male Disgust. A male actor expressing the emotion of disgust.

2.3. Procedure

Event-Related Potentials (ERP) were recorded in a sound-attenuated, dimly lit room while participants completed a forced choice emotion categorisation task. They were seated in a comfortable chair, with an approximate distance of 60 cm from the computer screen, with the keyboard directly in front of them. Participants were given oral as well as written instructions prior to the experiment. Visual stimuli were presented on a black background in the center of the screen, while auditory stimuli were presented through screen-mounted speakers. Six blocks of approximately 10 minutes each (two each of the auditory, visual and bimodal modalities) were presented. Each condition consisted of 400 trials, with 200 trials in each block. Four types of stimuli were distributed equally and randomly in a block – 50 trials each of Female Fear, Female Disgust, Male Fear and Male Disgust. The order of the blocks was counterbalanced across participants to account for effects of order. The actual stimulus (auditory/visual/audio-visual) lasted for 500 ms followed by a blank screen inter-stimulus interval of 2000 ms, which consisted of a white fixation cross on a black background. All stimuli were presented on a black background. The participants were asked to respond by pressing key A (with the index finger of the left hand) for an expression of fear, and key L (with the index finger of the right hand) for

disgust (via a QWERTY keyboard). They were instructed to answer as fast and accurately as possible.

2.4 Data Acquisition

2.4.1. Behavioural data. Behavioural responses for all blocks were obtained simultaneously with the electroencephalography (EEG) recording and processed offline. Reaction times, correct responses, errors and misses were recorded for further statistical analysis.

2.4.2. Electrophysiological data. Continuous electroencephalographic (EEG) data was recorded (referenced to electrode FCz) from a 65 channel ActiCap with Ag/AgCl-tipped active electrodes at a digitization rate of 500Hz using Brain Vision Recorder. Impedance was kept below 5 k Ω . The ground electrode used was AFz. Each electrode was applied a small amount of electrolyte gel. Horizontal and vertical eye electro-oculographic (EOG) movements were monitored by two additional electrodes (IO1 and IO2) placed at the infraorbital sites of each eye, and an electrode placed between the two eyebrows (nasion, Nz).

2.5. Data Analysis

2.5.1. Behavioural data analysis. Task accuracy was measured by the sensitivity index (d'), calculated by subtracting the z-score of the hit rate from the z-score of the false alarm rate, as described by (Snodgrass & Corwin, 1988). Only correct responses were considered for reaction time (RT) analysis. Performance can be estimated by both speed and accuracy. In tasks such as the one used in the present study, where both speed and accuracy are equally emphasized, an interpretive difficulty can be faced. Without a change in their underlying competence, participants may adopt difference strategies to respond. They may trade speed for accuracy, or compromise accuracy for faster responses. Therefore, forming a composite score of speed and accuracy may give a better measure of performance and variance. The Speed-

Accuracy Composite Score (SACS) is an extension of the more commonly used Inverse Efficiency scores (Townsend & Ashby, 1988). It has been used in analysis of between-group differences in performance (Charbonneau et al., 2013; Collignon et al., 2010). The SACS is calculated by normalizing the accuracy measure i.e. the d' sensitivity index, and the mean reaction times, and subtracting the normalized RTs from the normalized d' scores i.e. $SACS = [Z(d') - Z(RTs)]$.

The d' scores and mean RTs were subjected to a 2 (gender) x 2 (emotion) x 3 (modality) repeated measures ANOVA. To analyze differences in performance across modalities, the SACS scores were subjected to a one way repeated measures ANOVA. Bonferroni post hoc analyses were conducted (based on the significance values) when appropriate.

2.5.2. ERP/EEG Processing and Analyses. Brain Vision Analyzer 2.0 (Brain Products, Munich) was used to process EEG data offline. The data of one participant was excluded due to excessive artifacts. A preliminary semi-automatic raw data inspection (RDI) was used to remove any muscular activity, excessive movements, channel saturations and DC corrections. A high-pass IIR filter with a slope of 12 dB/octave of 0.1 Hz was used. Noisy electrodes were removed prior to the independent component analysis (ICA), and were interpolated topographically via spline interpolation after the ICA. ICA components that represented eye movements, muscle activity and drifts were excluded. A second, more stringent RDI (semi-automatic) was conducted, and trials with any residual artefacts over 150mV in any 200 millisecond time interval were rejected. Trials with excessive artefacts not identified by the ICA or RDI were also rejected at this stage. A 30 Hz Low Pass filter with a slope of 24dB/octave was used and then data was re-referenced. Average reference was used to include all electrodes including the old implicit reference FCz. Stimulus-locked epochs of 300 ms pre-stimulus to 2000 ms post-stimulus

onset were created, with each epoch baseline corrected with 200 ms. Data was segmented initially into all auditory, visual, and bimodal segments and then further into four groups: female fear, male fear, female disgust and male disgust, for each condition. Individual and grand averages were then created for each condition type to assess the waveform morphology of the three stimulus conditions.

After observing each individual average, and reviewing the literature, the following ERP peak amplitudes (with a +/- 10 ms interval around the peak) were exported. For visual and bimodal ERPs, the visual P1, N170 and P2 components were extracted from electrode PO8 (the electrode with the highest amplitude for both components in both conditions; see Fig. 2 (A)). The components are referred to as bimodal P1, N170 and P2 in the bimodal condition. The time windows used for peak-picking were 100 – 200 ms for the P1, 180 - 240 ms for the N170, and 200 - 300 ms for the P2. The auditory P2 was extracted from electrode FT9 (peaking between 200 – 300 ms; see Fig. 2 (B)). Peak amplitudes and latencies were exported for further analysis.

2.5.3. Correlation between electrophysiological responses and behavioural performance. To test whether behavioural performance for emotion recognition correlates with concurrent modality-specific ERPs, two-tailed Spearman's *rho* correlations were conducted between within-modality accuracy and reaction times and amplitudes and latencies of within-modality ERP components.

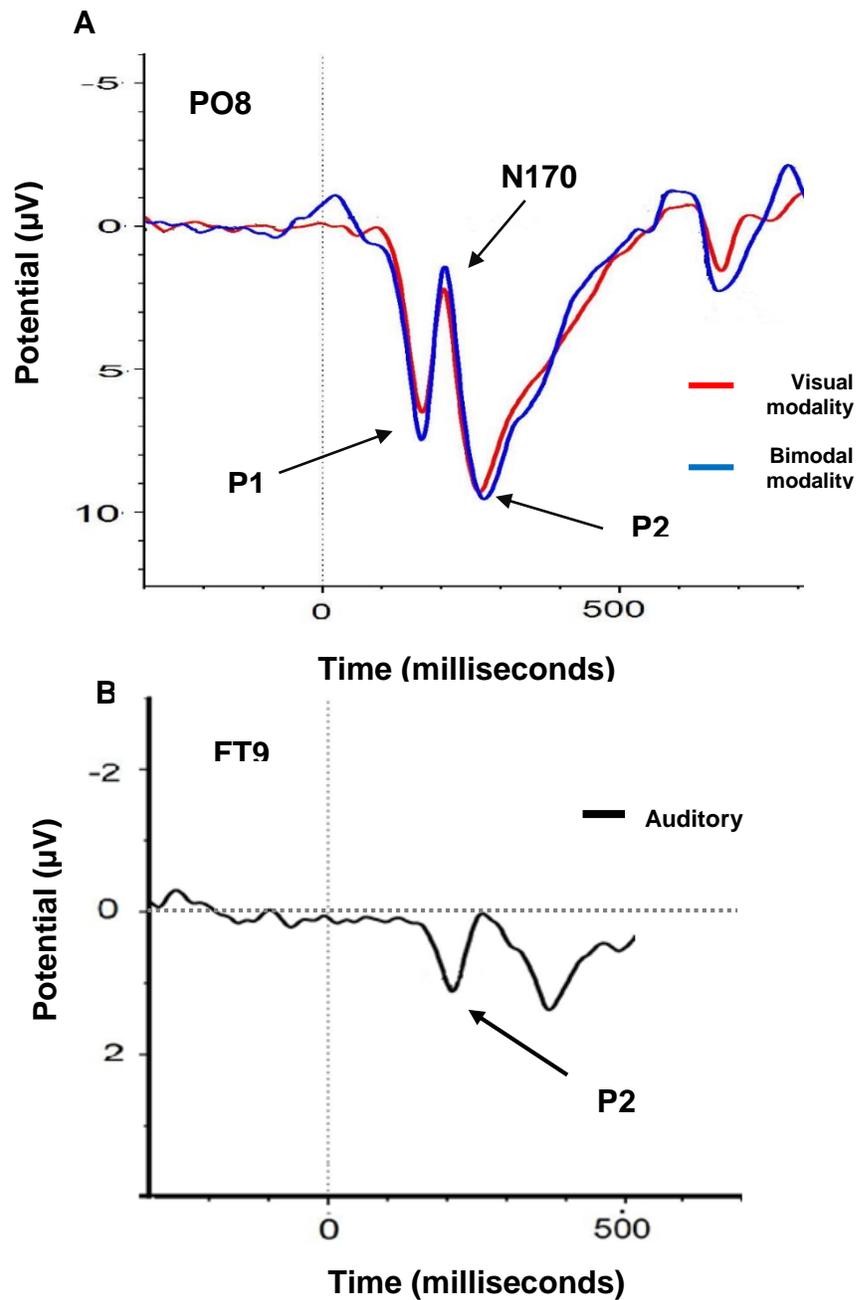
Grand Averaged Waveform for the Visual, Bimodal and Auditory Modalities

Fig. 2. The figure illustrates the waveform morphology of the ERP components in the auditory (B), visual, and bimodal modalities (A). Peaks P1, N170 and P2 for the visual and bimodal modalities have been extracted from electrode PO8, and peak P2 for the auditory modality has been extracted from the electrode FT9.

2.5.4. Multisensory Integration. Differences between the bimodal modality and each of the unisensory modalities were analyzed to investigate the Redundant Signal Effect (RSE). RSE occurs when the RT for the redundant condition is faster as compared to the unisensory conditions in a stochastic sense (Schwarz, 1989). In the present study, the redundancy gain (RG) was calculated for each participant, defined as the decrease in RT in percentage in the bimodal condition when compared to the fastest unisensory condition (Mohr & Pulvermüller, 2002).

The RSE or RG phenomenon has given rise to two main models for its explanation. Race models suggest that an independent detection process is elicited by each individual stimulus. The shorter RT in the redundant condition is due to the fastest detected cue triggering a response (Mordkoff & Yantis, 1991). Raab (1962) suggested that since visual and auditory processing latency variables had overlapping probability distributions, processing times which are slow are eliminated, thus leading to faster RTs in the redundant condition. He used the label “statistical facilitation” for this explanation. However, it has been shown that observable RG is sometimes larger than what the race model can predict i.e. faster RTs are attributed to not just statistical facilitation, but co-activation or combination of units of information from both the single-signal channels that trigger the response (Fournier & Eriksen, 1990). These co-activation models usually differ in where the units of information interact in the processing system. To test whether the faster RTs are a result of statistical facilitation or co-activation, Miller (1982) proposed the Race Model Inequality (RMI). Miller’s model has been widely used as a behavioral measure of investigating multisensory integration (Girard, Pelland, Lepore, & Collignon, 2013).

In the present study, the RMI was evaluated to investigate MSI by using the Matlab software, implementing the algorithm described in (Ulrich, Miller, & Schröter, 2007). This procedure consists in four main steps: 1. the cumulative distribution functions (CDFs) (i.e. G_x ,

Gy, Gz - auditory, visual, and bimodal) of the RT distributions were calculated for each participant. 2. $B = Gx + Gy$ i.e. the bounding sum of the CDFs of the two unimodal conditions was calculated which provides the limit at which the race model is violated. 3. Percentiles were determined for Gz and B i.e. the redundant condition and the bound for each participant. In this study, the RMI was investigated at every 5th percentile (5th, 10th, 15th...95th) point of the RT distribution. 4. $(B - Gz)$ was computed i.e. mean RTs from the bound minus the mean RTs in the bimodal condition at each percentile. Positive differences were subjected to a one-sampled t-test against zero to investigate whether the difference was statistically significant, supporting the existence of an integrative process (MSI).

3. Results

The differences in d' scores and mean reaction times across modality, emotion and gender were analyzed by a 2 (emotions: fear, disgust) x 2 (genders: male face, female face) x 3 (modalities: auditory, visual, bimodal) repeated measures ANOVA. To investigate differences in overall discrimination performance (SACS; see Methods) across modalities, the SACS were subjected to a one-way repeated measures ANOVA. Bonferroni post hoc analyses were conducted when appropriate.

3.1. Behavioural results

3.1.1. Redundancy Gain. There was an overall 3 percent reduction in average reaction time in the multisensory condition (when compared to the fastest unimodal condition – in this case, the visual condition). However, the RG was not significant i.e. there was no significant difference between the bimodal ($M = 600.13$, $SD = 116.93$) and the visual (i.e. the fastest unisensory condition) ($M = 615.70$, $SD = 98.64$) modalities, $t(16) = 1.302$, $p = .211$. A paired t-

test revealed a significantly higher RG for the emotion of fear ($M = 2.82, SD = 7.18$) compared to the disgust ($M = 2.63, SD = 7.17$) emotion $t(16) = 2.830, p = .012$ (Fig. 3).

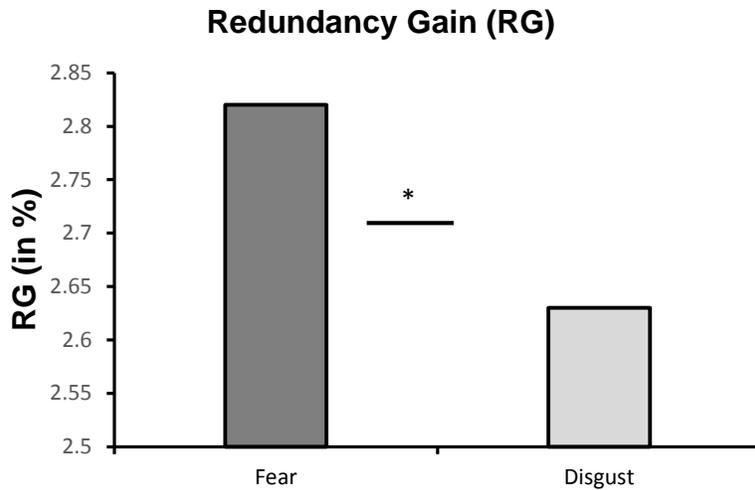


Fig. 3. Redundancy gain (in percent) for the emotion of fear and disgust. The figure indicates superior RG for the emotion of fear in comparison with the emotion of disgust.

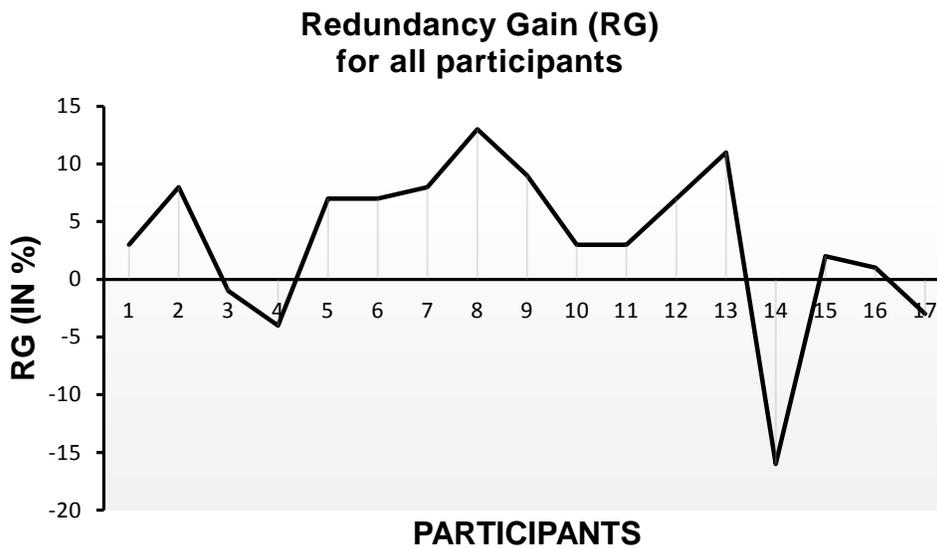


Fig. 4. Redundancy Gain (RG) for all participants in percentage. Participants 3, 4, 14, and 17 show no RG in the bimodal condition.

Further observation of the data revealed that four out of the seventeen participants showed a negative RG or no RG i.e. they were faster in the visual modality than the bimodal (see Fig. 4), and seemed to skew the data. Excluding these participants increased the RG to six percent. Hence, analyses were conducted both with all participants ($N = 17$) and with participants excluding those who did show a gain in the bimodal modality ($N = 13$).

3.1.2. d' Scores. For the d' scores (with $N = 17$), main effect of the factor “gender” ($F(1,16) = 38.26, p < .001, \eta^2_{\text{partial}} = .705$) was evidenced with more sensitivity to female faces than male faces ($p < .001$). There was a main effect of the factor “emotion” ($F(1,16) = 7.636, p = .014, \eta^2_{\text{partial}} = .323$) as well, with superior performance for disgust as compared to fear emotion ($p = .014$). However, a significant three way (emotion x modality x gender) interaction was observed ($F(2,32) = 7.906, p = .002, \eta^2_{\text{partial}} = .331$; see Appendix A for interaction graph). In the auditory modality, accuracy to Female Fear was significantly higher than Male Fear ($p = .002$). There was no significant difference between Female Disgust and Male Disgust ($p = .077$), Female Fear and Female Disgust ($p = .727$) and Male Fear and Male Disgust ($p = .085$). In the bimodal modality, Female Disgust was better detected than Male Disgust ($p = .012$), but no reliable differences were found between Female Fear and Male Fear ($p = .173$), Female Fear and Female Disgust ($p = .199$) and Male Fear and Male Disgust ($p = .786$). Similarly, in the visual modality, higher accuracy was evidenced for Female Disgust than Male Disgust ($p = .009$), and for Female Disgust than Female Fear ($p = .003$), but differences were insignificant for Female Fear and Male Fear ($p = .311$) and Male Fear and Male Disgust ($p = .410$). There was no main effect of “modality” ($F(2,32) = 2.899, p = .07, \eta^2_{\text{partial}} = .153$), as well as no significant modality x emotion ($F(2,32) = 1.041, p = .365, \eta^2_{\text{partial}} = .061$), emotion x gender ($F(1,16) = 1.063, p = .318$,

$\eta^2_{\text{partial}} = .062$) and gender x modality ($F(2,32) = 1.670, p = .204, \eta^2_{\text{partial}} = .095$) interactions. For $N = 13$ participants, similar results were obtained (see Appendix B).

3.1.3. Mean Reaction Times (RTs). With $N = 17$ participants, a main effect of “gender” was observed ($F(1,16)=6.22, p = .024, \eta^2_{\text{partial}} = .280$), with greater RTs for Female Faces as compared to Male Faces ($p = .024$). A main effect of the factor “modality” was also evidenced ($F(1.33, 21.37)= 126.22, p < .001, \eta^2_{\text{partial}} = .887$), revealing inferior performance (slower/larger RTs) for auditory stimuli as compared to visual ($p < .001$) and bimodal ($p < .001$) stimuli. Even though RTs for the bimodal modality were faster than the visual, the difference between these two modalities was not significant ($p = .645$) (see Fig.5).

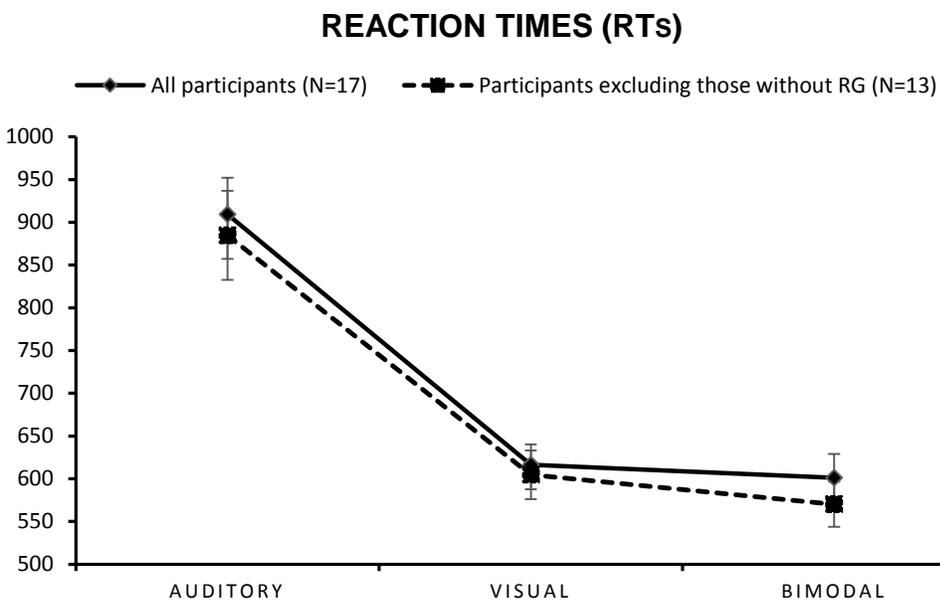


Fig. 5. Reaction times of all participants ($N = 17$), and participants excluding those without RG ($N = 13$) for the discrimination of stimuli presented in the auditory, visual and bimodal condition. Error bars denote standard error of the group. After participants without RG were excluded, visual RTs were significantly slower than bimodal RTs.

A significant “gender” by “emotion” interaction was also evidenced ($F(1,16) = 8.25, p = .011, \eta^2_{\text{partial}} = .340$) (see Appendix C for interaction graph). For fear expressions, there was no significant difference between male and female actors ($p = .228$). However, for disgust expressions, reaction time to female actors was higher than male actors ($p = .006$). When emotions were depicted by female actors, there was no significant difference in reaction times of the participants for fear and disgust emotions ($p = .067$), but when depicted by male actors, participants showed lower reaction times for the emotion of disgust than fear ($p = .031$). There was no main effect of “emotion” ($F(1,16) = .080, p = .781, \eta^2_{\text{partial}} = .005$), and no significant interactions between gender and modality ($F(1.11, 17.84) = .676, p = .438, \eta^2_{\text{partial}} = .041$), emotion and modality ($F(1.32, 21.21) = 1.047, p = .340, \eta^2_{\text{partial}} = .061$), and gender, emotion and modality ($F(1.48, 23.78) = .332, p = .720, \eta^2_{\text{partial}} = .020$). When the four participants without a RG were excluded from the analysis, similar results were obtained (see appendix B). However, post hoc analysis of the main effect of “modality” showed a significant difference not just between the auditory and bimodal, and auditory and visual modalities, but also between the visual and the bimodal modalities ($p < .001$) (see Fig.5).

3.1.4. Speed Accuracy Composite Score (SACS). As determined by a one way ANOVA, there was a significant difference in performance between modalities (with $N = 17$ participants) ($F(1.27, 20.39) = 31.580, p < .001, \eta^2_{\text{partial}} = .664$). Performance in the auditory ($M = -.929, SD = 3.27$) modality was significantly lower as compared to the visual ($M = .293, SD = .236$), $p < .001$, and bimodal ($M = .636, SD = 2.71$), $p < .001$, conditions. There was no significant difference between visual and bimodal conditions (p

= .320) (see Fig. 6). Similar results were obtained with N = 13 participants excluding those with a negative RG (see Appendix B).

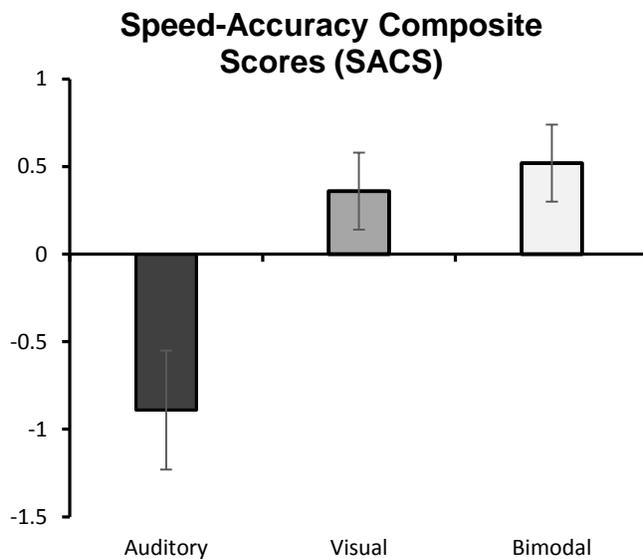


Fig. 6. Speed-Accuracy Composite Scores (See Methods) for all participants (N = 17) for the discrimination of emotional expressions in the auditory, visual and bimodal condition. Error bars denote the standard error of the group. There is a significant difference between auditory and visual, and auditory and bimodal modalities, with superior performance in the bimodal modality, followed by the visual, and

auditory modalities. There is no significant difference between the bimodal and visual conditions.

3.1.5. Multisensory Integration – Evaluating the Race Model Inequality (RMI). To further investigate whether multi-sensory integration occurred or not, the difference between the probabilistic bound and the RTs of the bimodal condition was computed at each percentile of the reaction time distribution. This positive difference was subjected to a one sample t-test against zero in order to determine whether it was significant or not i.e. whether it violated the race model prediction or not.

In the present study, when all participants' data was subjected to the t-test, no violation of the race model inequality was found, thus suggesting no multisensory integration (Fig. 7). The differences at every 5th percentile, and the corresponding significance values are displayed in Appendix D.

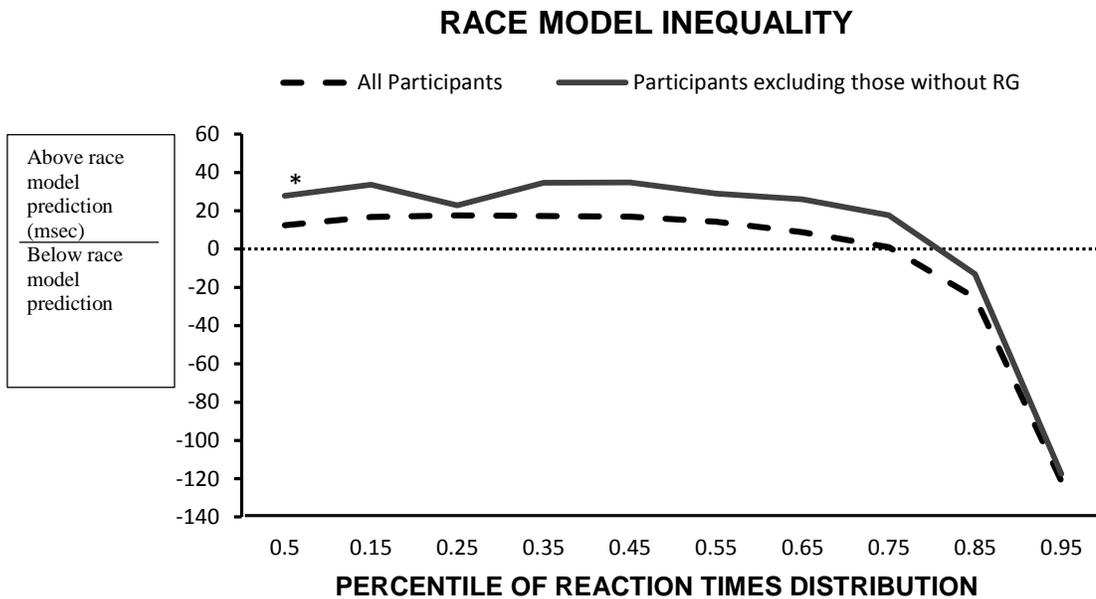


Fig. 7. Test for violation of the Race Model Inequality (RMI) (Miller, 1982; Ulrich, Miller & Schröter, 2007). The graph represents the difference (on the Y-axis, in milliseconds) between the RTs of the bound (model prediction calculated from the unisensory conditions) and the RTs of the redundant condition. The difference is plotted at each percentile (X-axis). Positive values refer to the RTs faster than the race model prediction; negative values refer to the RTs slower than the race model prediction. For all participants ($N = 17$) the positive values did not significantly exceed the race model inequality at any percentile of the RT distribution. For participants excluding those who had no RG ($N = 13$), the positive difference significantly exceeded the race model prediction at all 5th percentiles (except for the 25th percentile) (*: $p < .05$).

When the 4 participants without RG were excluded from the data, the analysis revealed a violation of the Race Model Inequality i.e. multisensory integration. The difference between the redundant condition and bound was significantly larger than zero at all 5th percentiles except the

25th and 85th (Fig.7). At the 95th percentile, the difference was significant, but negative. The mean RT differences and the significance values are displayed in Appendix E.

3.2. Electrophysiological results

3.2.1. P1. In the visual and the bimodal conditions, a strong posterior positivity (Fig. 8) (biased towards the right hemisphere) at around 160 milliseconds (identified as the P1 component) was observed (Fig.2 (A)). Paired sample t-tests revealed higher latencies for the visual modality ($M = 165.00$, $SD = 13.38$) than the bimodal ($M = 162.56$, $SD = 12.67$); $t(15) = 2.173$; $p = .046$; and lower amplitudes for the visual ($M = 6.32$, $SD = 4.82$) than bimodal ($M = 7.38$, $SD = 5.59$), ($t(15) = -2.561$; $p = .022$).

3.2.2 N170. Following the P1, there was a negative deflection at around 200 ms, identified as the N170 component. However, even though the bimodal condition ($M = -0.98$, $SD = 2.84$) evidenced a higher negativity than the visual ($M = 0.99$, $SD = 4.37$), the difference was not significant ($t(15) = 1.539$; $p = .145$). Similarly, there was no significant difference between the bimodal ($M = 196.87$, $SD = 26.33$) and visual ($M = 202.56$, $SD = 17.58$) latencies $t(15) = 0.891$; $p = .387$.

3.2.3. P2. Figure 2 (B) shows the morphology of the waveform in the auditory modality at electrode FT9 and its corresponding topography. Auditory stimuli evoked a positivity in the left fronto-temporal region, at around 200 milliseconds, identified as the P2 component (Fig. 8). In the visual and bimodal conditions, positivity at around 250-260 ms was seen in the posterior occipital sites, with a right hemisphere bias (see Appendix F for topographical maps). A paired samples t-test revealed no significant differences between visual ($M = 10.43$, $SD = 7.93$) and bimodal ($M = 10.74$, $SD = 6.96$) P2 amplitudes ($t(15) = -0.428$, $p = .675$). However P2 latency in the bimodal ($M = 274.50$, $SD = 22.31$) modality was significantly higher than in the visual ($M =$

267.62, $SD = 24.22$), ($t(15) = -2.368$, $p = .032$). The same statistical analyses were run excluding participants who had no RG. Similar results were obtained (see Appendix B).

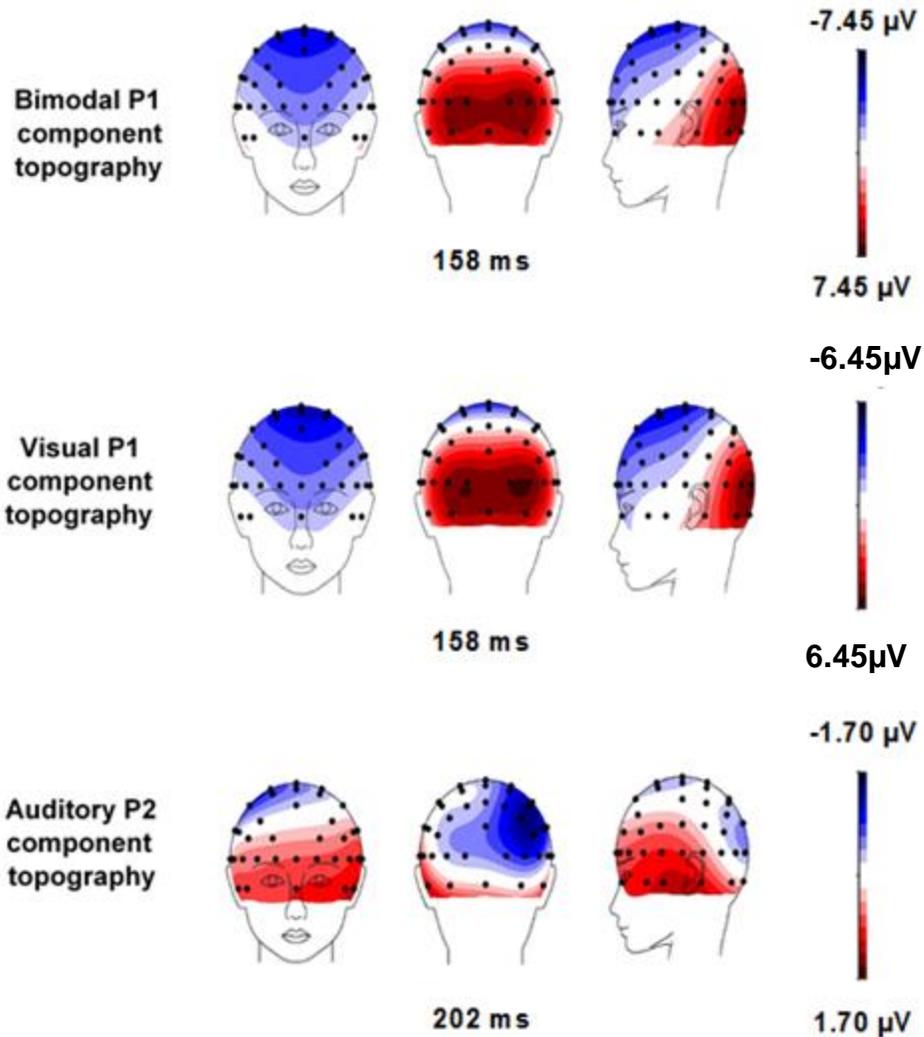


Fig. 8. Topographical voltage maps. Spatio-temporal distribution of grand averaged bimodal and visual P1 component, and auditory P2 component are displayed. Keys to the side show range of voltages (in μV).

3.3. Correlation between behavioural performance and ERPs

Table 1 shows the correlation matrix between the accuracy and reaction time in all three modalities and respective latencies and amplitudes of ERP components. A significant correlation was found between P2 amplitudes and reaction times of participants in the auditory condition

($\rho = -.54, p = .03$) suggesting that those with higher amplitudes responded faster. A significant correlation between reaction times and P1 amplitudes was found in both the visual ($\rho = -.52, p = .039$) and bimodal ($\rho = -.64, p = .007$) conditions, again indicating faster responses for those with higher amplitudes. In the bimodal modality, P2 latency correlated significantly with accuracy ($\rho = .570, p = .021$), indicating higher accuracy in those with longer latencies. P2 latency also correlated with reaction times ($\rho = .676, p = .007$), suggesting slower responses by those with longer latencies.

Table 1. Correlation matrix showing correlations between accuracy (d') and reaction time (RT) in auditory, visual and bimodal conditions, and respective within-modality ERP component amplitudes and latencies.

Component	Visual		Bimodal		Auditory	
	d'	RT (ms)	d'	RT (ms)	d'	RT
Visual P1 Latency	.22	-.18				
Visual P1 Amplitude	-.17	-.52*				
Visual N170 Latency	.10	.02				
Visual N170 Amplitude	-.10	-.38				
Visual P2 Latency	.38	.48				
Visual P2 Amplitude	-.20	-.30				
Bimodal P1 Latency			.34	-.18		
Bimodal P1 Amplitude			-.34	-.64**		
Bimodal N170 Latency			-.16	-.45		
Bimodal N170 Amplitude			-.16	-.27		
Bimodal P2 Latency			.570*	.676**		
Bimodal P2 Amplitude			-.26	-.18		
Auditory P2 Latency					.07	.02
Auditory P2 Amplitude					-.06	-.54*

Note: Spearman's ρ correlations. All are 2-tailed.

* $p < .05$

** $p < .01$

Discussion

Multisensory Integration (MSI), Behavioural and Electrophysiological Results

The present study sought to investigate the multisensory processing of non-verbal affective vocalizations and dynamic facial movements expressing the emotions of fear and disgust. As supported by previous findings in both multisensory processing of emotions (Charbonneau et al., 2013) as well as other stimuli (Giard & Peronnet, 1999), participants showed improved performance in the bimodal modality as compared to the unisensory modalities. However, response times and SACS (see Methods) in the bimodal and visual modalities were significantly higher than the auditory modality, but not statistically significant between the bimodal and visual modalities. A potential explanation for this asymmetry in findings may be visual dominance – individuals are inclined to rely on information coming from the visual modality when presented with concurrent information from other modalities (Diaconescu, Hasher, & McIntosh, 2013). The faster RTs and improved SACS in the bimodal modality as compared to the unisensory auditory modality may be a result of clear, unambiguous information from the visual modality that facilitates performance. However, the salience of auditory stimuli may be reduced when they are presented together with visual stimuli, an interpretation which is consistent with previous results (Colavita, 1974; Diaconescu et al., 2013). This finding has been seen in affect perception as well – emotions expressed in the visual modality were perceived to be more intense than the auditory modality, thus leading to a visual dominance effect (Collignon et al, 2008).

To further evidence multisensory processing, Miller's (1982) Race Model Inequality was evaluated. Inconsistent with previous studies (Collignon et al., 2008), no violation of the race model was found. If the positive difference between the mean RTs from the bound (i.e. the race

model prediction – the sum of the cumulative density functions of the RT distributions in the two unimodal conditions) and the mean RTs from the bimodal condition is significantly above zero, the race model is violated. The gain in performance cannot be attributed to statistical facilitation, but to co-activation or MSI. However, in the present study, no MSI was found. This absence of MSI can be potentially explained by the principle of “inverse effectiveness” (Meredith & Stein, 1983). This principle states that MSI is weaker when the constituent unisensory information is more salient and evokes a stronger response when presented alone. It is possible that the visual stimuli used in the paradigm were highly salient for the participants, and thus produced low or no MSI. This hypothesis is also supported by previous research (Stevenson et al., 2012; Stein & Stanford, 2008) which found weaker MSI when its unisensory components were more salient when presented in isolation.

Electrophysiological responses comprised of the amplitudes and latencies for the visual P1, N170 and P2, and the auditory P2 components. The visual P1 component showed increased amplitudes and shorter latencies in the bimodal condition when compared to the visual. The reliability of ERPs as more sensitive than behavioral measures, has been evidenced in many studies (for example, Russo et al., 2010). Thus, even though behavioral measures did not show a statistically significant difference in performance between the visual and bimodal modalities, this difference was noticeable in the amplitude and latency of the P1 component. Another interpretation of an increased P1 amplitude could be that the auditory stimulus that accompanied the visual one in the bimodal condition enhanced the processing of the visual stimulus. The literature on unimodal processing has demonstrated an increase in the amplitude of the P1 component when processing is enhanced (Hillyard, Vogel, & Luck, 1998; Luck, 2000). The P1 is said to originate in the primary visual cortex or the lateral extrastriate cortex (Gonzalez, Clark,

Fan, Luck, & Hillyard, 1994). A study using transcranial magnetic stimulation (TMS) found an increase in signals within low level primary cortex for visual stimuli when accompanied by concurrent auditory signals (Romei, Murray, Cappe, & Thut, 2009), thus further supporting the hypothesis that simultaneous auditory stimulus presentation enhances visual processing. Shorter latencies for the P1 in the bimodal condition further demonstrated faster sensory processing in this condition, as well as faster RTs (Jeste & Nelson III, 2008).

However, there was no significant difference in amplitudes and latencies of the N170 component and in the amplitudes of the visual P2 component. The N170 is said to be generated in the occipito-temporal sites, specifically the fusiform gyrus, and reflects higher order face processing such as the structural encoding of faces (Bentin, et al, 1996). The P2 is also representative of higher order perceptual processing, modulated by attention, language, and other higher order cognitive processes (Luck & Hillyard, 1994). Thus, the present results suggest that individuals integrated information in the early stages of processing, but higher order perceptual processing led to increased salience of the visual stimulus, demonstrating lower or no MSI in the later stages of stimulus processing. A significant increase in the P2 latency in the bimodal condition is, however, in contrast to the behavioral improvement in performance i.e. a faster response time. Jeste & Nelson III (2008) suggest that latencies of later ERP components (like the P2) in an active paradigm (a task which requires a motor response from the participant) reflect cognitive processing while response times denote the actual time taken to generate a motor response. Thus, a possible explanation of the discrepancy between faster response times and larger P2 latencies could be that the bimodal condition did not facilitate cognitive processing (no higher order MSI), but improved motor response speed, though insignificantly. Another possible explanation is that the presence of the auditory stimulus simultaneously with the visual one

actually interfered with the processing of the stimulus, instead of facilitating it. This explanation is in line with the findings of (Joassin, Maurage, Bruyer, Crommelinck, & Campanella, 2004) who observed an “interference effect” i.e. a decreased performance in the recognition of face-voice pairs as compared to faces only, due to interference by the auditory modality. This interference may possibly be reflected in the increase in latency of the P2 component in the bimodal condition.

Effects of Emotion and Gender

A higher redundancy gain was evidenced for the emotion of fear as compared to the emotion of disgust. A potential explanation could be that participants relied on both the auditory and the visual modalities for categorization of the fear expression in the bimodal modality, whereas they relied less on the simultaneous presentation of both the modalities, and more on only the visual modality for categorization of disgust. This is corroborated by previous findings by Collignon et al. (2010) who found that the auditory channel is said to dominate response selection for the emotion of fear. Studies using magnetic resonance imaging (MRI) have shown separate neuronal responses for fear and disgust (Phillips et al., 2004); the anterior insula was significantly more activated for the facial emotion of disgust as compared to fear but showed no activation by disgust auditory stimuli (Phillips et al., 1998).

Research suggests that different neuronal mechanisms are involved in the processing of female and male affect through the auditory (Sokhi, Hunter, Wilkinson, & Woodruff, 2005) and the visual (Little, DeBruine, & Jones, 2005) modalities. This can explain why performance in emotion categorization is affected by whether a female or a male actor depicts the emotion. Individuals showed an overall improved performance when emotions were depicted by female actors (except for fearful male faces), as also evidenced by Ramsey-Rennels & Langlois (2006).

However, an interaction between gender and emotion demonstrated faster RTs for female actors expressing fear, and faster RTs for male actors expressing disgust. This is supported by evidence from Collignon et al. (2010) who also found a bias towards fear for female actors and towards disgust for male actors.

Correlations between behavioral and electrophysiological methods

There was a significant correlation between some of the latencies and amplitudes of the ERP components and the behavioral measures of accuracy and reaction times. P1 and P2 amplitudes in the visual and bimodal conditions evidenced an inverse relationship with the RTs of the participants in the corresponding condition. This suggests that in the visual and bimodal modality, faster response times may be due to the increased salience of the (visual) stimulus (as evidenced by the increase in amplitudes). This is in line with previous findings by Lerner et al. (2013). In the auditory modality as well, a significant negative correlation between auditory P2 amplitudes and RTs in the auditory condition suggests that decreased salience of the auditory stimuli led to slower responses. The behavioral results indicate that RTs in the auditory condition are significantly slower than the visual and bimodal RTs. This supports previous findings of auditory stimuli being less intense than the visual ones (Posner, Nissen, & Klein, 1976). The P2 latency in the bimodal condition was positively correlated to both accuracy and reaction time. Thus, faster higher order cognitive evaluation of affective facial content allowed for faster responses (as also found by Lerner et al., 2013), but decreased accuracy. Participants may have traded accuracy for speed, and this is supported by behavioral findings which indicate highest accuracy in the auditory modality, followed by the visual and bimodal, though the difference is statistically insignificant.

Out of the 17 participants, four (all males) did not show a redundancy gain. They were faster in the visual modality than the bimodal modality. When these four participants were excluded from the analysis, the other 13 participants evidenced significantly lower RTs for the visual condition when compared to the bimodal, a difference not reflected with all participants. The RTs for the bimodal condition for all participants did not violate the race model prediction, thus suggesting that the RG was due to statistical facilitation (Miller, 1982). However, with the 13 participants, the race model prediction was violated, indicating co-activation or integration of information from the auditory and visual modalities. This suggests that for the four participants, simultaneous presentation of information did not facilitate, but hampered performance. A small sample size limits the ability to substantially support an argument as to why these four male participants showed no RG. A possibility could be that they showed greater visual dominance than others. Further, males are said to process multisensory information less efficiently than females (Collignon et al., 2010), and hence, they did not evidence a redundancy gain. It is suggested that the study be replicated with a bigger sample to increase the credibility of its findings.

Evaluation of the current paradigm

The paradigm used in the present study has been adopted from Charbonneau et al. (2013), but extended by the use of electrophysiological measures. Similar paradigms have been used before to elucidate multisensory affect processing in individuals (Collignon et al., 2008; Collignon et al., 2010). The paradigm involves the use of dynamic stimuli instead of static, prototypical faces. Dynamic but fully expressed emotions have also been used by a few studies, though they did not reveal a significant difference between ASD and TDs (Loveland et al., 1997). These fully expressed emotions are less frequently encountered in the real world, and

hence are considered less ecologically valid than subtle, slowly evolving dynamic stimuli (Harms et al., 2010) as used in the present study. As individuals with ASD have been known to show deficits in social interaction even when they show intact performance on emotion categorization tasks (Gepner, Deruelle, & Grynfeldt, 2001), emotions differing in intensity (from neutral to full expression or from one expression to another) may be more sensitive in identifying differences between individuals with ASD and TDs (Harms et al., 2010). Thus the dynamic stimuli used in the present paradigm may help better elucidate differences between these two groups. In the study by Charbonneau et al., auditory, visual and bimodal stimuli were presented randomly, instead of being grouped into blocks of each modality. There is a possibility that the observed differences for MSI in the ASD group may be a result of a deficit in switching modalities and not a deficit in MSI per se. In this respect, some studies have demonstrated attentional and modality switching abnormalities in the ASD group (Allen & Courchesne, 2001; Reed & McCarthy, 2012). The current paradigm avoided this problem by grouping together the stimuli from each modality, and may thus be more sensitive to MSI differences between groups. In addition to this change, the study extended the paradigm from Charbonneau et al. (2013) by using electrophysiological measures. ERPs have been shown to be more sensitive than behavioral measures, and help us to better understand the underlying neural mechanisms of behavior (Jeste & Nelson III, 2008). This is reflected in the present results as well; ERPs were more sensitive than behavioral measures as evidenced by a significant difference in the bimodal and visual P1 amplitudes, but no difference in the performance in the two conditions. Because the goal of the present study was to only assess ERP responses across modalities, the effect of emotion and gender was not taken into consideration. Previous studies have demonstrated changes in the latency and amplitudes of ERP components due to the emotion expressed

(Magnée et al., 2008). Further research is needed to investigate these effects in more detail. In order to make this paradigm more sensitive to differences in MSI, its reliability in eliciting an MSI effect needs to be evaluated. The results indicate that the task did not elicit robust MSI effects in all participants. Though all individuals show a visual dominance, it is a flexible phenomenon, dependent on the situation, which allows the combination of information across different modalities for maximum efficiency (Ernst & Bühlhoff, 2004). Thus, the uncertainty or ambiguity of different sensory modalities affects what is perceived in the multisensory condition. It is ecologically more beneficial to give more importance to that modality which is less ambiguous. The principle of inverse effectiveness also works similarly: MSI is more intense when the constituent unisensory signals are less salient (Meredith & Stein, 1983). Thus, a suggested task manipulation is the addition of noise to make the stimuli more ambiguous and less salient. Previous studies have demonstrated an accentuated multisensory benefit or a more salient redundancy gain when speech was perceived in background noise for both individuals with ASD and TDs (Foxy et al., 2013; Sumbly & Pollack, 1954), the very condition in which MSI is most beneficial. Thus, these manipulations in the current paradigm may help make the MSI effect more salient and be more sensitive in identifying differences in the ASD and TD groups.

Limitations and suggestions for future research

It is also essential to consider alternate interpretations of the results and the limitations of the present study. Though visual dominance and interference effects have been previously demonstrated and can account for the lack of MSI in all participants, the present study is limited by its sample size. It is possible that the current paradigm may elicit strong MSI effects with a larger sample size. Further, the emotions used were both negative emotions (disgust and fear). Further studies should make use of a larger pool of emotions (Bal et al., 2010) and measure ERP

effects for emotion and gender, along with modality. A further analysis of later components like the N300 and N250 (Lerner et al., 2013) and P300 (Campanella, Delle-Vigne, Kornreich, & Verbanck, 2012) will also aid in revealing the underlying mechanisms of higher order multisensory processing of affective content. If this task is to be used in investigating the differences between the ASD and TD groups, a certain number of factors need to be taken into consideration. Affective MSI may differ in sub-populations like AS and PDD-NOS in the broad spectrum of autism (Bonnel, et al., 2010) and may also be affected by demographic factors like age and IQ (Harms et al., 2010), and thus it is essential to control for these variables.

In conclusion, the current results both behaviourally and electrophysiologically demonstrate that using the present forced choice emotion categorisation paradigm does not compellingly show MSI in TDs, but corroborates already existing evidence on visual dominance. Lower SACS and larger RTs show a significantly reduced performance in the auditory modality as compared to both visual and bimodal, but no difference in the visual and bimodal modalities. However, electrophysiological measures are more sensitive in investigating multisensory processing of affective information. Further, both emotion and gender affect the behavioural measures of accuracy and response times. Though a small sample size limits the generalisability of the study, this pilot is useful in that it helps assess the reliability of the paradigm for investigation of MSI in ASD. In light of the data presented, certain manipulations have thus been suggested, and a modified affective MSI paradigm has been proposed which can be used to further elucidate differences in the ASD and TD groups. This will help better understand the etiology of the disorder, and assist in development of targeted interventions and better diagnostic instruments.

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doi:10.1111/j.1460-9568.2008.06328.x

Appendix A

Graphs for d' scores showing a three way interaction between Emotion, Gender and Modality

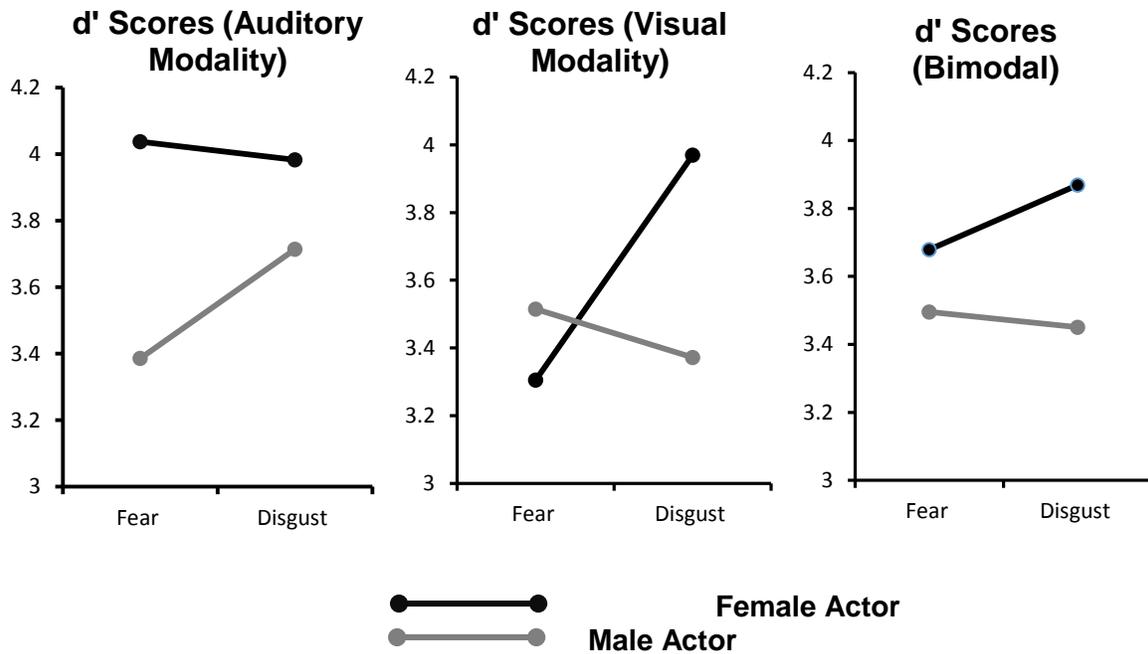


Fig. A1: The figure shows a three way interaction between emotion, gender, and modality for the d' scores (measuring accuracy). Participants have higher accuracy when it is a female actor depicting the emotion in all conditions except when a male actor depicts fear in the visual modality.

Appendix B

Results for only those participants who showed a reliable RG (N = 13)

Out of the 17 participants, 4 participants did not evidence a redundancy gain (RG), and thus the data of participants excluding those with no RG (N = 13) was subjected to the same statistical analyses used for all participants. The results obtained for these thirteen participants is as follows.

D' Scores: A main effect of emotion was observed ($F(1,12) = 7.61, p = .017, \eta^2 = .388$), with higher accuracy for disgust than fear ($p = .017$), but slightly less significant than earlier results. A main effect of gender was also evidenced ($F(1, 12) = 32.73, p < .001, \eta^2 = .732$), with higher sensitivity to female faces than male faces ($p < .001$). There was a significant interaction between gender, emotion and modality ($F(2, 24) = 6.69, p = .005, \eta^2 = .358$), but no significant main effect of modality, and no gender by emotion, emotion by modality, and modality by gender interactions.

Mean RTs: There was a main effect of gender ($F(1, 12) = 6.47, p = .026, \eta^2 = .350$), with larger RTs for female faces than male faces ($p = .026$). A significant effect of the factor modality was also evidenced ($F(2, 24) = 88.01, p < .001, \eta^2 = .880$), with a significant difference between bimodal ($M = 570.02, SD = 26.54$) and visual ($M = 604.74, SD = 28.47$) and auditory ($M = 884.55, SD = 52.10$), ($p < .001$) and visual and auditory as well ($p < .001$). In contrast with earlier results (when N = 17), a significant difference between bimodal and visual was also evidenced ($p < .001$), with superior performance in the bimodal condition. There was a significant gender x emotion interaction ($F(1, 12) = 8.50, p = .013, \eta^2 = .415$).

SACS: As in the previous results, modality significantly affected mean RTs ($F(1.26, 15.31) = 21.00, p < .001, \eta^2 = .636$). There was a significant difference between auditory and bimodal ($p = .002$), auditory and visual ($p = .004$), but not between visual and bimodal ($p = .162$).

ERP Amplitudes and Latencies:

P1. Paired sample t-tests revealed higher latencies for the visual modality ($M = 165.07, SD = 13.38$) than the bimodal ($M = 162.53, SD = 14.50$); $t(13) = 1.852; p = .089$, but not insignificant; and lower amplitudes for the visual ($M = 7.00, SD = 5.03$) than bimodal ($M = 8.25, SD = 5.86$), ($t(12) = -2.592; p = .024$).

N170. The bimodal condition ($M = -1.08, SD = 2.84$) evidenced a higher negativity than the visual ($M = 1.73, SD = 4.37$), the difference was not significant ($t(13) = 1.971; p = .072$). Similarly, there was no significant difference between the bimodal ($M = 197.84, SD = 27.74$) and visual ($M = 201.92, SD = 19.57$) latencies ($t(13) = 0.550; p = .592$).

P2. A paired samples t-test revealed no significant differences between visual ($M = 11.94, SD = 8.06$) and bimodal ($M = 12.12, SD = 7.02$) P2 amplitudes ($t(13) = -0.208, p = .839$). However P2 latency in the bimodal ($M = 269.07, SD = 23.04$) modality was significantly higher than in the visual ($M = 261.84, SD = 21.26$), ($t(13) = -2.072, p = .061$).

Appendix C

Gender x Emotion Interaction for Reaction Times for All Participants



Fig. C1. Gender by Emotion Interaction of Reaction Times for all Participants.

Participants showed a higher reaction time for expressions depicted by female actors than male actors. However, this difference was significant only for disgust emotions.

Appendix D

Miller's Race Model Inequality – Difference between the RTs in the bound and bimodal condition and the corresponding significance values for all participants.

Table D1. Miller's Race Model Inequality. For all participants N = 17. There was no violation of the race model, indicating no multisensory integration.

Percentile	Difference between bound and redundant condition	Significance Value (p)
0.5	12.38	.261
0.15	16.69	.135
0.25	17.55	.138
0.35	17.32	.144
0.45	16.84	.162
0.55	14.28	.238
0.65	8.73	.467
0.75	0.91	.941
0.85	-25.51	.058
0.95	-121.35	<.001

* $p < .05$

Appendix E

Miller's Race Model Inequality – Difference between the RTs in the bound and bimodal condition and the corresponding significance values for participants with RG.

Table E1. Miller's Race Model Inequality. Only for participants with RG. A violation of the race model was evidenced, indicating multisensory integration.

Percentile	Difference between bound and redundant condition	Significance Value (p)
0.5	27.79	.002*
0.15	33.69	< .001*
0.25	22.83	.135
0.35	34.68	< .001*
0.45	34.73	< .001*
0.55	29.05	.001*
0.65	25.95	.001*
0.75	17.73	.027*
0.85	-13.12	.245
0.95	-117.48	.002

* $P < .05$

Appendix F

The topographical maps for the P2 component in the visual and bimodal modalities

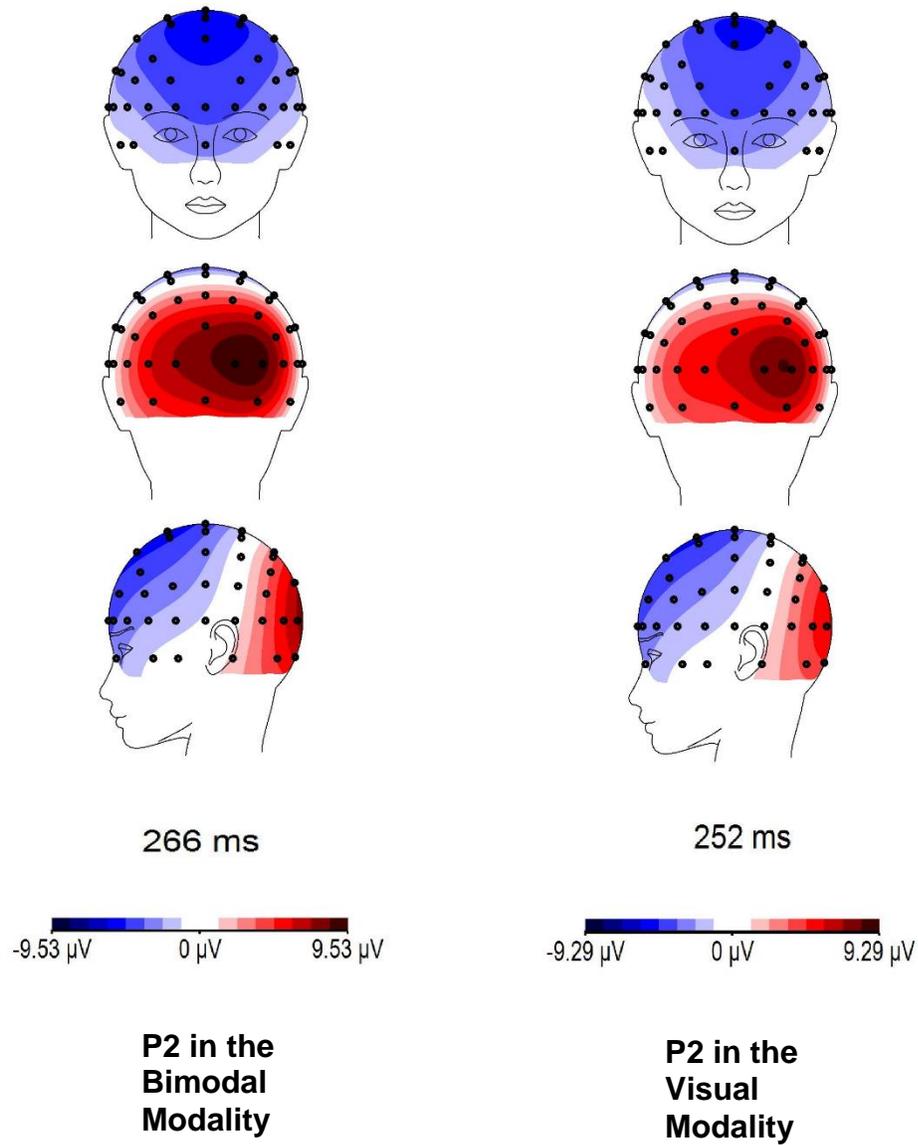


Fig. F1. Topographical voltage maps. Spatio-temporal distribution of grand averaged bimodal and visual P2 component. Keys to the bottom show range of voltages (in μV).