INTERACTION BETWEEN PROCESSING OF IDENTITY AND EMOTIONAL EXPRESSION IN FACES. COGNITIVE AND NEURAL MECHANISM

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Abstract

The central aim of the present thesis was to examine the relationship between processing of identity and emotional expression in faces. This was addressed by testing for independence versus interaction between the two processes at behavioural and neural level using the redundant target paradigm that involves examining redundancy gain when both facial identity and facial emotion targets are present, comparing performance against conditions where only one target is present. Responses to redundant targets were faster than responses to either single target when a universal emotion was conveyed, and performance violated predictions from a model assuming independent processing of emotion and face identity. The effects were not modulated by varying inter-stimulus and non-target contingencies and were eliminated when the faces were inverted. The results here indicated that greater experience with faces was associated with greater redundancy gains and super capacity in processing of identity and emotional expression. The coactive processing was preserved with age. At the neural level the redundancy effect was supported by functional connectivity between the Orbitofrontal cortex and the Occipital cortex. The findings are discussed and possible mechanisms for processing of identity and emotional expression in faces are proposed.

Key words: identity and emotional expression in faces, redundancy effect, own-race effect, aging, multivariate pattern analysis, principal component analysis, co-activation, processing capacity.

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Alla Yankouskaya

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Chapter 1

Introduction

1.1 Thesis overview

Human faces provide important signals in social interactions. Two critical types of information are facial identity and emotional expression. The importance of these facially transmitted signals in guiding interpersonal behaviour is reflected by complex relation between processing of these two facial dimensions. For example, there is evidence from studies with individuals who have lost the ability to either process face identity or facial emotion – both of which can be very disruptive for everyday life (Baudouin & Humphreys, 2006a, 2006b; Ramon, Busigny, & Rossion, 2010; Riddoch, Johnston, Bracewell, Boutsen, & Humphreys, 2008).

It is well established that facial identity and emotion are conveyed by overlapping physical features and can be equally quickly extracted and discriminated (Blau, Maurer, Tottenham, & McCandliss, 2007; Bruce & Young, 1986; Calder & Young, 2005; Calder, Young, Keane, & Dean, 2000; Schweinberger & Soukup, 1998; Vuilleumier, Armony, Driver, & Dolan, 2001). Views differ, however, on whether identity and emotion information are thought to be processed independently or in an integral fashion. This critical question, fundamental to building models of face processing, will be examined thoroughly in this thesis. The importance of exploring the relationship between these two facial dimensions links to neuropsychological rehabilitation of patients with impaired ability in face processing and methods for improving the quality of life in aging populations and the development of facial recognition software (should identity and expression codes be combined or kept separate?).

The central aim of the current thesis is to examine the relationship between identity and emotional expression in faces. To that aim, I have used a paradigm developed to investigate dependency/inter-dependency between two processing channels but applied in this instance to facial identity and emotions. The paradigm involves examining redundancy gain when both facial identity and facial emotion targets are present, comparing performance against conditions where only one target is present. Studies of redundancy effect can enable us to make inferences about the relations between processing two dimensions on the cumulative distribution function of reaction times (RTs) in an experiment (an introduction to the redundant target paradigm is provided in chapter 2). The redundant target paradigm was applied to different identities and emotional expressions (chapter 3,4) with different ethnical (chapter 5) and aging groups (chapter 6) of participants to explore the mechanisms determining the relationship between the two types of information in faces. As well as examining the behavioural consequences of having both target types present, I also examined the neural bases of the effects using fMRI chapter 4), testing how redundant targets change the coupling between relevant brain regions across an entire network of areas. Here I apply voxel-to-voxel connectivity measures combined with Principal Component Analysis (PCA) to explore the functional connectivity pattern underlying the relationship between the processing of identity and emotional expression in faces.

Prior to introducing the two novel methods redundancy gains with faces and the fMRI approach adopted), I will briefly review the literature on the processing of identity and emotional expression in faces. I will describe the main cognitive models for face perception. I also highlight those properties of faces which we may consider to be important for perception of identity and emotional expression (section 1.1.1). This review does not intend to make a systematic analysis of face processing, but merely highlights crucial points in the perception and recognition of facial cues, to provide a background context for the central question of whether identity information from faces modulates the processing of emotional expression and vise versa. Current cognitive and computational models of face processing have strong links to neural models of face perception. In section 1.1.2 I will try to chart this link through a short overview of neural models of processing facial identity and emotional expression. Following that in sections 1.2 and 1.3 I will present evidence supporting independent and interactive accounts of the processing of facial identity and emotional expression based on both behavioural and neuroimaging data. The sections (1.2 and 1.3) are organized in similar way to make a parallel argument between contrasting findings. Where relevant, I highlight some comments on methodological issues for particular studies. In section 1.4 I will explain the rationale for the present approach and I will outline hypotheses for the thesis (section 1.4.3). The general methodology I used to test the hypotheses is described in Chapter II, and this includes a detailed description of the main methods employed in the thesis (the redundant target paradigm and the voxel-to-voxel functional connectivity analysis). Neither of these methods has been used previously to test the hypothesis about separate versus interactive processing of identity and emotional expression in faces. As a consequence of this, I describe stimulus selection, the design, procedure and analysis of data in a very elaborate way. The following experiments (Chapters 3-6) tended to use similar designs and, if the procedure was slightly different it will be noted in the method for the individual experiment.

Chapters 3-6 provide evidence for the integrative processing of facial identity and emotional expression. Part of chapter 3 has been published (Yankouskaya, Booth and Humphreys, 2012) and it provides the first experiment to demonstrate a redundancy gain for expression and identity in faces. In chapter 3, I go on to discuss cognitive mechanisms for the redundancy effect I observed (Chapter 3). Chapter 4 examined the neural basis of the redundancy effect in faces and suggested possible neural mechanisms for redundancy gains. This was done by using a novel analysis tool to assess connectivity across the brain. I next explored the effects of two factors on the redundancy gain for processing facial identity and emotion. Chapter 5 presented a study that tested whether individual experience with faces modulates the redundancy effect (by varying whether participants saw their own or another race face) (paper submitted in Journal of Experimental Psychology and currently under revision). Chapter 6 investigated if the redundancy effect is preserved with age (chapter submitted to Psychology of Aging). Finally, Chapter 7 provides a general discussion and is organized to give answers to the questions I set to address in this thesis.

1.2 Models of face processing

1.2.1 Cognitive perspective

Cognitive studies of face processing can be divided into two main approaches: studies dealing with how and whether different types of information are processed, and those examining which processes are mandatory. Here I will try to give a basic overview of the both approaches, outlining only those models and studies relevant for this thesis.

Cognitive models of face perception. A large amount of research has explored the complex architecture of cognitive operations that underlie the processing of facial identity and emotional expression (Bredart, Valentine, Calder, & Gassi, 1995; Bruce &

Young, 1986; Burton & Bruce, 1993; H.D. Ellis, 1986; Massaro & Cohen, 1993; A. W. Young, Hay, & Ellis, 1985). This work has also been linked to explicit computational models of face processing (Martinez, 2003; Schwaninger, Lobmaier, Wallraven, & Collishaw, 2009; Wallraven, Schwaninger, & Bulthoff, 2005; Zana, Mena-Chalco, & Cesar, 2009). One of the most influential accounts of face coding over the past twenty-five years, proposed by Bruce and Young (1986), holds that there is independent, parallel processing of identity and expression information from faces. This model assumes several hierarchically ordered levels to serve the recognition of familiar faces (Figure 1.1).

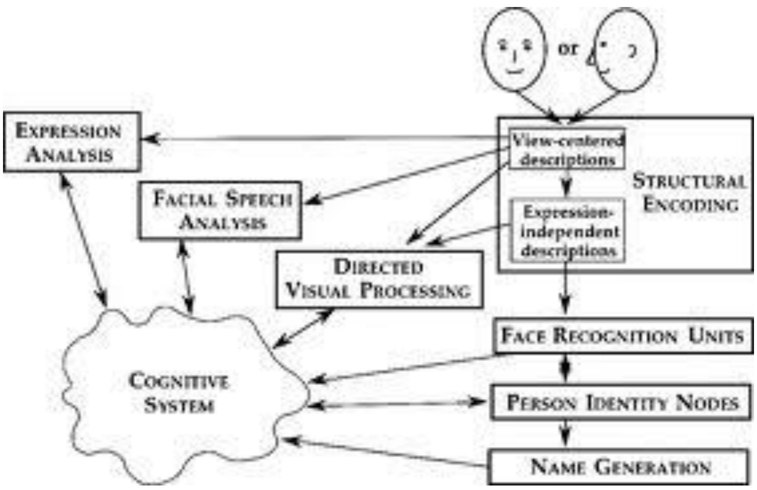

Figure 1.1. The model of face recognition proposed by Bruce and Young, 1986.

The first stage of this model, "the structural encoding stage", extracts invariant representations from different views of the same face. At this stage, the recognition of unique personal information (facial identity) is separated from the recognition of visual information in faces such as the facial expression, age, gender and ethnicity of the person. Bruce and Young (1986) propose that seven distinct codes are generated as outputs from a first stage of face processing: *the pictorial code* that is determined by variations in the visual information present (e.g., varying with the static pose, lighting, surface information available in an image); *the structural code* which distinguish one face from another across different view-points; *the visually derived semantic code* which provides information about gender, age, race, etc.; *the identity-specific semantic code* which comprises person specific information; *the name code* which specifies the name of the person; *the expression code* which comprises information about emotional expressions; *the speech code* which depends mainly on dynamic facial movements. According to this model, the expression code is derived independently of structural identity codes which support recognition of the person (Bruce & Young, 1986).

Young, Hay and Ellis (1985) developed a model (extended by Ellis in 1986) of person recognition using 922 records from people reporting difficulties they experienced when recognizing people (Figure 1.2). The authors propose that representational systems create structural descriptions of the person. Subsequently that information is passed to recognition units representing known people. These stored representations are used to access person identity information (person identity nodes), and any additional information (the additional information stores). Outputs from the recognition units and from the person identity nodes are controlled by a higher-level cognitive system where the final decision about the identity of the person is made.

Although the model by Young et al. (1985) does not consider the processing of emotional information in faces, the main idea about identity recognition is similar to the Bruce and Young (1986) model. However, there are two points on which these two models differ: (1) unlike Bruce & Young (1986), Ellis (1986) suggests an initial structural encoding stage that categorizes viewed objects as faces (versus non-faces); (2) in contrast to Bruce & Young (1986), Ellis (1986) emphasized that visual analyses of age, gender, race, etc. of the person form an essential part of recognizing the person.

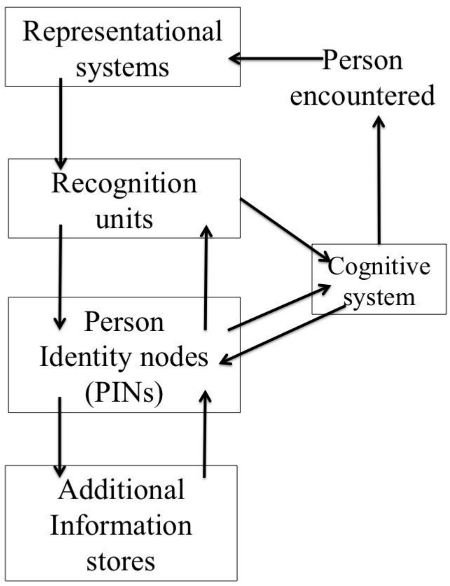

Figure 1.2. The model of person recognition proposed by Young, Hay, Ellis (1985).

Computational models of face recognition vary in the way changes in facial identity or/and emotional expression are captured. For example, the model proposed by Martinez (2003) focused on textural changes in a face. This model incorporates both the independent and interdependent processing of different facial dimensions (Figure 1.3). The proposed model did not incorporate a direct connection between the processes of coding facial identity and expression, however both processes are activated by information from common modules. For example, both processes rely on facial dynamic cues, which reflect the visible physical deformation of a face (DF) whilst expressing emotion. It is proposed that the hierarchy of processes in the proposed model starts diverging toward the specialized nodes for identity and expression recognition only after the DF process (Martinez, 2003). In contrast, in the Bruce and Young model (1986) this separation was assumed to occur at a much earlier stage.

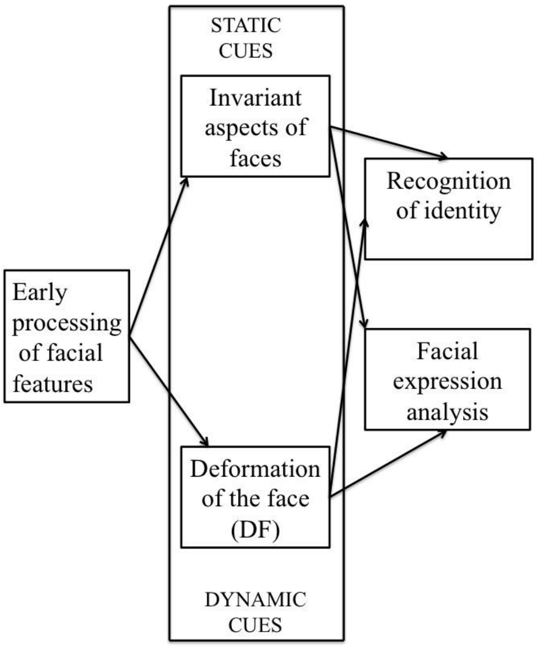

Figure 1.1. A computational model of face recognition (Martinez, 2003).

In sum, models of different aspects of face processing are consistent with the idea that face recognition is a complex multistage processing, that include a series of visual and perceptual operations that are made on the viewed stimulus. The stimulus is analysed in order to derive a unique (person's specific or invariant) representation of the face. This invariant representation is then matched to a recognition unit if the face is already known or resembles a known one. Simultaneously, there are visual operations that can be accomplished on known and unknown faces: the analysis of facial expression, the "visually-derived semantic codes" (age, gender, race, etc. of the face seen) (however, see Ellis (1986) for different view). Although the models of face perception/recognition explain a large number of empirical data (see Bruce and Young, 1986 for reviews), there are growing number of behavioural findings (see in section 1.3.1) that challenges this model. Of particular interest to the current thesis is evidence of non-independent processing of identity and emotion in faces.

Processing facial identity. A large body of research focuses on retrieval of visual representations, or type of visual information used when processing facial identity and emotional expression. I will outline only general ideas about what kind of information in faces is processed. Due to the fact that many of these ideas are still under debate, I focus on those which have received support by many studies.

It is well established that face processing uses different features (attributes) that constitute the face (Bruce & Young, 1986; Calder, Burton, Miller, Young, & Akamatsu, 2001; Calder et al., 2000; Garcia-Marques, Mackie, Claypool, & Garcia-Marques, 2004; Itier & Taylor, 2004; A. W. Young, McWeeny, Hay, & Ellis, 1986). These attributes have typically been placed into two groups: ‘internal’ attributes comprising the eyes, nose and mouth, and ‘external’ attributes comprising the hair and jaw-line (Bruce, Doyle, Dench, & Burton, 1991; Farah, Tanaka, & Drain, 1995; Hosie, Ellis, & Haig, 1988; Rhodes, 1988). Recently, behavioural and neuroimaging studies suggest that internal and external features are stored as a single unit within memory (Andrews, Davies-Thompson, Kingstone, & Young, 2010). Though it has been argued that the external attributes by themselves are important but not sufficient for face recognition

(Riesenhuber, Jarudi, Gilad, & Sinha, 2004; Sadr, Jarudi, & Sinha, 2003), as some external features can easily be changed (Chan & Ryan, 2012) and hence deemed unreliable.

Within the internal attributes another distinction has been made between “first order” and “second order” relations in faces (Chan & Ryan, 2012; Collishaw & Hole, 2000; Hancock, Bruce, & Burton, 2000; Matheson, Bilsbury, & McMullen, 2012; Tanaka & Farah, 1993). Although operational definition of these terms is varied between studies, majority of researchers defines the first order as the basic relation (canonical relation, canonical configuration) between facial features such as eyes, mouth, nose, that allows recognize a face as a face (e.g., a nose is above a mouth, two eyes above a nose). The second order relation is a perceiving the distances among these features (Maurer, Grand, & Mondloch, 2002; Mondloch, Le Grand, & Maurer, 2002).

There is an ongoing debate on the importance of each type of attribute/ information used when processing different faces (e.g. famous or unfamiliar), and for extracting different information. For example, Schwaninger, Lobmaier and Collishaw (2002) examine the extent that human face recognition relies on local information in parts and on their spatial relations. The authors report no differences for newly learned and familiar faces. Both the recognition of previously learned faces and familiar faces relied on featural and configural[1] information. It is proposed that the balance between configural and featural information does not differ for familiar and unfamiliar faces, and both types of facial information are used in integrative manner for processing all

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[1] In the literature the term ‘configural information in faces’ is often used as a synonym of ‘the second order relation’ (see, for example, Schwaninger et al., 2002 and Maurer et al., 2002).

faces (Schwaninger, Lobmaier, & Collishaw, 2002). Others show that the internal representation for familiar faces is qualitatively different from unfamiliar ones. For instance, familiarity with faces make specific features of the face salient (H. D. Ellis, Shepherd, & Davies, 1979) and can also affect the differential weighting of different features (A. W. Young, Hay, McWeeny, Flude, & Ellis, 1985). In support of that it is demonstrated that an accurate face recognition can be performed even based on only internal features (Anaki, Boyd, & Moscovitch, 2007). Furthermore, recognition of familiar faces is suggested to be based mainly on internal features (H. D. Ellis et al., 1979), while recognition of unfamiliar faces is predominantly guided by the second order relation in faces (Frowd, Bruce, McIntyre, & Hancock, 2007; Veres-Injac & Meinhardt, 2008). On the other hand, a number of studies reported that matching of unfamiliar faces was predominantly guided by external features (Frowd et al., 2007; Sadr et al., 2003; A. W. Young, Hay, McWeeny, Flude, et al., 1985; A. W. Young et al., 1986).

These inconsistencies may arise due to differences in tasks and stimuli across studies (Nestor, Vettel, & Tarr, 2008; Rotshtein et al., 2010). For example, Nestor, Vettel and Tarr (2008) examine how different tasks (face detection and face individuation) impacted the featural code used in human face processing. The authors report a small correlation between types of information in faces used across the tasks. They suggested that partial but reliable separability occurs with regard to task-specific features (Nestor et al., 2008). Notably, recently, it was suggested that negative emotions are linked with a local, rather than global, visual processing style, which may preferentially facilitate feature-based, relative to holistic, processing mechanisms (Curby, Johnson, & Tyson, 2012).

Processing of facial emotions. As far as the processing of facial emotions is concerned it is well established that “basic emotions” (i.e., joy, surprise, anger, sadness, fear, and disgust) have a universally recognized facial expression (Ekman and Friessen 1972). These expressions reflect changes in multiple facial regions, which may in turn facilitate emotion discrimination (Baudouin, Gilibert, Sansone, & Tiberghien, 2000; Curby et al., 2012; Ekman, 1993; Kaufmann & Schweinberger, 2004; Kirkpatrick, Bell, Johnson, Perkins, & Sullivan, 1996; Phelps, Ling, & Carrasco, 2006). The changes that characterise different emotions are typically based on variations in local spatial position or displacement of specific points and regions of the face. A number of studies have attempted to discover if particular facial features are associated with a particular emotion (Sadr et al., 2003; Seyama & Nagayama, 2002; Sullivan & Kirkpatrick, 1996). For example, Sullivan and Kirkpatrick (1996) show that people attend more to the lower component (the mouth) when selecting faces that express happiness, sadness, surprise, and disgust, while they attend to the upper component (eyebrows) when selecting faces expressing anger and fear. Sadr et al. (2003) examine the role of the eyebrows in expression processing. It was found that specific eyebrow densities and positions are associated with different emotional expressions and therefore the eyebrows are essential cues for triggering emotion recognition (this have been widely exploited by cartoonists who use the eye brows to express a character’s emotion).

Seyama and Nagayama (2002) investigated the impact of expression on the perception of facial features by manipulating whether the eyes expressed happy, surprised, and neutral expressions. The authors reported that 82% of participants judged the happy face composites as having larger eyes than the surprised face composites, even though the eyes were the same size. It was concluded that the lower component of the face (smiling, in a happy face) affected the perceived size of the middle and upper components of the face (the eyes). Sheller, Bucher and Gamer (2012) recently examine participants scanning patterns as they viewed particular features in happy, fear and neutral emotional expressions. The authors report that in two classification tasks participants fixated on the eye region for much longer than they fixated on any other region in the face. Also with fearful and neutral faces the eye region was attended to more - whereas more attention was directed toward the mouth of happy facial expressions (Scheller, Buchel, & Gamer, 2012). Sheller et al. (2012) postulated the existence of a pre-attentive mechanism that automatically detects relevant facial features in the visual field and facilitates the orienting of attention towards them.

A number of studies have reported more general changes in processing for happy and/or fearful emotional expression in faces, compared with when faces have neutral expressions, in particular in visual search tasks (Calvo & Nummenmaa, 2008; Calvo, Nummenmaa, & Avero, 2008; Eastwood, Smilek, & Merikle, 2003; Horstmann & Bauland, 2006; Juth, Lundqvist, Karlsson, & Ohman, 2005; Phelps et al., 2006). The most common explanations of this effect are linked to social reward and general adaptive function – for example, when aimed at avoiding a potential harm (see Calvo & Nummenmaa, 2008 for a review). An alternative account is that the advantage in processing happy and fearful expressions in faces is due to the better discriminability of facial features constituting these expressions (Calvo & Nummenmaa, 2008; Nothdurft, 2006). Interestingly, Calvo and Nummenmaa (2008) examined the six basic emotions in faces by computing the most relevant information for each type of expression. The authors suggest that the perception of a sad emotional expression relies more on configural features of faces, whereas happy faces have more salient features. It is further shown that the happy, surprised, and disgusted detection advantage is strongly dependent on the perception of single features (e.g. a shape of the mouth) rather than on emotional meaning. Furthermore, in Experiment 1 of the study where visual search performance is examined as a function of emotional facial expression, the author report poorest performance for sad expression as compared to happy, disgust, anger, fear and surprise expressions (Calvo & Nummenmaa, 2008). Similar findings for poor performance for a sad expression was reported in study examined transmitting and identifying facial expression signals over a range of viewing distances (Smith & Schyns, 2009).

Taken together, recognition of some facial emotion appears to rely on a combination of facial features. However, what the specific combination is for each type of expression is still a matter of debate. There is advantage for happy and fearful emotional expression being detected and recognized faster compared to sad, surprise, disgust and angry emotion in faces. Sad faces are processed slower as compared to others emotional expressions.

Summarizing this section, it can be said that from cognitive perspective, recognition of facial identity and emotional expression involves different cognitive mechanisms that are modulated by familiarity of faces. The cognitive mechanisms comprise several distinct processes that seemed to be integral to normal face recognition (i.e., perception of faces, accessing representation of faces stored in memory, facial expression processing, etc.). Although the two facial dimensions derived information from the same physical properties, the inputs for identity and emotional expression processing are different.

1.2.2 Neural perspective

Several models have been proposed for face processing at the neural level (Haxby & Gobbini, 2011; Haxby, Hoffman, & Gobbini, 2000; Ishai, 2008; Sergent, Ohta, & MacDonald, 1992). The model by Ishai (2008) proposes that face perception is mediated by a distributed neural system including the lateral fusiform gyrus (FFG), the superior temporal sulcus (STS), the amygdala, the insula (Ins), the inferior occipital gyrus (IOG) and the inferior frontal gyrus (IFG). The model assumes that various task demands are associated with differential coupling among face regions and the temporal dynamics of these activation patterns (Ishai, 2008). For example, viewing emotional faces increases the effective connectivity between the FG and the AMG, viewing famous, attractive faces increases the coupling between the FG and the OFC. Notably, the model made a few further predictions of such coupling, for instance, between STS and the occipital face area (OFA) (Ishai, 2008). The predictions made by this model were crucial in guiding the choice of analysis applied in the fMRI chapter, as I chose to focus the analysis on change of the coupling between the regions, rather than on change in activation strength within a specific region.

Haxby et al. (2000) propose a model very similar to the Bruce and Young model (1986) of parallel neural rotes for processing of identity and emotional expression, and mapped it onto brain regions. This model consists of a core and an extended system. The core system is comprised of the occipital face area, the fusiform face area, the superior temporal sulcus. The path from OFA to FFA corresponds to processing of identity and the path from OFA to STS corresponds to processing of changeable aspects of faces (e.g. emotion). The extended system includes, among other regions, anterior temporal cortex for retrieving semantic information of faces and amygdala, insula and limbic cortices for processing emotions conveyed by faces. In the earlier version of this model (Haxby et al., 2000) all regions of the core and extended system were interlinked showing that the distributed system may allow interactions of the functional processes that are ascribed to the different regions (Figure 1.4, a). In contrast, the updated version (Figure 1.4, b) emphasizes a distinction between representation of invariant features that are critical for recognizing facial identity and representation of changeable features that are critical for facial gestures, such as expressions (Haxby & Gobbini, 2011). In addition, the latest version of the distributed neural network for face perception focuses on familiar faces, and is silent on perception of unfamiliar faces. The authors emphasize that ‘Familiar face recognition involves visual codes for familiar individuals in Core System areas in the fusiform, and possibly anterior temporal, cortex, along with the automatic activation of person knowledge and emotional responses. Facial expression involves visual codes in the STS, along with activation of representations of emotion and motor programs for producing expressions. Perception of eye gaze similarly involves visual codes in the STS, along with activation of brain areas for shifting attention and oculomotor control’ (Haxby & Gobbini, 2011).

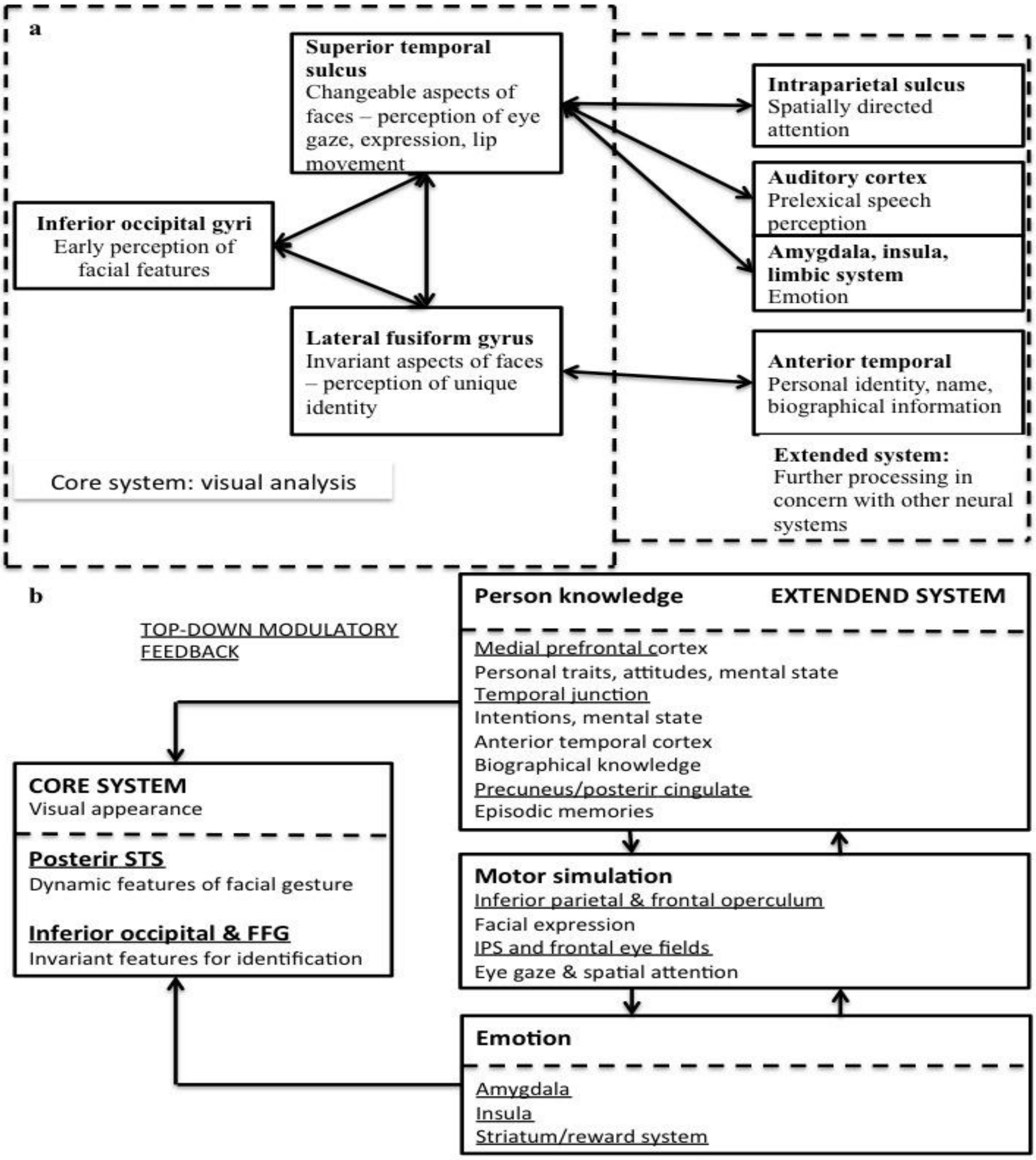

Figure 1.2. The model of distributed neural systems in face perception proposed by Haxby and Gobbini (2000) (a - the earlier version, b - the updated version).

Haxby and Gobbini mention that an adequate account of the neural architecture that underlies face perception, cannot be achieved by exclusively focusing on a single area, but rather '… must take into account the context in which that region functions, both in terms of the distributed system of cortical areas and in terms of the full range of cognitive operations that fall within the domain of face perception' (Gobbini & Haxby, 2007). Although the functional specialization of regions in processing of different aspects of faces is debated, functions of some regions are consistently reported in neuroimaging studies. For example, the fusiform gyrus (FFG) is found to be preferentially involved in processing temporally-invariant facial structure that provide cues to properties such as identity and gender (Fairhall & Ishai, 2007; Gobbini & Haxby, 2006; Haxby & Gobbini, 2011; Kanwisher, McDermott, & Chun, 1997; Sergent et al., 1992). STS is suggested to process variant (changeable) facial properties such emotional (Adolphs, 2003; Andrews & Ewbank, 2004; Campbell, Brooks, de Haan, & Roberts, 1996). The amygdala and insula has been shown to respond to emotionally valenced information in faces (Adolphs, 2003; Cools et al., 2005; Ewbank, Fox, & Calder, 2010). The inferior occipital gyrus is sensitive to the second order relation in faces to faces; while a more dorsal part is sensitive to facial features (Rotshtein, Geng, Driver, & Dolan, 2007).

Taken together, distributed neural networks for face processing propose: task-specific modulation of functional coupling between all regions in processing of identity and emotional expression (Ishai, 2008) and anatomical and functional separability of regions in the brain involved in processing of identity and emotional expression in faces (Haxby & Gobbini, 2011) (supporting evidence for the models see in the section 1.3.2). The question what neural network supports the interaction between processing of identity and emotional expression in faces is one of issues addressed by the present thesis, in chapter 4.

1.3 Independent processing of facial identity and emotional expression: supporting evidence

1.3.1 Behavioural studies

The main support for the separate-parallel routes for processing of identity and emotional expression (Bruce and Young, 1986) came from neuropsychological studies showing double dissociations. Case studies of patients are reported to have impaired recognition of face identity but not emotion (Bruyer et al., 1983; Campbell, Landis, & Regard, 1986; Jones & Tranel, 2001; Nunn, Postma, & Pearson, 2001), while other patients have impaired discrimination of face expression but not identity (Bruyer et al., 1983; Humphreys, Donnelly, & Riddoch, 1993).

Studies with healthy participants also provide some support to the parallel route hypothesis (Etcoff, 1984; A. W. Young et al., 1986). For example, Young et al. (1986) ask participants to make identity judgment (are a pair of faces represents the same person?) or emotion judgment (do a pair of faces express the same emotion?) of familiar and unfamiliar faces. Familiarity affected identity judgment but not emotion judgment (Young et al., 1986). The authors suggest that analyses of facial expressions proceed independently from processes involved in processing of the person's identity. Etcoff (1984) use the Garner’s task (Garner, 1974) to assess the inter-relation between identity and expression processing. In this paradigm the two stimulus dimension of expression (happy or sad) and identity (person A or B) are either correlated (e.g. person A always shows happy expression, person B always shows sad expression), constant (e.g. person A shows both happy and sad expressions) or orthogonal (e.g. both person A and B show happy and sad expressions equal times). They show that decision times are not affected by different task conditions, indicating a relatively independent processing of identity and expression dimensions (Etcoff, 1984).

Calder, Young, Keane, & Dean (2000) examine the same issue using the composite face paradigm where the top of one digitized photograph of a face and the bottom of another digitized face image are formed to create a test image of a face, either aligned or misaligned (the top half is slightly offset from the bottom half). When two different faces are aligned, responses to one component (e.g., the top half) are slowed relative to when the faces are misaligned, presumably due to the forming of a new ‘Gestalt’ to the aligned components (the ‘face composite effect’). Calder et al. (2000) report that identity judgements are slowed by aligning two different face identities but not two different expressions, with the reverse occurring for expression judgements (Calder et al., 2000). The authors argue that their results suggest that the composite effects for identity and expression judgments operated independently of one another. Furthermore, Calder et al. (2001) using Principal Component Analysis (PCA) found that facial expression and identity are coded by largely different components, suggesting a functional dissociation between facial expression and identity as the two facial characteristics are loaded on different dimensions of the stimulus (Calder et al., 2001). These arguments for the fractionated processing of structural information about face identity and emotion have recently been bolstered by computational work which suggests that independent processing of these two types of information is a natural consequence of statistical independence between the image features for structural identity and emotion (Tromans, Harris, & Stringer, 2011).

In the next section I will try to outline evidence from neuroimaging studies that support the independent account for processing of identity and emotional expression in faces.

1.3.2 Neuroimaging studies

The idea of separate neural systems for processing of identity and emotional expression (Haxby et al., 2000) has been supported by number of studies in patient and healthy adults. This neural model predicts selective activation to facial identity in the fusiform face area (FFA) and facial expression and changeable aspects of faces in the STS (Engell & Haxby, 2007; Gobbini & Haxby, 2006; Grill-Spector, Knouf, & Kanwisher, 2004; Kanwisher et al., 1997; Sergent et al., 1992; Vuilleumier, Armony, Driver, & Dolan, 2003; Winston, Henson, Fine-Goulden, & Dolan, 2004). For example, Engell and Haxby (2007) compare the FFA and pSTS responses to dynamic changes in the eye gaze direction and identity. The authors find that the FFA responds to identity and less to gaze changes, whereas the pSTS shows the opposite pattern. Grill-Spector et al. (2004) investigate the neural correlates of face detection and identification using a rapid event-related design with brief masked stimuli. It is reported that FFA activation correlates with both face detection and face identification. In contrast, the pSTS region is active in the localizer experiment, but its activation is not correlated with face detection or identification. The authors argue that the lack of activation in the pSTS region to face stimuli in the event-related experiments indicated that activation in this area is not necessary for face detection or identification, and that this region might be involve in other aspects of face processing that require longer stimulus presentation durations such as determining gaze direction or interpreting facial expressions (Grill-Spector et al., 2004). Though, it important to note that this latter conclusion is drawn based on null results. Winston et al. (2004) provides neuroanatomical evidence for the dissociable neural representations of identity and emotional expression. Using pair repetition paradigm, they report that repeating identity across face pairs led to reducing fMRI signal in fusiform cortex and posterior superior temporal sulcus (STS), whereas repeating emotional expression across pairs led to reduced signal in a more anterior region of STS. The two regions in the right STS, did not overlap: a caudal segment coding identity and a more rostral region coding emotional expression (Winston et al., 2004).

Recently, it has been demonstrated that the neural response to seven categories of dynamic facial expressions can be decoded in both the posterior STS (pSTS) and anterior STS (aSTS) and in the frontal operculum (FO), a structure that has also been shown to respond to facial expressions (Said, Moore, Engell, Todorov, & Haxby, 2010). Moreover, in a task where participants viewed computer generated videos of emotional expressions containing either anger, fear, or an intermediate expression taken from a morph continuum between anger and fear the left STS is sensitive to morphing, showing a non-categorical representations of expressions; whereas the right STS showed evidence for both stimulus-related gradations and a categorical boundary (Said, Moore, Norman, Haxby, & Todorov, 2010). Both these findings support the claim of the distributed system for face perception and that emotions in faces are processed via the dorsal pathway (Haxby & Gobbini, 2011).

Another line of evidence for the independence between facial familiarity and facial expressions comes from ERP studies (Balconi & Lucchiari, 2005; Bentin, Allison, Puce, Perez, & McCarthy, 1996; Eimer & Holmes, 2002; Herrmann et al., 2002). Bentin et al. (1996) report that the N170 component is sensitive to the structural encoding of faces. Similar conclusion is made in a study by Eimer (2000) who suggests that the N170 component might reflect to attention-independent, pre-categorical encoding of faces. Moreover, this component has shown insensitive to facial familiarity and facial expressions (Eimer & Holmes, 2002; Herrmann et al., 2002). Balconi and Lucchiari (2005) report that the N170 is sensitive to structural properties of expressed emotion (morphed stimuli) as compared to neutral faces. Taken together, results of ERP studies above support by large the main claim of the model of face recognition (Bruce & Young, 1986) about independence between processing of identity and emotional expression in faces.

The independence between processing of identity and emotional expression came from single-unit recordings in macaque cortex (Hasselmo, Rolls, & Baylis, 1989; Perrett & Oram, 1998; Perrett, Oram, & Ashbridge, 1998). It is demonstrated that neurons tuned to variations in identity are located more ventrally in the inferior temporal (IT) cortex whereas neurons that are tuned to variations in expression are found in greater concentrations in the STS (Hasselmo et al., 1989). The neuronal recording studies show that individual neurons can be highly tuned in that they convey information about face identity, face expression, head movement, objects, or spatial view. It has also been demonstrated that within these different classes, individual neurons by responding differently to different members of the class convey information about whose face it is, what the face expression is (Rolls & Tovee, 1995).

Taken together, the results from behavioural and neuroimaging studies reviewed above provide evidence for independent processing of facial identity and emotional expression. However, there are some issues that remain unclear. For example, the most straightforward evidence for separate processing of the two dimensions is based on neuropsychological double dissociations (Bruyer et al., 1983; Etcoff, 1984). However, some authors argue that, for instance, severe difficulties in identity recognition and less impairment in emotion recognition do not necessarily support separate visuo-perceptual codes for the two facial dimensions (Calder & Young, 2005). Moreover, Calder and Young (2005) question some methodological aspects (assessment procedure, calculation of error rate) of studies examined cases with prosopagnosia that doubt the prediction of separate representation codes for identity and emotion in faces.

Results based on the selective attention paradigm used for assessing inter-relation between processes provide conflicting results. While some show no effects of varying either expression or identity when judging the other, suggesting independence (Etcoff, 1984), others show asymmetrical effects (effects of identity on expression but not vice versa; Schweinbger & Soucup, 1998) or symmetrical effects (Ganel & Goschen-Gottstein, 2004), which I would describe in more detailed in the next section. One possible reason for such varied results could be that sometimes participants misplaced their attention, so that they make a decision based on the irrelevant dimension for a given task. Thus, the effects of the unattended stimulus dimensions may arise due to trial-by-trial fluctuations in attention that lead to the irrelevant dimension sometimes being attended (Lavie & Tsal, 1994; Weissman, Warner, & Woldorff, 2009). On these occasions performance will be affected by variation in the irrelevant dimension, even though the dimensions might be processed independently of one another. This evidence does not mean that processing is non-independent, but would appear as an interference from the relevant dimension.

In the Garner task often a small stimulus set is used, with only two different stimuli exemplars displaying one of two emotions (e.g. see Schweinberger & Soukup, 1998). This limited set of stimuli is repeated across trials allowing a development of strategy for example discriminating stimuli based on local image details (e.g., variations in lighting and photographic grain) rather than on expression and identity, limiting any interference from one dimension on the other. Another important issue is that different picture based strategies may be used for either identity and emotion decision tasks in the Garner paradigm. In the identity decision task pictorial strategies might be used to discriminate the individuals based on a shape of a face and non-facial cues such as hair style (e.g. see Schweinberger & Soukup, 1998, Ganel & Goshen-Gottstein, 2004). For the expression decision task, where participants are required to attend to internal facial features, this strategy may be inappropriate. This can in turn lead to differences in task difficulty, and possible asymmetric interference effects between identity and emotional expression judgments. Although, Ganel & Goshen-Gottstein (2004) controlled for external features, the issue about increasing variability of the relevant stimulus dimension within the orthogonal condition compared to the irrelevant dimension is still there (see also Kaufmann (2004) for detailed discussion about the effects of increasing variability along the relevant stimulus dimension within the orthogonal condition in the garner-paradigm).

In addition, the evidence for the non-dependence between facial identity and emotion that based on studies used the composite paradigm is not clear. For example, it is found that identity judgements are slowed by aligning two different face identities but not two different expressions, with the reverse occurring for expression judgements (Calder et al., 2000). However, there may be different difficulties in the composite effect for the identity and emotions.

The model for separate neural pathways for processing identity and emotion (Haxby & Gobbini, 2011) can also be challenged. The anatomical separation does not necessarily imply that the areas are functionally independent as it is shown by Ishai (2008). Additionally, the issue about how specific each region is for a different type of function is a matter of debate (K. J. Friston, 2005). Furthermore, it has to be noted that in majority of neuroimaging studies that support the neural dissociation in processing of identity and emotional expression representation participants are asked to attend to identity or emotion in faces. This might affect identification of neural regions involved in the interaction.

I next consider evidences that support the interactive account in processing of identity and emotional expression in faces.

1.4 Interactive processing of facial identity and emotional expression: supporting evidence

1.4.1 Behavioural studies

A growing number of studies suggest that processing of identity and emotional expression in faces are not entirely independent (Aguado, Garcia-Gutierrez, & Serrano-Pedraza, 2009; Atkinson, Tipples, Burt, & Young, 2005; Baudouin et al., 2000; Baudouin, Martin, Tiberghien, Verlut, & Franck, 2002; Curby et al., 2012; D'Argembeau, Van der Linden, Etienne, & Comblain, 2003; Ganel & Goshen-Gottstein, 2004; Kaufmann & Schweinberger, 2004; Levy & Bentin, 2008; Schweinberger, Burton, & Kelly, 1999; Schweinberger & Soukup, 1998).

Kaufman and Schweinberger (2004) asked participants to perform speeded two-choice decisions according to whether or not a face was familiar on a range of familiar and unfamiliar faces that are morphed from a happy to an angry expression within a given identity. It was found that reaction times for classification of unfamiliar faces are independent of facial expressions, while emotional expression influence the recognition of familiar faces, with fastest recognition for moderately happy expressions. The authors conclude that representation of familiar faces for recognition preserves some information about typical emotional expression (Kaufmann & Schweinberger, 2004). Similar results are reported in Baudouin, Gilibert, Sansone, and Tiberghien (2000) where subjects categorize emotional faces presented for different durations (15 ms vs 1000 ms) as famous or unknown, and estimate their degree of familiarity on a rating scale. Results revealed a facilitation of the expression discrimination for famous faces when compared to unfamiliar faces only in the condition of short presentation. The authors suggest that facial familiarity increases the “perceptual fluency” and makes the recognition of facial expressions easier under hard conditions.

Another study showed that unfamiliar faces had been learned with happy rather than angry expression are recognized better when tested with a neutral expression, a result which is only present in intentional and not in incidental learning conditions (D'Argembeau et al., 2003). Conversely, there is also evidence that facial expressions have an influence on the perception of familiarity (Baudouin et al., 2000; Garcia-Marques et al., 2004) and that expression improve identity recognition in patients (de Gelder, Frissen, Barton, & Hadjikhani, 2003).

Recently, Otten and Banaji (2012) examined interdependent neural representation of emotion and race of faces using a visual face adaptation paradigm. In this study visual emotion afterimage effects for the adapting face and ambiguous test face differed in race. The authors report smaller emotion afterimage effects in different race trials than same race trials and interpret this finding as demonstrating different neural representations for white and black faces. Importantly, the authors suggest that facial identity cues (such as race) and emotional expression interact not just at a response level, but also at the level of perception and early neural representation. The suggestion is linked to one of hypotheses tested in the present study, and will be discussed in a later section.

As mentioned above the Garner paradigm provide the most straightforward tool to test possible interactions between facial identity and the perception of facial expressions (Garner, 1974). While earlier study report no-dependence between identity and expressions (Etcoff, 1984), more recent studies show an asymmetrical or even symmetrical dependence. Schweinberger and Soucup (1998) ask participants to classify unfamiliar faces along one dimension while disregarding an irrelevant dimension. The faces are presented in three different Garner's conditions: a control condition (in this case the task irrelevant dimension was held constant while the relevant dimension varied), an orthogonal condition (both the irrelevant and relevant dimensions were varied) and a correlated condition (changes in the irrelevant dimension covaried with changes in the relevant condition). Reaction times (RTs) for identity judgments are not influenced by variations in expression, but expression recognition is affected by variation in identity. Notably, the correlated condition was faster than the control condition, suggesting potential redundancy gain when both dimensions could be used to support the decision.

Similar results are obtained by Atkinson et al. (2005) who investigate the relationship between facial emotion expression and facial gender. In two separate experiments participants are asked to respond to the emotional expression (fearful and happy) or to the face's sex ignoring other aspect of the face. It is found that RTs are slower in the orthogonal than control condition of the emotion classification task, whereas there is no significant difference in RTs between the orthogonal and control conditions for sex classification (Atkinson et al., 2005). Atkinson et al. (2005) suggest that although people are able to attend selectively to the sex of faces while ignoring variations in facial expression, they are less able to attend selectively to facial expressions while ignoring variations in the sex of the faces. As the authors noted, the nearly significant emotion and sex interaction for sex classification suggests that for the male faces in this experiment, the participants could not entirely ignore variations in emotional expression.

In another study, Baudouin et al. (2002) evaluate attention to facial identity and expression in both healthy and individuals with schizophrenia using the Garner task. It is found that both patients and healthy participants show an asymmetrical pattern of performance: they are able to selectively attend to the identity of the face presented, regardless of the emotion expressed on the face, but variation in identity interfered with the classification of facial emotion (Baudouin et al., 2002). Moreover, inter-dependence between facial identity and emotion are reported in others patient studies: a correlation between identity judgments and expression recognition in lobotomized patients (Braun, Denault, Cohen, & Rouleau, 1994); improved identification of expressive faces compared with neutral faces in prosopagnostic patients (de Gelder et al., 2003).

While the studies above show asymmetrical interferences of expression on identity but not vice versa, other report symmetrical dependency as well. Ganel & Goshen-Gottstein (2004) explore face processing using the Garner task, which tests for interference effect from one stimulus property on responses to another. Participants categorized photographs according to personal identity information or the emotional expressions. The stimuli were selected photographs of two different people shown in two different emotional expressions and in two different views. Task irrelevant information interfere equally in the identity and emotional expression categorization tasks. The authors argue that the systems involved in processing identity and expression are interconnected and that facial identity serve as a reference from which different expressions are more easily derived (Ganel & Goshen-Gottstein, 2004). It has to be noted that in this study the discriminability of identity and expression judgements were equated – an aspect that was not well controlled in other studies that could potentially lead to the masking of the inter-dependence relations. Moreover, the authors demonstrate that this interaction is held for familiar and unfamiliar faces (Ganel & Goshen-Gottstein, 2004). The interactive relation between processing of facial identity and emotion for unfamiliar faces has got further support in a task where participants are required to match identity and emotional expression (Levy & Bentin, 2008).

Thus, majority of behavioural studies that examined independent or interactive processing of facial identity and emotional expression point to an asymmetric interaction between facial identity and the discrimination of facial expressions, with expression judgements more affected than identity and gender judgements by variations in the other dimension, though some argue that when task difficulty is properly controlled symmetrical effects are observed.

Evidence supporting the interaction in the neuronal level for processing of identity and emotional expression of faces will be outlined in the following section.

1.4.2 Neuroimaging studies

A number of neuroimaging studies that investigate the functional network for face processing provided further evidence against complete independence between facial identity and emotional expression (Eimer & Holmes, 2002; Ellamil, Susskind, & Anderson, 2008; Fairhall & Ishai, 2007; Ganel, Valyear, Goshen-Gottstein, & Goodale, 2005; Ishai, 2008; Turk-Browne, Norman-Haignere, & McCarthy, 2010; Wild-Wall, 2004; Wild-Wall, Dimigen, & Sommer, 2008; Xu & Biederman, 2010). For example, Ellamil et al. (2008) using face adaptation paradigm reported that adaptation to the basic emotions of anger, surprise, disgust, and fear resulted in biased perception away from the adapting expression. However, when the adapting and the test images belonged to different people, the afterimage effect decreased. This suggests that there is at least partly overlapping neural processing of identity and facial expression (Ellamil et al., 2008). Similar results are obtained by Fox & Barton (2007) who show that an expression afterimage effect is produced with congruent and incongruent identities (when the adapting and test faces are of different people). The authors conclude that at least some of the expression afterimage effect can be attributed to an identity-invariant representation of expression (Fox & Barton, 2007). Facial expression afterimage effects are argued not be due to local adaptation to image elements but reflect high-level adaptation of neural representations that involve both facial features and facial configuration (Butler, Oruc, Fox, & Barton, 2008).

Wild-Wall, et al. (2008) tested the interaction between identity and expression and reported a symmetric facilitation between identity and emotion in familiar faces. It was shown that during an expression discrimination task responses for personally familiar faces expressing happiness were faster that responses for unfamiliar persons displaying happiness. Further, Wild-Wall (2004) suggested that an interaction between facial expression and facial familiarity only emerge for some expressions (happiness and neutral) but not for others (such as disgust, fear etc.). The lack of interaction between identity and some expressions has been explained by the observation that different emotional expression related to different neurocognitive processes, and expressions, excluding happiness and neutral, generated greater distortion for the configuration of facial features (Wild-Wall, 2004).

Fairhall and Ishai (2007) examined effective connectivity within the distributed cortical network for face perception using blocks of black and white line drawings of unfamiliar faces, grey scale photographs of unfamiliar, famous, and emotional (fearful and happy) faces. Participants were instructed to attentively view the faces without a direction toward specific facial dimension. The authors reported that emotional and famous faces significantly increased the coupling between the IOG and the FG within the left & right hemisphere core system. Though no effects of familiarity or emotions on coupling between the IPG and the STS were observed. Moreover, using model comparison, the authors showed that the data is explained better if the coupling with the extended face network is mediated by the FFG when compared with a model that include both the FFG and the STS. Though it should be noted that model comparison method used favour the more simplistic model. The authors further suggest that emotional faces increased the effective connectivity between the IOG, FG, and the AMG, whereas famous faces increased the effective connectivity between the IOG, FG, and the OFC (Fairhall & Ishai, 2007). Thus, the study by Fairhall and Ishai (2007) provide strong evidence for functional coupling between regions involved in processing of facial identity and emotional expression with a dominant role of the FFA exerted influences on all regions of the extended system. However, other researchers argue that the STS (but not the FFA) plays the crucial role in initial analysis of social cues because "… STS is anatomically well situated to integrate information derived from both the ventral ‘what’ and the dorsal ‘where’ visual pathways” (Allison, Puce, & McCarthy, 2000). It has to be noted that Allison et al. (2000) does not consider the STS as implicated in expression processing only, but rather in "social perception", that reflects processing of both facial identity and emotional expression. Interestingly, a face-specific functional coupling between the FFA and the STS has been demonstrated recently in a study during period of rest when no faces were presented (Turk-Browne et al., 2010). A correlation between these two areas is robust in both a voxelwise and region-of-interest analyses. The authors suggest that processing of facial information may reflect not only as activation changes in single region but also in the degree to which these changes are synchronized across regions (Turk-Browne et al., 2010).

Haxby et al. (2000) model predicts that the occipital face area (OFA) and the FFA contribute to the processing of facial identities, while the STS and the amygdala contribute to the processing of emotional expression. Challenging this dichotomized view, there is evidence that the FFA, is also responding to expressions, as it is activated more by fearful compared with neutral faces (Vuilleumier et al., 2001), the FFA shows more activity for expressive than neutral faces (Ishai, Schmidt, & Boesiger, 2005), and this area has been linked to processing emotional expression (Ganel et al., 2005).

Studies using fMRI-adaptation paradigm also challenges the model’s predictions (Haxby et al., 2000): the FFA and the posterior STS (pSTS) release from adaptation when subjects perceived a change in either identity or expression suggesting a functional overlap in the FFA and pSTS (Fox & Barton, 2007); the pSTS shows significant fMRI adaptation not only to expression but also to identity (Winston et al., 2004); both identity and emotional expression show release from adaptation in the FFA (Xu & Biederman, 2010). For example, Xu and Biederman (2010) examine the representation of viewpoint, expression, and identity of faces in the fusiform face area (FFA) and the occipital face area (OFA). Subjects viewed sequences of two faces varied in viewpoint, expression and/or identity and judge whether they depict the same person. The effects of image similarity on face discrimination performance were controlled by the Gabor-jet metric. It is found that in the FFA, changes of both identity and emotional expression produce the largest release from adaptation, while the OFA is sensitive only to changes in identity (Xu & Biederman, 2010) The authors suggest that the FFA is involved in the perception of both identity and expression of faces. Similar conclusion has been made in study by Tsuchiya, Kawasaki, Oya, Howard, Adolphs (2008) where neuronal activity is directly recorded directly from the cortical surface of nine neurosurgical subjects undergoing epilepsy monitoring while they viewed static and dynamic facial expressions. Better representation of both invariant and changeable aspects of faces is found in ventral (FFA) than lateral temporal cortex. The same pattern is reported even in a task when the individuals performed discrimination of fearful and happy expressions in faces (Tsuchiya, Kawasaki, Oya, Howard, & Adolphs, 2008).

It should be noted that face-identity changes activation not only in the face-responsive regions (see Haxby & Gobbini, 2011), but also outside ‘the face system’ in the brain. For example, decreased activation for repeated faces in face-selective regions and not face-selective, including the parahippocampal place area (PPA) and early visual cortex (EVC) is reported in fMRI study where participants viewed familiar faces that were shown repeatedly throughout the experiment. These effects are consistent and independent of viewpoint and lighting (Mur, Ruff, Bodurka, Bandettini, & Kriegeskorte, 2010). This result is explained in terms of general attentional effects and carryover of activation from connected regions, leaving, however, a place for alternative explanations. The notion that the FFA is coding face identity has been challenged, as it is shown different patterns of activations in the anterior part of the temporal cortex (aIT), but not in the FFA can be reliably used to tease apart different identities (Kriegeskorte, Formisano, Sorger, & Goebel, 2007). Thus, suggesting that identity information is encoded in the anterior temporal regions, but not in the FFA.

While many studies show that identity related regions, e.g. FFA, respond to emotional manipulation; studies also show how emotion related regions, e.g. amygdala respond to identity manipulation. Roder, Mohr and Linden (2012) asked participants to perform a face-identity or face-emotion working memory task at different load levels during fMRI. The authors report that limbic areas in the amygdala and parahippocampal gyrus demonstrate a stronger activation during the identity than the emotion condition.

Taken together, the behavioural and neuroimaging studies show that some kind of functional-neural interaction between identity and emotion processes, challenging the dissociation between these two facial dimensions. However, some of the supporting evidence for inter-dependence maybe problematic. For example, the main supporting evidence for the interactive relation between identity and emotion in faces came from studies used the Garner task. However, as it was discussed earlier (section 1.2.2) some methodological limitations of the task may hinder the ability to interpret the results. Equating for task difficulty seems an important factor, when physical discriminability of faces in identity and emotion not controlled asymmetrical effects are observed (Atkinson et al., 2005; Baudouin et al., 2002; Schweinberger & Soukup, 1998), but when it is controlled symmetrical effects are reported (Ganel & Goshen-Gottstein, 2004).

In a seminal paper, Calder and Young (2005) review the evidence supporting the independent and interdependent accounts in processing of facial identity and emotional expression. The authors provide a detailed analysis of evidence of double dissociation between recognition of identity and expression in faces (including lips speech) in patients with prosopagnosia, results of fMRI and single-unit recording studies. Calder and Young (2005) conclude that current findings in patient studies cannot undoubtedly support both the cognitive (Bruce & Young, 1986) and neurological (Haxby, et al. 2000) models of face recognition. Furthermore, Calder and Young (2005) outlined new point of view regarding interactive processing of identity and emotional expression in faces that based on findings from the Principal Component Analysis. Their main idea (Calder & Young, 2005) suggesting highly interactive between identity and expression is used in the present thesis and applied to the analysis of neuroimaging data.

1.5 Rationale, approach and hypotheses for the current research

1.5.1 Rationale for examining interaction between identity and emotion in faces

The short literature review (sections 1.2 - 1.4) demonstrates a range of empirical findings supporting both the independent view on processing of identity and emotional expression in faces and the contrasting account for an interaction between the two facial dimensions. However, as was discussed in sections 1.2 - 1.4 both the independent and non-independent accounts have a number of limitations that restrict our understanding of neural mechanisms and the behavioural processes involved. Therefore the main of this thesis is to re-visit this debate and to use a novel paradigm to assess the possibility of the inter-dependent processing between these two face dimensions.

By re-visiting the question of interactive processing mechanisms I am to provide an answer to at least four questions: (1) what are the behavioural outcomes of the interaction? (2) what are the neural mechanism(s) that supports the interaction? (3) what are the conditions that modulate the interaction? (4) how the pattern of the interaction change across the lifespan? The independent and interactive accounts in face processing predict contrasting answers for these questions (Table 1.1).

Table 1.1

Processing of identity and emotion in faces from two alternative points of view

Question	Point of view	
	Independent	Interactive
What are behavioural outcomes of the interaction	Identity judgments do not interfere with emotion in faces, Emotion judgments do not interfere with processing of face identity	*Asymmetric*: identity judgments does not interfere with emotion in faces Emotion judgments interfere with identity judgments *Symmetric*: both identity and emotion interfere with each other
What neural mechanism(s) supports the interaction	Parallel and separate routes for processing identity and emotion Anatomical segregation of neural substrates for processing identity and emotion	Functional coupling between areas involved in processing of identity and emotion The same bran areas (such as FFA, STS) supported both identity and emotion processing
What conditions modulate the interaction	No condition modulate the inter-relation as they are independent	Equal discriminability of identity and emotion
Does the interaction change across the lifespan?	No change	Possible changes

As it can be seen in Table 1.1, both the independent and interactive accounts make a number of testable predictions that will be examined in the following experiments here. Moreover, there is a question that has never been in the focus of interest of any accounts – changes occur in processing over the life span of an adult. This gap limits our understanding of age related changes in processing of the most important information for social communication.

This study will use unfamiliar faces to investigate the inter-relations between processing of emotions and identity. It is always challenging to use familiar faces as stimuli because of ecological validity and well discriminable physical features. It is difficult to control the influence of the familiarity on processing of both identity and emotional expression. For instance, it is unclear whether the *level of familiarity* with famous people affects the discrimination of physical features or whether *a particular emotional expression* may trigger recognition performance. Indeed, to get a conclusive result about the relations between the processing of two dimensions sharing physical properties, it is mandatory to ensure that either dimension has an equal chance to be processed. In the present research these issues were overcome by using unfamiliar faces that are well controlled for discriminability of both identity and emotional expression.

Human faces are well-learned stimuli. However the recognition of identity and emotional expression in faces is affected by *the level of individual experience* with faces, in particular, by the own-race bias (Cassidy, Quinn, & & Humphreys, 2011; Levin, 2000; Meissner & Brigham, 2001). Examining the relations between the processing of facial identity and emotional expression, past studies have mainly used Caucasian facial stimuli and the question whether the own-race bias might modulate the relationship has not been assessed. If individual experience with faces affects the interaction between facial identity and expression, then the reduced expertise with other race faces would be associated with diminished integrative processing of identity and expression for other race faces. Examining this assumption is important for further understanding cognitive mechanisms underlied face processing.

In sum, the evidence for interactive (or completely independent) processing of facial identity and emotional expression is still inconclusive and need to be further investigated. This thesis attempts to shed some light on the issues noted in Table 1.1.

1.4 2 Methodological approach

1.4.2.1 The divided attention task

To overcome the limitations highlighted in section 1.2 & 1.3 (in particular, of the Garner task) *the divided attention task* is employed in the present research.

The divided attention task has been commonly used with written words and auditory stimuli (Grice & Reed, 1992; Krummenacher, Muller, & Heller, 2001; Miller, 1982; Miller, Ulrich, & Lamarre, 2001; Mordkoff & Miller, 1993) but not in studies of identity and emotional expression perception in faces excluding set of studies by Wenger and collaborators who examined holistic versus featural processing in faces (M. Wenger & Townsend, 2001; M. J. Wenger & Townsend, 2000a, 2000b, 2006).

In the divided attention task, participants are required to monitor two sources of information simultaneously for a target, and then make a decision about the presence or absence of the target. There are two main advantages in employing the divided attention task. First, the divided attention task requires people to attend to identity and emotional expression in unfamiliar faces simultaneously – a situation that closely resembles daily life. Second, in contrast to the selective attention task, the divided attention task controls for performance in the single target conditions by including the double target display (control targets identification). To the extent that facial identity and emotion are independent, the time for encoding a face containing both targets will not differ reliably from time for encoding faces either containing a single target (assuming equal perceptual discriminability of identity and emotional expression).

1.4.2.2 The divided attention paradigm: theoretical and methodological issues

Generally, *independence versus interaction* is one of four distinct but closely interrelated characteristics of human information processing which also includes *capacity* (Townsend & Eidels, 2011; Townsend & Honey, 2007; Townsend & Nozawa, 1995); *the architecture of processing* (serial, parallel, or coactive) that indicates whether elements (cues) of the stimulus can be processed one at a time, or can be processed simultaneously (Egeth & Dagenbach, 1991; Fific, Nosofsky, & Townsend, 2008; Kwak, Dagenbach, & Egeth, 1991); the stopping rule (self-terminating and exhaustive processing) implies whether all elements or dimensions of a stimulus need to be processed, or whether there is some sufficient minimum (Fific, Nosofsky, et al., 2008; Townsend & Colonius, 1997). Although these characteristics complement each other, perceptual independence vs. interaction is a crucial one in many psychological applications, including processing of identity and emotional expression in faces (Atkinson et al., 2005; Baudouin et al., 2002; Burton & Bruce, 1993; Campbell et al., 1996; Martens, Leuthold, & Schweinberger, 2010a, 2010b).

There are many varieties of the independence vs interaction construct (Ashby & Townsend, 1986) which can result in a range of mathematical models of general decision behaviour (Brown & Heathcote, 2008; Brown, Marley, Donkin, & Heathcote, 2008; Mordkoff & Yantis, 1991; Raab, 1962; Vickers, 1970; Wagenmakers, Ratcliff, Gomez, & McKoon, 2008). One of them is a group of Independent Race Models (Miller, 1982; Mordkoff & Yantis, 1991; Raab, 1962)

All Race models assume separate channels for processing distinct types of information (e.g., a shape and a colour) and the fastest process on a given trial affects the decision. However, the level of independence of the channels from each other vary across these models (Miller, 1982; Mordkoff & Yantis, 1991; Raab, 1962; Vickers, 1970). For example, in Mordkoff and Yantis's model (1991) the channels exchange the information prior the decision has been made. In the Vickers's model (1970), the channels are not strictly independent in a sense of having selective input structure, such that the stronger the input for the one channel, the slower the accumulation rate of the second channel. Raab's model (1962) proposes that in two unrelated channels only the fastest channel affects the decision. In contrast, Miller (1982) demonstrates that predictions made by Raab's (1962) model may be violated, if signals from two channels are combined prior the decision 'target present' is made (Miller, 1982).

It has to be noted that the term 'independence' is used here in a sense that two dimensions (identity and emotional expressions in faces) are functionally unrelated to one another rather than in a pure probabilistic sense. Lets us consider the property of processing facial identity and emotional expression in relation to two polar models: Raab's model (1962), which predicts strict independence between facial identity and emotional expression, and Miller's (1982) model, which assumes co-active processing of these two dimensions.

There is considerable evidence that, when a visual display contains two targets that require the same response, reaction times (RTs) are faster when only one target appears (Miller, 1982; Miller et al., 2001; Mordkoff & Miller, 1993; M. J. Wenger & Townsend, 2006). For example, in Mordkoff & Miller's (1993) study participants were required to divide their attention between the separable dimensions of colour and shape, with all stimulus features being attributes of a single object. In this task participants were asked to press a button if the target colour (green), the target shape (X), or both target features (green X) were displayed, and no response if neither of the targets is present. In this case, single-target displays include a purple X or a green 0, and redundant target displays always included a green X. The mean RT on redundant target trials was significantly less than mean RT on single target trials (Mordkoff & Miller, 1993).

There are different explanations that account for this redundant target effect (RTE), the most relevant being the Independent Race Model (Raab, 1962) and the Coactivation Model (Miller, 1982). According to the Independent Race Model, redundancy gains are explained by means of ‘statistical facilitation’ (Raab, 1962). Whenever two targets are presented simultaneously, the faster signal determines the response ‘target present’ (i.e. this signal wins the race). As long as the processing time distributions for the two signals overlap, RTs will be speeded when two targets occur since the winning signal can always be used for the response (Raab, 1962). Note that which signal finish ‘first’ may depend on whether it is attended. For example, emotional expression or identity may be computed first, if there are fluctuations in attention to each independent dimension (Figure 1.5, top).

According to the coactivation view, the information supporting a response ‘target present’ response is pooled across the features defining the targets prior to response execution (Miller, 1982). When both target identity and target emotional expression contribute activation toward the same decision threshold, the response has to be activated more rapidly relative to when only one attribute contributes activation (Figure 1.5, low).

The critical contrast for the two models compares the probability for the response times obtained on redundant targets trials relative to sum of probabilities for responses being made to either single target trial. The Independent Race Model holds that at no point in the cumulative distribution functions should the probability of a response to redundant targets exceed the sum of the probabilities for responses to either single target. In contrast, according to the coactivation account, responses to the redundant targets can be made before either single target generates enough activation to produce a response. Thus, here the fastest responses to a face containing both the target identity and the target emotional expression should be faster than the fastest responses to either target facial identity or target expression.

Mordkoff & Yantis (1991) proposed a conceptual compromise between the Independent Race Model and the Coactivation model. The Interactive Race Model, assumes a race between parallel processes on redundant targets trials, but holds that these two targets may exchange information prior to a response being made. Two mechanisms have been proposed for information exchange: inter-channel crosstalk and non-target-driven decision bias (Mordkoff & Yantis, 1991). Crosstalk occurs when identification of one signal is influenced by another signal (e.g. when a stimulus contains both targets, person A with a sad expression). If participants associate the identity with the expression, then processing face identity could reduce the threshold to detect the target expression, speeding responses when both the target identity and emotional expression are present relative to when the expression is present in a face not bearing the target identity.

Non-target-driven decision bias concerns the possible effects that the non-target attributes may have on “target present” decisions (Mordkoff & Miller, 1993; Mordkoff

& Yantis, 1991). In contrast to the Independent Race and the Coactivation Models, both of which hold that only target signals activate a response, the Interactive Race Model proposes that non-target signals correlated with "target not present" decisions (Figure 1.5, middle). This has also been described as the context invariance assumption made by both the race and the Coactivation models (Townsend and Wegner, 2004). For instance, if a display of a face contains both the target identity along with a non-target emotional expression, then the expression could activate an absent response. This could slow RTs on trials with just one target is present, relative to when both attributes are present with "target present" response. Thus the Interactive Race Model explains redundancy target effect in terms of the influence of non-target signals on "target present" responses, rather than interactive processing between the target signals.

The model closely relates to the question about independence vs co-activation processing is capacity model which defines the processing system in terms of workload capacity (Townsend & Nozawa, 1995). The concept of workload capacity reflects efficiency of cognitive system to perform a task. This framework includes different capacity assays (e.g., Miller race bond, capacity coefficient by Townsend) that allows direct comparison between distinct models (Townsend & Wenger, 2004b). Mathematically, the workload capacity (C(t)) is defined by hazard function that gives the rate of process completion at any point time (when the process under an observation has not yet completed) (Townsend & Wenger, 2004b). Importantly, the yardstick for the capacity model (Townsend & Nozawa, 1995) is the standard parallel model where characteristics on individual channels do not change with increasing workload and signals are processed in parallel without interfere with each other. In terms of the capacity model, the standard parallel processing is associated with unlimited capacity

($C(t) = 1$). Processing with limited capacity ($C(t) < 1$) is associated with decreasing performance (e.g., slowing in RT) when the workload increase. If increasing workload facilitates performance (e.g., faster RT) the system is said of super capacity ($C(t) > 1$)) and it was shown to always violate the race model inequality (Townsend & Eidels, 2011; Townsend & Wenger, 2004b). In the present thesis I use the capacity coefficient to better understand the architecture of processes underlying the mutual relation between processing of identity and emotional expression in faces. For example, it would be interesting to know how much better it is than the standard parallel processing. Whereas the race inequality (Miller, 1982) forces the dichotomy, “violated vs. satisfied”, $C(t)$ yields a dynamic function of time revealing the exact quantity of capacity at each moment. It can be valuable to know when here the system is limited or super capacity. Furthermore, if decision of target present is based on the interaction between channels, it would be interesting to know at what stage the interaction occurs. This question I discuss in the discussion section in Chapter III.

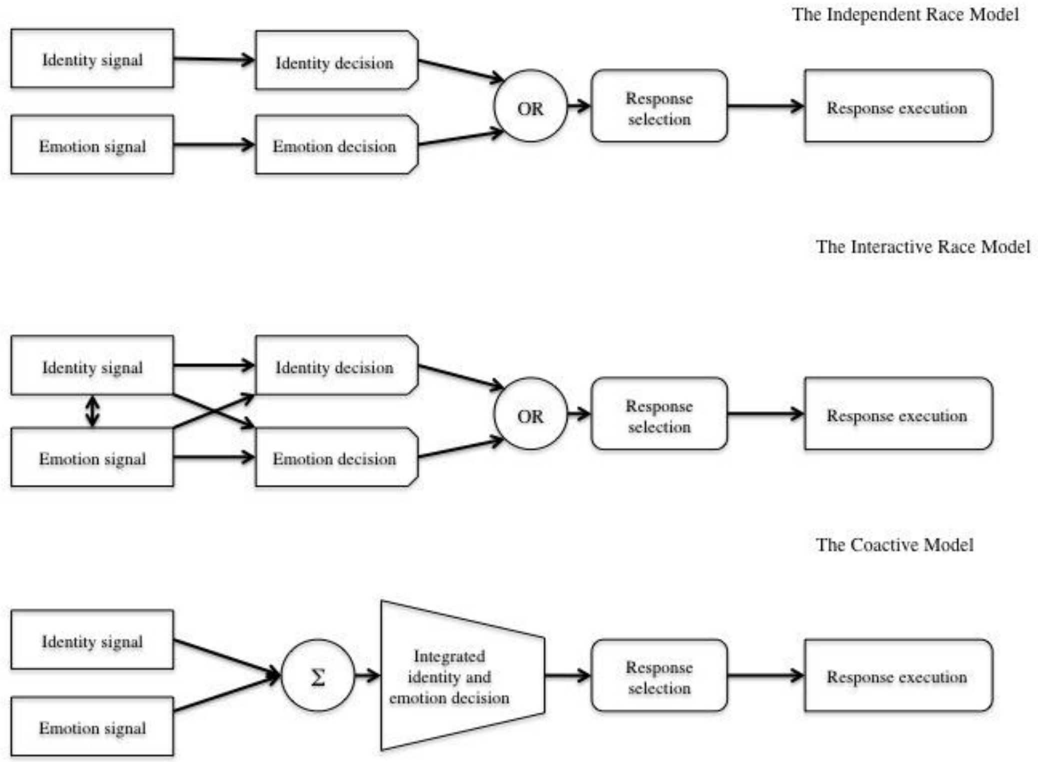

Figure 1.3. The Independent Race model, The Interactive model, The Co-activation model. Modified from Mordkoff and Yantis, 1991

1.5.3 Hypotheses

Six hypotheses are tested in the current thesis.

1. The first hypothesis reflects the question of whether identity and emotional expression are processed independently or in a co-active manner. If identity and emotion signals are integrated, than RTs to a face containing both the target identity and the target emotional expression will be shorter than RTs to either target emotion or target face identity when it appears alone. Specifically, if the probability of responses on a trial with redundant face and emotion targets is greater than the summed probabilities of responses on single target trials at any part of the cumulative response distribution and the capacity coefficient will be greater than predicted by the standard parallel processing ($C(t) > 1$) then the Independent Race Model is refused. This is

examined in Experiments 1-3. In these experiments target identity and targets emotional expression were manipulated to see whether the results are specific for a particular combination an identity and emotional expression.

2. The second hypothesis is linked to the question whether facial identity and emotion are processed coactively or interactively. The target inter-stimulus and non-target contingency were manipulated in order to see whether information between targets and non-targets might be exchanged. If the redundant targets effect is modulated by manipulation of stimuli contingency, this may support the Interactive model (Mordkoff & Yantis, 1991). This hypothesis was tested in Experiment 4.

3. The third hypothesis is reflected to the question of whether the apparent coactivation effect is based on pictorial properties of image or depended on the discrimination of structural features from faces, by testing redundancy gains with inverted images. Redundancy gains from pictorial properties should be found with inverted as well as upright faces. This hypothesis is examined in Experiment 5.

4. The fourth hypothesis concerns neural basis of the relation between facial identity and emotional expression. If the interaction between facial identity and emotion occurs there should be a specific neural network supporting the interaction. This hypothesis is examined in Experiment 6 (Chapter 4).

5. The fifth hypothesis is related to the question what conditions modulate the interaction between identity and emotional expression in faces. Reduced familiarity with faces, such as in other race faces, may diminish the interaction between the processing of facial identity and expression. This hypothesis is tested in Experiment 7 (Chapter 5).

6. The sixth hypothesis concerns whether the relation between identity and emotional expression in faces is preserved across the life span of an adult. This also provide an additional way of measuring the impact of experience, as it is assumed that age positively correlate with the amount of experience gained in processing faces. If the ability to integrate information from two signals is spared with increased age, then the magnitude of the interaction will be increased with age. This assumption is examined in Experiment 8 (Chapter 6).

Taken together, the findings across the Experiments 1-8 provide important new evidence about how facial identity and expression are computed, at the functional and neural levels. The main implications of the results are reviewed in the General Discussion (Chapter 7).

Chapter II

General method

All experiments carried out in this thesis were run in accordance with the ethical guidelines of the British Psychological Society.

2.1 Stimuli and Apparatus

All face images were sourced from The NimStim Face Stimuli Set (Tottenham, Borsheid, Ellertsen, Marcus, & Nelson, 2002). Recognition of facial expression in all photographs used was rated as 80% and more (Tottenham et al., 2002).

In total, 7 selected sets of face images (selection images for each set see in section 2.1.1) were used in the present research. Table 2.1 displays the assignment of images-sets to experiments.

Table 2.1

The assignment of the images-sets to experiments

Set of images	Experiment
Set 1	1, 4, 6, 8
Set 2	2
Set 3	3
Set 4	7
Set 5	7
Set 6	7
Set 7 (inverted images of Set 1)	5

Each set comprised six photographs: three of these photographs contained targets: stimulus 1 had both the target identity and the target emotion (IE); stimulus 2 contained the target identity and a non-target emotional expression (I); stimulus 3 contained the target emotional expression and a non-target identity (E); stimuli 4-6 were photographs of three different people, and expressed emotions different from those in target faces: non-target identities and non-target emotional expressions (NT1, NT2, NT3). The seven images sets are displayed in Appendix A.

The photographs in each set were cropped around the hairline to eliminate the possibility of target judgments being based on hairstyle. Any visible background was coloured black for sets 1, 2, 3 and 7. The background for the sets 4-6 was white (to contrast African faces). The faces were approximately 10 x 13 cm when displayed on a 17-in monitor. The presentation of stimuli, experimental control and data collection was controlled using Cogent 2000 developed by the Cogent 2000 team at the FIL and the ICN and Cogent Graphics developed by John Romaya at the LON at the Wellcome Department of Imaging Neuroscience (http://www.vislab.ucl.ac.uk/cogent_2000.php). The stimuli were presented on the monitor at the viewing distance of 0.8 m. The angular width subtended by the stimulus was approximately 10°.

2.1.1 Stimuli sets selection

The strongest test between the different models of information accumulation (Figure 1.5) requires that RTs distribution for the single targets (I and E) to be as close as possible in order to obtain maximal redundancy gain. To ensure that this was the case here, an initial set of experiments were conducted in which participants made perceptual match decisions to pairs of faces differing in identity and emotional expression. Based on the speed with which "different" decisions were made, face identities and emotional expressions were chosen such that the time to discriminate between a potential redundant target (target identity + target emotional expression present) and a potential target with just one attribute (target identity + neutral emotion; non-target identity + target emotion) was the same for both attributes (i.e., the possibilities that the target identity was discriminated faster than the target emotional expression, or vice versa, was eliminated). Images from pairs with no reliable differences in RTs were selected for the main experiments.

In total, five pilot experiments (Experiment A, B, C, D, E) were carried out. The aim of these experiments was to select stimuli sets 1-6 (in Experiments A, C, D, E selected sets were 1, 4, 5, 6 respectively; in Experiment B selected sets were 2 and 3).

2.1.1.1 Method

Participants

Five groups of undergraduate students participated in this study. Group 1 - 18 participants (11 females), Group 2 - 15 participants (10 females), Group 3 - 15 participants (9 females), Group 4 - 15 participants (8 females) and Group 5 - 15 participants (10 females) took a part in the pilot experiments A, B, C, D, E respectively. Groups 1-3 were consistent of European individuals, in Groups 4 and 5 participants were African and Asian respectively.

All participants were aged between 19 and 23 years. All individuals reported normal or corrected to normal vision.

Stimuli and Apparatus

Experiment A. For this experiment photographs of faces of three European men (labelled 20M, 21M, 34M in the database; here labelled as Person 1, 2 and 3 respectively) expressing a happy and sad emotions were selected. The combination of these images gave three pairs of images of the same person expressing two different emotions and six pairs of different people expressing the same emotion.

Experiment B. Photographs of faces of three European men were selected with either angry, fearful or neutral expressions (labelled 21M, 24M, 31M in the database, here labelled as Person 4, 5 and 6 respectively). There were nine pairs of images of the same individuals expressing different emotions and nine pairs of photographs of different people expressing the same emotion.

Experiments C-E. Photographs of three European (labelled 1F, in the database; here labelled Person 7, Person 8, Person 9 respectively), three African (labelled 1F, in the database; here labelled Person 10, Person 11, Person 12 respectively) and three Asian (labelled 1F, in the database; here labelled Person 13, Person 14, Person 15 respectively) women expressing a happy and sad emotions were tested in Experiments C, D, E respectively. The combination of these images in either experiment gave three pairs of images of the same person expressing two different emotions and six pairs of different people expressing the same emotion.

Display presentations were controlled using E-Prime. Each pair of stimuli was counterbalanced with respect to the left and right sides of display. The paired images were approximately 23x15 cm when displayed on 17-in monitor at the viewing distance of 0.8 m. The angular width subtended by the stimulus was approximately 10°.

Procedure

Participants were required to make a speeded judgment if images displayed in pairs were the same or different by pressing ‘the same’ or ‘different’ buttons on the keyboard. An example of stimuli presentation and responses is displayed in Figure 2.1.

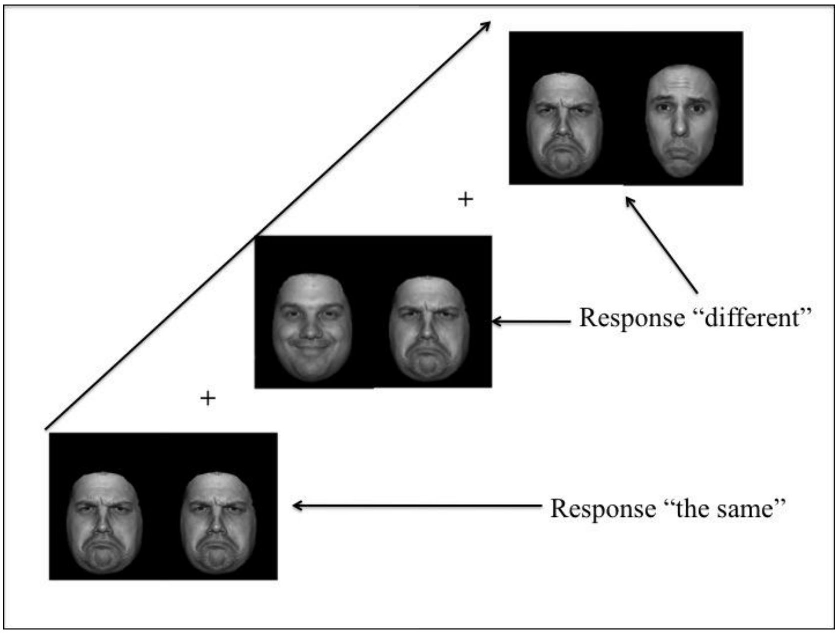

Figure 2.1. Experimental design in Experiments A-E

Each trial started with the presentation of a fixation cross at the center of the screen for 500 ms. Displays of two paired images were presented successively in a random order.

Analysis of data

RTs for correct ‘different’ responses were taken for the analysis. Mean RTs for responses to display containing images of the same person expressing different emotions were compared with displays of different people expressing the same emotions, using related t-test. For each comparison two corresponding displays were taken (i.e., the displays differed in one of two paired images; for example, one display containing a sad and a happy image of Person 1, and another display a sad face of Person2; Figure 2.2).

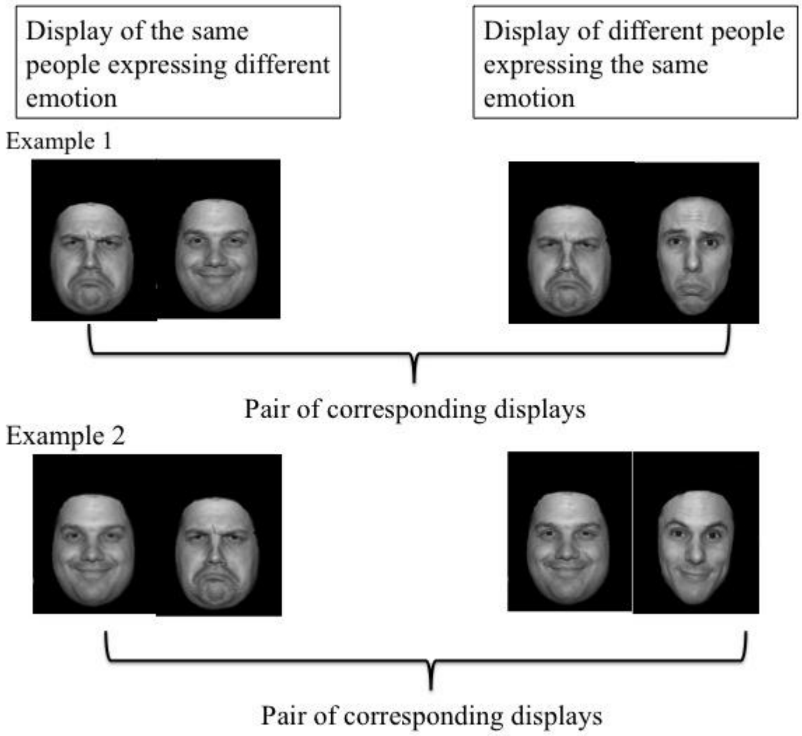

Figure 2.2. Examples of corresponding displays.

The number of corresponding pairs of displays may be calculated by using the following formula: N = P x (E x c) x2, where N – the number of corresponding pairs; P the number of tested faces; E – the number of tested emotional expressions; c – the number of paired combinations of E (i.e. two emotional expressions dive 1 combination, 3 emotional expressions give 2 combinations, etc.).

In Experiments A, C, D, E there were 12 pairs of corresponding displays, in Experiment B, 36 pairs of corresponding displays were analyzed (Figure 2.3).

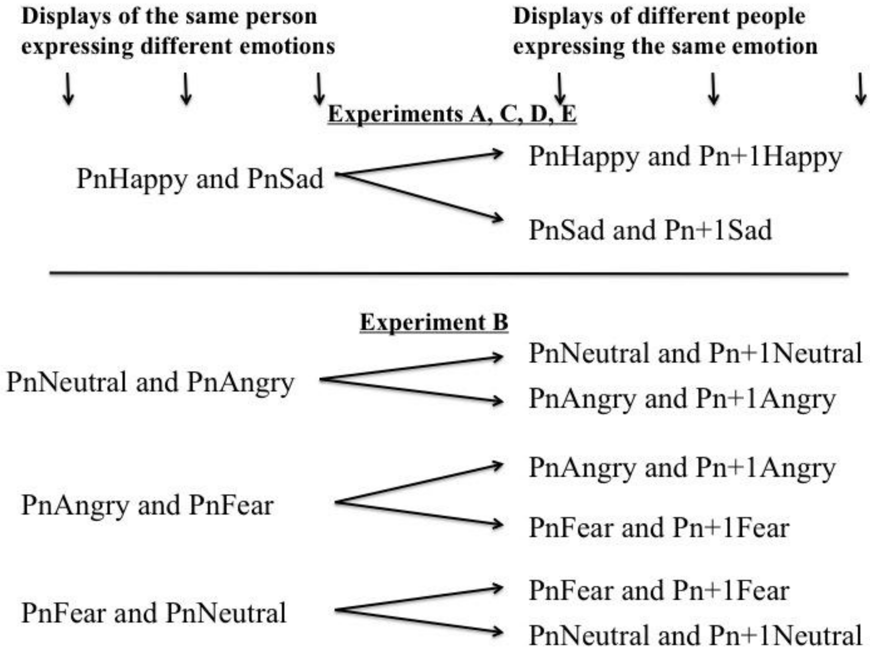

Figure 2.3. Pairs of corresponding displays in Experiments A-E, where P denoted 'a person' and 'n' - individual's number (i.e. Pn = Person 1, Pn+1 = Person 2).

2.1.1.2 Results and discussion

Experiment A. The average number of errors was 4.0 (out of how many trials/or give percentage). There were reliable differences between displays of the same person expressing different emotions and displays of different people with the same emotion in 11 of 12 corresponding pairs of displays (all $p < 0.5$). The difference between the mean RTs to pairs containing a sad and happy expression of Person 1 ($M = 812$, $SD = 46.7$) and the mean RT to displays with a sad face of Person 1 and a sad face of Person 3 ($M = 821$, $SD = 35.2$) was not statistically significant ($t(17) = 1.81$, $p = .09$). The error rates for these corresponding displays were not reliably different ($t(17) = 1.2$, $p > .1$).

Experiment B. The overall percentage of incorrect responses for categorization pairs of images was 4.65. Participants were less accurate in responses to pairs of photographs of the same person with different emotions (1.85% of incorrect responses) than to images of different people with the same emotional expression (0.5% of incorrect responses).

Paired t-test was applied to all 36 corresponding displays. Eight pairs of corresponding displays were found as having no reliable differences in means RT (all p > .09). However, paired t-test for error rates showed significantly more errors in responses to displays of the same person expressing different emotions than to displays of different people with the same emotional expression for four out of eight corresponding displays (all p < .05). These four corresponding displays were excluded from further analysis. The remaining four pairs are shown in Table 2.2.

Table 2.2

Means RT (ms) and error rates for selected pairs of corresponding displays in Experiment B

Pairs of corresponding displays	Mean RT*(SD)	**Test for RT differences	Error rates		Test for error differences
Fear Person 4 and Angry Person 4 - Fear Person 4 and Fear Person 5	818 (54.3) – 844 (42.2)	0.9, p = .36	1.7	0.9	0.9, p = .38
Fear Person 6 and Angry Person 6 – Fear Person 6 and Fear Person5	816 (56.1) – 844 (42.2)	1.2, p = .2	2.7	0.8	1.8, p = .26
Angry Person 4 and Neutral Person 4 – Angry Person 4 and Angry Person 5	820 (41.4) – 841 (37.3)	0.5, p = .5	1.5	0.9	1.5, p = .13
Fear Person 4	820 (55.4) –	1.29, p = .6	2.8	1.9	1.4, p = .13

and Neutral	866 (33.6)
Person 4 – Fear Person 4 and fear Person 5	

*Note: the left column reflects to the first pair of corresponding displays, the right column reflects to the second pair of corresponding displays.

** *t*-test (two-tailed)

Experiment C. The average number of errors was 2.03. There were reliable differences between displays of the same person expressing different emotions and displays of different people with the same emotion in 10 of 12 corresponding pairs of displays (all $p < 0.5$). The difference between the mean RTs to pairs containing a sad and happy expression of Person 7 ($M = 756$, $SD = 76.1$) and the mean RT to displays with a sad face of Person 7 and a sad face of Person 9 ($M = 794$, $SD = 64.3$) was not reliable ($t(14) = 0.81$, $p = .3$). The error rates for these corresponding displays were also not reliably different ($t(14) = 0.8$, $p > .1$). Similar result was obtained for pair Person 8 with a sad and happy expression – a sad Person 8 and a sad Person 9 ($t(14) = 1.1$, $p > .1$). However, participants made reliably more error for this pair ($t(14) = 3.2$, $p < .05$).

Experiment D. The average number of errors was 5.1. Differences between displays of the same person expressing different emotions and displays of different people with the same emotion were reliable in 9 of 12 corresponding pairs of displays (all $p < 0.5$). The difference between the mean RTs to pairs containing a sad and happy expression of Person 11 ($M = 834$, $SD = 52.6$) and the mean RT to displays with a sad face of Person 10 and a sad face of Person 12 ($M = 852$, $SD = 59.2.3$) was not reliable ($t(14) = 0.5$, $p = .14$). Similar result was obtained for pairs: Person 12 with a sad and happy expression – a sad Person 10 and a sad Person 11 ($t(14) = 1.1$, $p > .05$); Person 11 with sad and happy expression – a sad Person 10 and a sad person 12 ($t(14) = 1.26$, p

> .05). The error rates for all these corresponding displays were also not reliably different (t(14) = 0.92, p > .05; t(14) = 1,32, p > .05; t(14) = 0.6, p > .05;).

Experiment E. The average number of errors was 3.2. In one out of 12 corresponding display differences between displays of the same person expressing different emotions and displays of different people with the same emotion was not reliable for reaction time (t(14) = 1.1. p = .08) and accuracy performance (t(14) = 0.5, p = .14) (pairs containing a sad and happy expression of Person 15 (M = 812, SD = 60.3) and a sad face of Person 13 and a sad face of Person 15 (M = 823, SD = 49.1).

In sum, one pair of corresponding displays in Experiment A and four pairs of corresponding displays in Experiment B, one pair in Experiment C, three pairs in Experiment D and one pair in Experiment E satisfied the selection criteria for RTs to be equated for identity and emotional expression judgments. Because in Experiment D thee pairs of stimuli satisfied the selection criteria, for the main experiment only one pair was chosen. These stimuli were than made available for the main experiment Appendix A).

2.2 Design and procedure

2.2.1 Pilot study

A way to address the issue of independent processing of facial identity and emotional expression is to examine performance under the divided attention conditions (see section 1.4.2.2 for detailed description). In this paradigm, both dimensions are relevant to the task and are influenced by the dimensions when combined performance is measured. For example, participants are required to detect three targets: (i) Person A depicted with a neutral expression, (ii) Person B with a sad expression, and (iii) Person A with a sad expression. Here the third target has redundant information of the identity properties and the emotion properties that define targets (i) and (ii). We can ask whether the combination of identity (Person A) and emotional expression (sad) leads to an improvement in performance - a redundancy gain effect (iii) relative to single targets (i) and (ii). Moreover, by examining the nature of this redundancy effect, we can learn new details about how facial identity and emotional expression modulate information processing, if redundancy gains effects are above and beyond effects that can be accounted for by any model assuming independent processing of facial dimensions.

The presence or absence of a target was equally likely: 3 stimuli contained targets and required answer 'target present', 3 stimuli contained 'target absent' trials depicting three faces showing no target identity and no target emotion. A main criterion for selecting the three non-target faces is dissimilarity to the faces containing targets. Previously, this design has been reported in the literature for various stimuli but not for face processing. A pilot experiment was carried out to examine accuracy and RT performance in this task.

There are two ways in which participants can respond: i) 'go-no/go' in which subjects are required to respond to one of the choices (e.g. target present) but must withhold a response to the other alternative (e.g. 'target absent'); and ii) 'yes/no' procedure where one of two choices is made. A number of past studies have raised questions as to which procedure ('go-no-go' or ''yes/no') provides a better time window into cognitive processes that are involved in the task (Chiarello, Nuding, & Pollock, 1988; Espinoza-Varas & Watson, 1994; Perea, Rosa, & Gomez, 2002). The aim of the pilot study here is to explore the difference in RT performance using two types of trials: 'go-no/go' and 'yes/no'.

Sixteen participants (aged between 23 and 26.7 years) took a part in this pilot experiment: half performed ‘go-no/go’ trials and half performed the ‘yes/no’ trials. Participants in the ‘go-no/go’ group (5 female) were asked to make a response ‘target present’ as quickly and accurately as possible when any target appeared on the screen, and withdraw response if no target was displayed’. Participants in the ‘yes/no’ group (4 female) were required to make both responses, ‘target present’ and ‘target absent’. Stimuli were presented successively in random order with one block of tested trials. The participants took part in 600 trials (100 trials on each of 6 faces). Each trial started with a central fixation cross for 500 ms following offset of the cross, the face display appeared and remained until the participant responded (for the yes/no trial) or remained for 2000 ms (for go-no/go trials). The results of both tasks are displayed in Table 2.3.

Table 2.3

Results of pilot experiment for the implementation of the divided attention task in face processing

	Types of trial	
Parameters	Go-no/go	Yes/no
RT* (ms)	487.4	562.8
SD_{RT} (ms)	86.2	73.1
Errors**	3.2	2.6
SD_{errors} (%)	2.9	2.1
Average time of performance (min)	15.4	16.9

*Averaged RT

** mean % of incorrect responses

Taken together, the results presented in Table 2.3 suggested similar performance for the ‘go-no-go’ and ‘yes/no’ trials.

The effect of practice on accuracy and RT performance was examined for each type of trial. RT distribution for each type of trial were divided into 5 subsets of 120 trials (Table 2.4).

Table 2.4

Means RT (ms) and errors (%) in subsets for go-no/go and yes/no trials

	Go-no/go		Yes/no	
Trials	RT (SD)	Errors	RT (SD)	Errors
1-120	534.7 (104.4)	5.4	639.6 (101.1)	6.1
121-240	478.3 (98.1)	2.3	578.7 (98.6)	4.2
241-360	436.7 (82.2)	2.2	593.8 (91.04)	2.1
361-480	462.3 (67.2)	3.1	547.21 (74.45)	3.2
481-600	449.5 (63.1)	2.4	549.48 (62.8)	2.3

A mixed ANOVA with subsets of trials (5 levels, see in Table 2.4) as the within subject factor and procedure (go-n0/g0 and yes/no) as the between subject factor was carried out on RT and error data. There was a main effect of subset of trials for RT performance ($F(4, 132) = 4.28$, $p < .05$, $p\mu^2 = 0.45$), and a main effect of procedure ($F(1, 33) = 3.6$, $p < .05$, $p\mu^2 = 0.32$). But importantly there was no interaction subset* procedure ($F(6, 354) = 0.67$). Post hoc Bonferroni corrected comparisons revealed that RT for the first subset (1-120) was reliably slower than in subsequent subsets ($p < .05$). The differences in RT for yes/no and go-no/go were not reliable ($p = 0.07$).

The results indicate slower RT n the beginning of the task that may be due to learning of the stimuli. Although it is unlikely that slower RT in the beginning of a task dramatically affects the RT analysis, in sequential experiments participants performed a practice block of 18 trials (three repetitions of each face stimulus) with feedback on accuracy and RT performance.

2.2.2 Design and procedure for Experiments 1-8

A “present/absent” reaction time task was employed in Experiments 1-3, 5 and 7. In Experiment 4 the ‘go-no/go task was used because stimulus contingencies were manipulated to test specific hypothesis about interactive versus coactive processing of identity and emotion in faces (see in design section for Experiment 4). Also, the ‘go-no/go’ task was used with the elderly participants, as it was assumed to be easier for them to provide only one type of a response only, as this procedure was relatively easier (see above). Half of the trials contained images with at least one target (‘present’ trials) and half had non-target faces (‘absent’ trials or ‘no/go’ trials).

Participants were asked to decide whether a target was present be it a specific person or a specific expression. If no target signals were presented, participants were required to press button “target absent” (or withdraw the response in Experiment 4). Experimental design for Experiments 1-3 and 5-7 is displayed in Figure 2.4. The instruction was displayed on the monitor, and then repeated orally by experimenter.

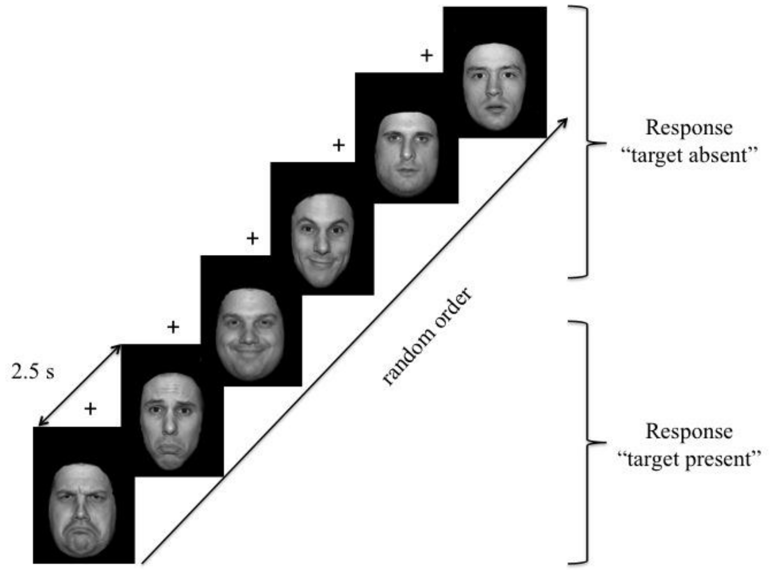

Figure 2.4. Experimental design for Experiments 1-3, 5-7.

The stimuli were presented subsequently in random order in one block of 600 trials (100 trials on each of the six images) in all experiments. In the experiment with the elderly participant (Chapter 6) stimuli presentations were divided into three blocks to enable rest in-between. In each experiment the test trials were followed by 18 trials of training. Each trial started with a central fixation cross for 500 ms following offset of the cross, an image display appeared and remained until the participant responded. Each experiment lasted about 20 min. Additional display times and inter stimuli intervals were introduced in the fMRI study (see specific methods for details).

2.3 Analysis of RT data for testing independence

For each study the redundancy gain was first assessed by a repeated measured ANOVA comparing responses with single targets (I, E) to those with redundant target (IE). In addition two analyses were conducted comparing cumulative distribution functions for redundant targets (IE) and either single target (I and E) for testing independence vs coactivation in the processing of identity and emotional expression.

The magnitude of the redundant targets gain is commonly estimated by comparing the observed RT distributions with the distributions predicted by the Independent Race Model (Raab, 1962, see Miller (1982, 1986) for implementation the procedure). A number of computational model-fitting approaches have been proposed to compare RT distributions for redundant and single target conditions. The majority of these approaches were developed to test specific assumptions about probability summation mechanisms for observed magnitude of the facilitation effect (Colonius, 1990); determining the level of statistical significance of empirically observed violations (Maris & Maris, 2003); and testing the prediction for serial and parallel architecture of cognitive processes involved in a particular task (Townsend & Ashby, 1983). In the present thesis I adopted a standard procedure introduced by Miller (1982) and extended later for a group level analysis (Ulrich, Miller, & Schroter, 2007) for testing the hypotheses. The main advantage in using the procedure here is that Miller's test (1982) allows direct comparison between two models without restricting them by specific distributional assumption or experimental paradigm. To increase the diagnostic power of the procedure, the individual RT distributions were corrected for 'fast guesses' (when responses are given without processing the stimuli) and the 'kill-the-twin' procedure was applied to the data (Gondan & Heckel, 2008; Ulrich et al., 2007).

First, each individual's correct RTs to target faces were examined to see if there was general evidence for the redundancy effect. Mean RTs across the two single targets (e.g., emotion only, or identity only) were subtracted from the mean RT for redundant targets for each participant. A positive value following this subtraction constitutes a redundancy gain. Subsequently the size of an individual's redundancy effect was corrected using the fixed favoured dimension test (Biederman & Checkosky, 1970). It has been shown that, when some observers favour one dimension over another there is an overestimation of the mean RT redundancy gain relative to the fastest single dimension condition for each observer (Biederman & Checkosky, 1970; Mordcoff & Yantis, 1993). The fixed favoured dimension test involves comparing the two single target conditions for each observer against each other. When the two conditions differ, the faster mean RT is retained as the conservative estimate of single target mean RT; when the two conditions do not differ, the overall mean from both single target conditions is used.

The second analysis tested whether the Independent Race Model inequality is violated (Miller, 1982). The test makes use of the cumulative probability density functions (CDFs) of the latencies obtained for the redundant targets and for each of the single targets, and can be expressed as follows:

$G_{IE}(t) < G_I(t) + G_E(t)$, (1) where

$G(t)$ – is the probability that a response has been made by time t,

E and I refer to a target defined by identity and a target defined by emotional expression,

IE refers to redundant targets, defined by both identity and emotions.

The G_{IE} variable, in inequality (1), sets an upper boundary for the cumulative probability of a correct response at any time (t) given redundant targets (IE). According to the Independent Race Model, the redundant target (IE) cannot exceed this upper bound, because the mean of the minimum of two random variables (IE) is less than or equal to the sum of smaller means of both variables (I and E). In contrast, the

Coactivation Model holds that the upper bound should be violated, because responses to redundant target must be faster than the fastest responses to either single target (Miller, 1982).

To conduct the Miller (1982) test, empirical CDFs were estimated for every participant and every target condition. All calculations followed the algorithm for testing The Independent Race model inequality (Ulrich et al., 2007). First, the 100 RTs generated by each participant for all target trials were sorted in ascending order to estimate 19 percentiles (5^{th} through the 95^{th} at 5% intervals). Then these numbers were averaged across participants to produce the composite CDF for redundant targets and each single target conditions. To produce the sum of CDFs for I and E trials RTs for these trials were pooled together and 19 quintiles were estimated based on only the fastest 100 of the 200 trials. All calculations were conducted using MatLab script for computing the Independent Race model test (Ulrich et al., 2007).

The nineteen percentiles points and CDFs were calculated for each participant and then averaged. Paired two-tailed *t*-tests were used to assess reliability the difference between G_{IE} and the sum of G_I and GE at each percentile point.

Graphic representations of the distributions were constructed using group RT distributions obtained by averaging individual RT distributions (Ulrich et al., 2007). When the CDFs are plotted, the Independent Race Model requires that the CDF of the redundant targets trials be below and to the right of the summed CDF of the single trials. Examples of the group graphic representation are shown in Figure 2.5. I adopted Matlab codes for computing CDFs and plotting individual graphic representation originally introduced by Ulrich et al., 2007 (Appendix B).

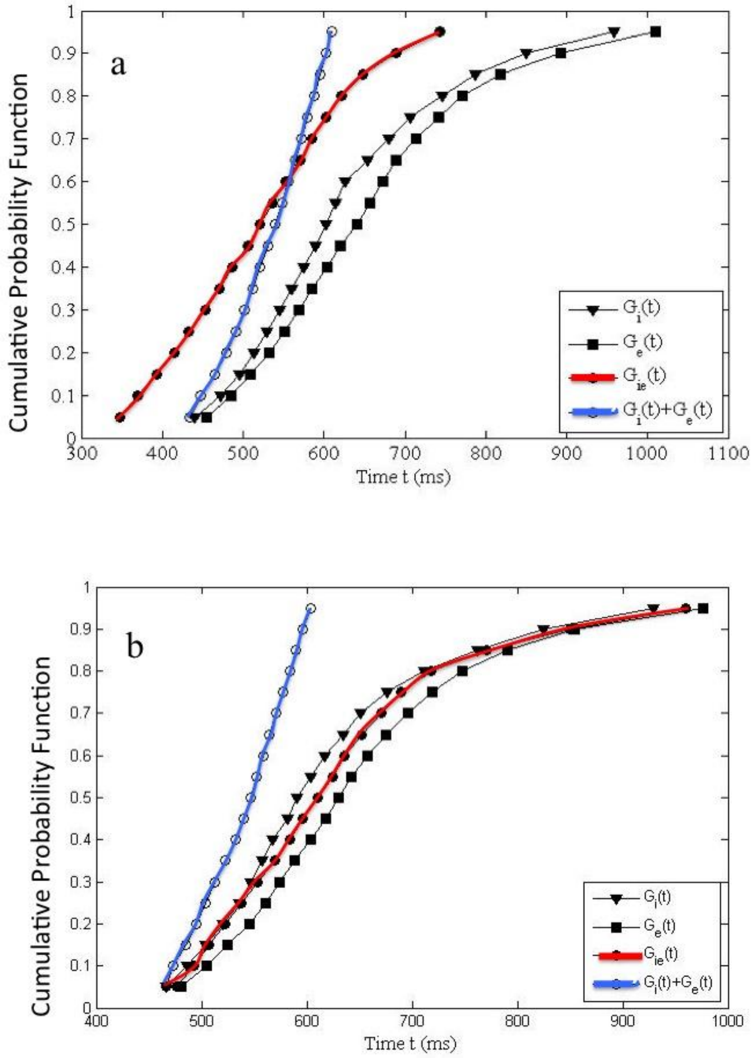

Figure 2.5. Examples of the group graphic representations: a - satisfied The Co-activation Model, b - satisfied the Independent Race Model. CDF for the redundant targets is shown in red, CDF for the sum of two single targets is shown in blue

The third analysis examines capacity effects in the data by defining the capacity coefficient ratio (C(t)) for processing facial identity and emotional expression.

Here I used a method of computing a capacity coefficient proposed by Townsend and Eidels (2011) for OR-task. It has been demonstrated that in order to access the internal efficiency in processing it is critical to take into account the stopping rule used by participants to perform the task. In OR-task either stimulus containing a target can produce a correct response. In AND-task the system must complete information from two sources (the decision is made when two targets are detected) (Townsend & Eidels, 2011; M. J. Wenger & Gibson, 2004; M. J. Wenger & Townsend, 2000a).

It has been suggested to estimate the capacity coefficient by taken a negative of the logarithm of the value for the empirical survivor function at any time bins (see mathematical advantage in Wenger & Townsend (2000)):

$$C_{OR}(t) = \frac{-\log[S_{IE}(t)]}{-\log[S_I(t) * S_E(t)]}$$

where the redundant targets condition (IE) is in the numerator and the two single target conditions (I and E) are in the denominator;

S_{IE}, S_I, S_E – survivor functions for the face containing both targets (IE), and either single targets (I and E).

First, for each condition I calculated the empirical CDF using 10 ms time bins. Then the empirical survivor function was computed for each condition at each time bin. All computation has been performed using Matlab codes (Townsend & Eidels, 2011). The group-level plot for capacity coefficient was generated as following. After averaging CDFs for the redundant targets and either single target face for the group, they were converted into survivor functions in order to create integrative hazards ($H(t) = -\log [S(t)]$ (Hugenschmidt, Hayasaka, Peiffer, & Laurienti, 2010). Then a ratio of these averaged hazards at each time bin was computed:

$$H(t) = \frac{H_{IE}(t)}{[H_I(t) + H_E(t)]}$$

where H_{IE}, H_I, H_E = are integrative hazards for redundant targets, the identity target and the emotional expression target (Townsend & Eidels, 2011).

Statistical significance for group capacity coefficients was assessed by calculating confidence interval. Confidence interval was defined for the group capacity coefficient using the bootstrapping technique (Townsend & Eidels, 2011). Here 1000 bootstrapped CDFs were created for each face containing target and then capacity coefficients were calculated by the algorithm described above. Confidence interval was calculated then based on mean and standard deviation of the bootstrapped derived capacity coefficients (Hugenschmidt et al., 2010).

2.4 Approach to analysis of fMRI data

Two approaches to analysis of neuroimaging data have been used here to explore the neural basis of any interaction between identity and emotional expression in faces: the univariate voxel-base approach implemented to statistical parametric mapping (SPM) and multivariate pattern analysis (MVPA) implemented through the toolbox conn (Whitfield-Gabrieli & Nieto-Castanon, 2012)

SPM. Statistical Parametric Mapping is a widely used tool for assessing statistical significance of neural correlates in the brain. In SPM the General Linear Model (GLM) that expresses the observed signal as a linear combination of components of interest (signal) and confound effect (noise) is applied to every voxel in the brain (K. Friston, Phillips, Chawla, & Buchel, 1999; K. J. Friston, 2005; K. J. Friston, Frith, Frackowiak, & Turner, 1995; K. J. Friston, Frith, Liddle, & Frackowiak, 1993; K. J.

Friston, Holmes, et al., 1995). The resulting SPM contains t or F-statistics for every voxel under tested assumption about effect of interest. Performing a statistical test at each voxel produces an enormous false-positive rate that needed an appropriate statistical procedure for correction for multiple comparisons. Distributional approximations are used to predict the probabilistic behaviour of SPMs under the hypothesis of no activation. The distributional approximations (p-values) are calculated using the theory of Gaussian Fields (Kiebel, Poline, Friston, Holmes, & Worsley, 1999; Poline, Worsley, Holmes, Frackowiak, & Friston, 1995). The effect of each condition is modelled as a column in individual design matrix (for each voxel), where individual time-series that consists of samples of blood-oxygen-dependent responses to the sequence of stimuli presented to the individual are convolved with the canonical hemodynamic response function (HRF). After the design matrix is created, GLM is conducted applying *t*- or F-tests to each voxel. Individual SPMs are entered then in a random-effect analysis to create a group SPM. Voxels in the group SPM that exceed the predefined level of significance (p-value) are usually considered as activation for a particular condition.

The univariate voxel-based approach has been extremely useful in identifying cortical and subcortical brain regions involved in processing of both identity (Andrews et al., 2010; Pitcher, Charles, Devlin, Walsh, & Duchaine, 2009; Winston et al., 2004) and emotional expression in faces (Adolphs, 2002a, 2002b; Andrews & Ewbank, 2004; Dolan et al., 1996; Fox & Barton, 2007) in various experimental tasks (Ishai, Haxby, & Ungerleider, 2002; Leveroni et al., 2000; Otten & Banaji, 2012; Xu & Biederman, 2010; A. W. Young, Hay, McWeeny, Ellis, & Barry, 1985). However, as each voxel in the brain is treated independently, the univariate approach ignores cooperative interactions between regions in the brain focusing mainly on exploring the specific function of a given region. Moreover, the mass-univariate approach requires an accurate priory model of fMRI signal changes in responding to the experimental conditions. In cases when fMRI signal changes are different across voxels (i.e. deviated from the canonical HRF), estimation of the activation map be under-estimated leading to increased misses of activations. In addition to this, the conservative correction for multiple comparisons may also lead to increase false negatives (when voxels with real activation are not detected). Furthermore, the activation of a voxel per condition is averaged across trials, ignoring variability between trials. The most common practice in the univariate approach is to use the difference between conditions. If the conditions do not elicit dramatic activation difference (e.g., varied in a level of intensity of emotional expression), these subtle differences are unlikely to be detected in that task.

MVPA. The multivariate pattern approach has been implemented in fMRI data analysis in order to overcome main limitations of the mass-univariate approach based on GLM. For the last ten years there is a growing number of neuroimaging studies in face processing field employs MVPA to test for systematically intrinsic variations in the brain activity (Haxby, 2012; Haxby et al., 2001; Haxby, Hoffman, & Gobbini, 2002; Kriegeskorte et al., 2007; Nestor, Behrmann, & Plaut, 2012; Nestor, Plaut, & Behrmann, 2011; Otten & Banaji, 2012; Ratner, Kaul, & Van Bavel, 2012). There are a number of MVPA methods employed for fMRI data analysis (O'Toole, Abdi, Jiang, & Phillips, 2007; O'Toole, Jiang, et al., 2007; Ratner et al., 2012). The difference between many MVPA methods relates mainly to the criteria for choosing meaningful components, and time-series partitions (e.g., spliting the data into two sets, using the third part of the data in machine learning). Generally MVPA methods are data-driven and do not require a priory model for the systematic variations. Though multivariate analysis based on training classifiers to predict the cognitive state from the spatial brain activation pattern, (Haynes & Rees, 2006; Kuncheva & Rodriguez, 2010; Pereira, Mitchell, & Botvinick, 2009) and suffer from limitations such as dealing with a noise in training data set and classification accuracy (Whitfield-Gabrieli & Nieto-Castanon, 2012). Furthermore, most MPA approaches aim to identify the function of a specific region, and hence asking similar questions to those asked by the mass univariate approaches, but using a more sensitive tools. However, the approach I chose here focus on examining the pattern of functional coupling between regions.

In the present study, Principal Component Analysis (PCA) is used to explore the neural pattern of correlated activity that supports the interaction between identity and emotional expression in faces. Generally, PCA is a technique of data reduction by identifying component(s) that account for most variation in the data. The main problem with applying PCA to fMRI data concerns extremely big number of dimensions (number of voxels in the whole brain) and relatively small number of observations (number of scans or volumes). Several techniques have been proposed in the literature to overcome this problem (McIntosh, Bookstein, Haxby, & Grady, 1996; Viviani, Gron, & Spitzer, 2005; Whitfield-Gabrieli & Nieto-Castanon, 2012). In the present study the approach offered by Whitfield-Gabrieli and Nieto-Castanon (2012) implemented in the Functional Connetivity Toolbox (Conn) (Whitfield-Gabrieli & Nieto-Castanon, 2012) was employed. In this approach a low-dimensional multivariate representation characterizing the connectivity pattern between one voxel and the rest of the brain is created for each voxel separately. This representation is defined by performing PCA on the variability in connectivity patterns between this voxel and the rest of the brain across all subjects and condition. The resulting representation characterizes the observed variability in connectivity patterns across subjects/conditions, and it allows the investigator to evaluate connectivity differences across subjects directly using second-level multivariate analyses. In Conn, PCA is performed as a singular value decomposition (SVD) (K. Friston et al., 1999) . The SVD is expressed as follows:

B (r x c) = U * S* V', where

B is a matrix with r dimensions (voxels in the brain) and c is number of observations (scans). For example, matrix 100 000 x 600 consists of 100 000 voxels across 600 scans;

U – a matrix containing eigenvectors r x r;

S – a diagonal matrix r x r containing eigenvalues;

V' – a reverse matrix c x r; the columns of V-matrix are mutually orthogonal to U.

In the present study only the first principal component that explained the largest part of variance in the data was used.

It should be noted that PCA on fMRI time series might pick up any signal in data set regardless of its relation to experimental conditions. The noise signals can dramatically affect the connectivity pattern by including some regions that are not related to experimental conditions, but rather reflect physiological, movement noise, etc. In order to reduce the effect of 'task-irrelevant' signals, conn uses the CompCor strategy for physiological and other noise signals (Behzadi, Restom, Liau, & Liu, 2007), additional removal of movement, and temporal covariates, temporal filtering and windowing of the residual BOLD signal (Whitfield-Gabrieli & Nieto-Castanon, 2012). In addition, to avoid the possibility that functional connectivity is driven by shared task-related responses, the effect of each target condition is entered as a confound prior computing the PCA (i.e., any variance in the BOLD signal that is directly related to the main task is removed from the connectivity measures).

The detailed computation of the PC scores is provided in Chapter 4 (Method section).

Chapter III. Do processing of facial identity and emotional expression interact?

3.1 Independent and coactive processing of facial identity and emotional expression (Experiments 1-3)

The present study examined the presence of redundancy gains when people respond to target face identities and emotional expressions. If identity and emotion signals are integrated, than RTs for a face containing both the target identity and the target emotional expression will be shorter than RTs when either target emotion or target identity appears alone. Specifically, if the probability of responses on a trial with redundant face and emotion targets is greater than the summed probabilities of responses on single target trials at any part of the cumulative response distribution, then an independent processing model is refuted.

Three separate experiments (Experiments 1-3) were conducted to test whether the processing of face identity and emotional expression took place in an independent or coactive manner. The aim of these experiments was to examine whether there was a redundancy gain when a face image contained both the target identity and expression relative to when it contained only the identity or emotional expression. All three experiments employed the same experimental design, but varied in the target identity present (using different actors) and the emotional expression (sad, angry and neutral expressions in Experiments 1, 2 and 3 respectively). An image set with neutral faces as targets was tested in Experiment 3 to assess if redundancy gains in responses required a definite emotion to be present. Emotions such as sadness and anger are likely conveyed by a universal set of muscle movements (Ekman, 1993). In contrast neutral facial expressions are likely to be more idiosyncratic and also to reflect the absence of one configuration of muscles rather than the presence of a distinct and detectable configuration. This may mean that identity is less likely to be integrated with a neutral expression than with a universal one such as anger or sadness.

If evidence for redundancy gains will be found are greater than can be predicted by an independent processing model (in both Miller test and the capacity coefficient), then the evidence will provide strong constraints against models in which emotional expression and identity are processed independently of each other.

3.1.1 Method

Participants

Three groups of twelve undergraduate students participated in Experiments 1-3 (ten males). The participants were aged between 20 and 23 years. They received credits for participation. All individuals reported normal or corrected to normal eyesight.

Stimuli and Apparatus

Stimuli sets 1, 2, 3 (Appendix A) were employed in Experiments 1, 2, 3 respectively. The stimuli sets are described in details in section 2.1.

Design and procedure

In Experiments 1-3 participants had to detect target identities and target emotional expressions from six photographs presented subsequently in random order. Three of these photographs contained targets: stimulus 1 had both the target identity and the target emotion; stimulus 2 contained the target identity and a non-target emotional expression; stimulus 3 contained the target emotional expression and a non-target identity. Three non-target faces were photographs of three different people, and expressed emotions different from those in target faces (Detailed description can be seen in section 2.2).

Analysis of data (see detailed description in section 2.3)

3.1.2 Results

Experiment 1: Identity and sad expressions

The percentage of errors in Experiment 1 was very low (less than 2%). Participants showed high sensitivity to images containing target signals ($d' = 3.64$).

The results of the RTE analysis showed that the overall redundancy effect did occur: the redundant condition was faster ($M = 536.3$, $SD = 85.8$) than the fastest (in this case the emotional expression target) single target ($M = 664.7$, $SD = 85.6$) condition. A one-way repeated-measures ANOVA with Bonferronni correction for multiple comparisons showed a reliable difference between the mean RTs for redundant targets and both the identity-defined target ($M = 669.9$, $SD = 99.4$) and the emotional expression target [$F(2, 22) = 75.03$, $p < .001$, $p\eta^2 = .69$; $t(11) = 8.8$, $p < .001$, $d = 0.55$; $t(11) = 11.6$, $p < .001$, $d = 0.72$].

The CDFs for redundant targets exceed the CDFs for the sum of the emotional expression target and the identity target at the first nine quintiles (all $p < .05$) (Figure 3.1, upper panel).

Capacity coefficients for processing of identity and emotional expression are displayed in Figure 3.1 (lower panel).

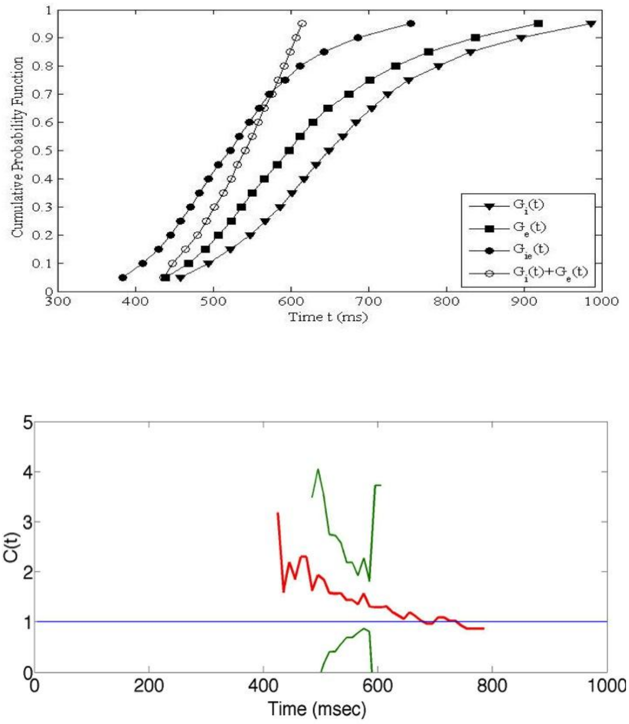

Figure 3.1. CDFs (top panel) for Redundant Targets (IE), the sum of distributions of Emotional Expression and Identity Targets (I + E) , the Emotional Expression Target (E) and the Identity Target (I) in Experiment 1. Group capacity coefficient (lower panel) in Experiment 1. The horizontal line at C(t) = 1 (in blue) indicates the reference value for unlimited capacity. The capacity coefficients are depicted in red; the confident interval for capacity coefficient in green

Here, capacity coefficients (Figure 3.1) are significantly greater than those predicted by the standard parallel model for about 180 ms (range of time bins from 485ms to 665 ms) with peak value of 1.9 at time bin 495 ms. The highest value of capacity coefficient were found at very early time bins (415 ms), however calculation of the confidence intervals was impossible using the bootstrapping technique because there was high number of zeros and relatively low number of responses. As it can be seen in Figure 3.1 (lower panel), the capacity curve crosses the point of C(t) = 1 at time bin 685 ms and exhibiting unlimited capacity for about 60 ms before dropping down to limited capacity at time bin 735 ms.

Experiment 2: Identity and angry expressions

The overall percentage of errors in Experiment 2 was low (less that 1.5 %). Here participants tended to use a conservative response bias (β = 1.54), but they showed good discrimination between images containing target information and those where the target was absent (d′ = 3.22).

The redundant condition was faster (*M* = 520.9, *SD* = 69.7) than the condition with just an emotional expression target (*M* = 683.8, *SD* = 132.6) or an identity-defined target (*M* = 648, *SD* = 105.3). A one-way repeated-measures ANOVA with Bonferronni correction for multiple comparisons revealed RT differences across the test blocks between trials with redundant targets compared with trials with emotion expression and identity targets ($F(2, 22) = 50.4$, $p < .001$, $p\eta^2 = .81$; $t(11) = 7.4$, $p < .001$, $d = 0.64$; $t(11) = 10.2$, $p < .001$, $d = 0.76$).

RTs for redundant targets were reliably shorter than the sum of the RT distributions for the identity and emotional expression targets at the first eight quintiles (all $p < .05$) (Figure 3.2, upper panel).

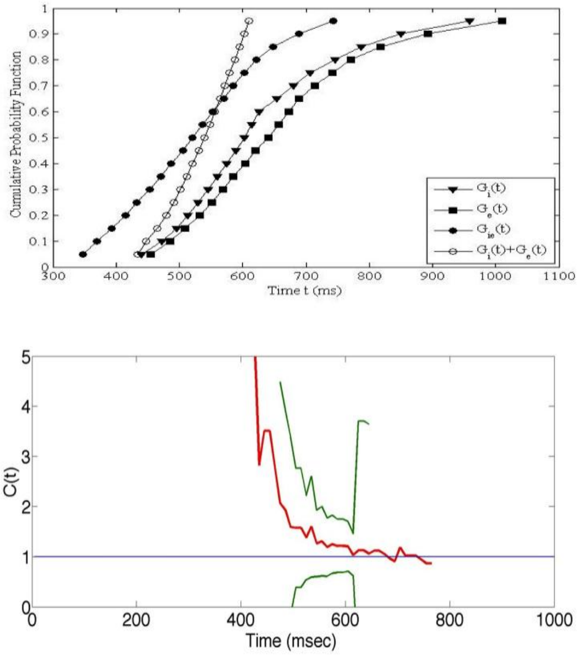

Figure 3.2. CDFs for Redundant Targets (IE), the sum of distributions of Emotional Expression and Identity Targets (I + E), the Emotional Expression Target (I), the Identity Target (I) in Experiment 2. Group capacity coefficient (lower panel) in Experiment 2. The horizontal line at C(t) = 1 (in blue) indicates the reference value for unlimited capacity. The capacity coefficients are depicted in red; the confident interval for capacity coefficient in green.

The pattern of capacity coefficients in Experiment 2 (Figure 3.2) is similar to Experiment 1 (Figure 3.1). Super capacity processing is found for the range of time bins from 425 ms to 645 with pick value of 3.1 at time bin 425 ms. As it can be seen in Figure 3.2 (lower panel), the capacity curve crosses the point of C(t) = 1 at time bin 655 ms and exhibiting unlimited capacity for about 90 ms before dropping down to mild limited capacity (= 0.8) at time bin 775 ms.

Experiment 3: Identity and neutral expressions

The overall percentage of errors was 2.09 %. Participants showed a conservative response bias (β = 1.4) and good stimuli discrimination (d′ = 3.94).

For RTs a one-way repeated-measures analysis of variance failed to reveal a significant difference between the different targets (redundant, identity and emotional expression; $F(2,22) = 1.67$, $p > .05$, $p\eta_2 = 0.08$). The RTs are displayed in Table 3.2. Redundant targets failed to exceed the sum of two single targets at any quintile (Figure 3.3).

Table 3.1

Mean RTs of responses to Redundant Targets (IE), Identity (I) and Emotional Expression (E) Targets in Experiment 3

Stimuli	M (SD), ms
IE	653.1 (103.4)
I	639.3 (108.9)
E	674.0 (100.8)

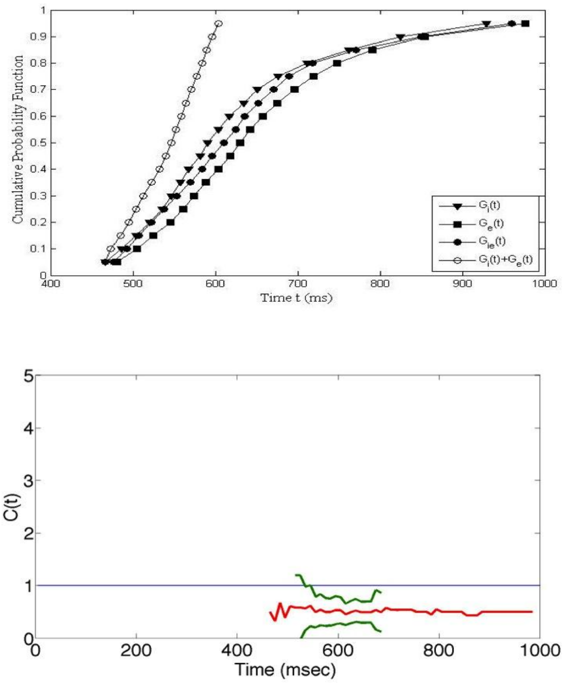

Figure 3.3 CDFs for Redundant Targets (IE), the sum of distributions of Emotional Expression and Identity Targets (I + E), the Emotional Expression Target (E) and the Identity Target (I) in Experiment 3. Group capacity coefficient (lower panel) in Experiment 3. The horizontal line at C(t) = 1 (in blue) indicates the reference value for unlimited capacity. The capacity coefficients are depicted in red; the confident interval for capacity coefficients in green

As it is shown in Figure 3.3, the capacity coefficients do not exceed the limit predicted by the standard parallel model (C(t) = [0.45 – 0.7]). The overall capacity coefficient (averaged across time bins) is 0.5 that suggest limited capacity processing for the face containing identity and neutral expression.

Comparisons across Experiments 1-3

A one-way repeated-measures ANOVA compared the size of the redundancy gains across Experiments 1, 2 and 3. The sizes of redundancy gains differed significantly across experiments ($F(2, 34) = 37.75$, $p < .001$, $p\eta^2 = 0.72$). The size of the redundancy gain in Experiment 3 (M = -16.9, SD = 44.9) was reliably smaller than in Experiments 1 (M = 88.57, SD = 34.74) and 2 (M = 124.8, SD = 44.09) (all $p < .001$, Bonferronni corrected). There was no difference in the size of the redundancy gains for Experiments 1 and 2 ($p > .09$).

3.1.3 Discussion

In Experiments 1 and 2 responses to redundant targets were faster than responses to the targets defined by identity and emotional expression alone. This is consistent with findings from prior experiments using simple stimuli where the performance was facilitated if targets were present in two rather than one stimulus

(Miller et al., 2001; Mordkoff & Miller, 1993; M. J. Wenger & Townsend, 2006). The present results show for the first time, though, that identity and emotional expression can combine to facilitate discrimination performance. Particularly striking is the finding that there were violations of the Miller inequality test when structural identity was combined with a specific, universal emotional expression in a single target. This test provides a strict assessment of whether discrimination performance can be accounted for by independent processing of the critical, target-defining properties. The results of Experiments 1 and 2 indicate that it cannot.

Violation of the Miller inequality occurred for combinations of identity and a sad (Experiment 1) and an angry expression (Experiment 2), but not for the combination of identity and a neutral expression (Experiment 3). Furthermore, there were consistent patterns of capacity coefficients for shortest reaction times that reflect super capacity in Experiments 1 and 2. In contrast, the capacity coefficient pattern in Experiment 3 demonstrated mild to moderate limitations in processing of the redundant targets face with neutral expression. Indeed, in the last case there was not even evidence for any redundancy gain. This result suggests that viewing a distinct emotional expression (e.g. sad or angry) paired with target identity benefits recognition, perhaps, because these emotions are conveyed by distinct visual features. In contrast, unfamiliar faces bearing a neutral expression do not carry expression-contingent features and a neutral expression may be defined by the absence of a universal emotional expression, making it more idiosyncratic to the particular face. For these reasons, there may be no redundancy gain when the neutral expression for one face combines with the structural identity of another target face. In terms of capacity measurement, processing of the face containing both targets where the target emotional expression was valenced, is associated with higher level of cognitive resources that resulted in better performance (here, faster RTs for the redundant targets faces compared to two single target faces).

Interestingly, the overall capacity coefficient in Experiment 3 is 0.5. Previously, it was shown that both the parallel model with fixed capacity (i.e. fixed amount of processing resources is shared equally between channels) and a standard serial model predicted capacity coefficient of 0.5 (Fific, Townsend, & Eidels, 2008; Townsend & Fific, 2004). It is unlikely here that processing of identity and emotional expression are processed serially, because results of Experiments 1 and 2 here and studies by Wenger and Townsend previously (Townsend & Wenger, 2004a, 2004b) evidence against serial processing. It is also difficult to expect that the information about the redundant targets face in Experiment 3 is equally divided between two channels, because in this case there will be extremely limited capacity on either channel that is in contradiction to results in Experiments 1 and 2. Most likely, that the neutral expression here is acting as a very limited resource of information. Moreover, in Experiment 3 capacity coefficients are very consistent across all time bins that may further support the assumption about lack of information on the emotional expression channel when the emotion is neutral.

The data can at least partly explain why emotional expression may help in identity recognition, if the two dimensions combine to form a unitary identity-expression code (e.g. D'Argembeau et al., 2003). Positive effects of emotional expressions on face identification performance have also been demonstrated by de Gelder at al. (2003), Frissen, Barton, & Hadjikhani (2003). These authors reported that, for patients with impaired configural processing, the matching of face identities was improved dramatically when the faces had emotional rather than neutral expressions. De Gelder et al. (2003) suggested that their result arose because emotional expressions provided the patients with additional facial cues to make recognition of the person more efficient.

Having established that supper-additive redundancy gains occur between face identity and emotional expression, at least when facial expressions convey distinct emotions, however, does not rule out a possibility that responses ‘target present’ has been driven by non-target information. For example, in Experiment 1 participants might associate target identity with a sad expression in the redundant face, and use emotional expression cues only for “target present” responses (or vice versa for the face identities). In this case, increasing the probability of the combination of a sad expression with a target identity will lead to the shortening of RTs on redundant trials. Another possibility that might benefit redundant targets trials over the identity and emotional expression target trials is that each single target trial included non-target information (e.g. see Mordkoff & Yantis, 1991). For instance, in Experiment 1 the identity-defined target face contained a non-target happy expression and the emotional expression target face contained non-target identity information (Appendix 1). This issue will be examined in Experiment 4.

3.2 Coactive and interactive processing of facial identity and emotional expression (Experiment 4)

The Interactive Race Model (Mordkoff & Yantis, 1991) assumes that the probability of one target can be made dependent on the occurrence of the second target and non-target information at different stages of target identification. One factor is that the greater predictability of one stimulus should speed RTs (the inter-stimulus contingency effect: ISC). A second factor is a non-target response contingency bias (NRCB), which refers to the possible use of attributes of non-targets to cue responses to targets. Therefore, including stimuli containing target and non-target information in the experimental design slows RTs for the single identity and the emotional expression target trials, because these target trials are biased by the non-target properties that are present.

The Interactive Race Model (Mordkoff & Yantis, 1991) holds that a) if both ISC and NRCB are zero (i.e. there are equal number of trials for all stimuli), The Independent Race Model inequality (1) will be always satisfied, while b) if ISC and NRCB are positive (i.e., the probability of the redundant target or non-target trials is higher compared with either single target trials), The Independent Race Model inequality will be violated. In contrast, the Coactivation Model (Miller, 1982) assumes that variation in ISC and NRCB does not affect the redundancy gain and violation of the Independent Race Model will be relatively constant across these conditions.

To test the effect of ISC and NRCB on RTs, three settings (Experiments 4a, 4b, 4c) were designed using go/no-go tasks. These experiments had the same stimuli, timing parameters, trial order and response demands, differing only in the probability with which the stimuli were displayed. In Experiment 4a both ISC and NRCB were zero, in Experiment 4b ISC was positive, while in Experiment 4c NRCB was positive (see Table 3.3 in Design and procedure section).

3.2.1 Method

Participants

Three groups of 15 undergraduate students (13 males) were recruited. The participants were aged between 19 and 26 years. All participants reported normal or corrected-to-normal eyesight.

Stimuli and Apparatus

In the three experiments (4a, 4b, 4c) the stimuli of set 1 were used (Appendix A).

Design and procedure

A “go/no-go” task was employed to examine the effect of inter-stimulus contingency and non-target response bias on identity and emotional expression judgments. Half of the trials used stimuli containing at least one target attribute (target identity, target emotional expression, or both targets; ‘go’ trials). On the other half of the trials, the stimuli did not convey any target attribute (“no-go” trials).

Participants were randomly assigned to one of three experiments. They were asked to respond as quickly and accurately as possible when the target identity and/or the emotional expression were displayed by pressing a button “target present” on the keyboard. The targets were: Person1 expressing a sad emotion (redundant targets); Person 1 with a happy expression (target identity and non-target expression); Person 2 with a sad expression (target expression and non-target identity). A face of Person 2 with a happy expression (non-target-identity and non-target emotion); Person 3 with a neutral expression (non-target-identity and non-target emotion) and Person 4 with neutral expression (non-target identity and non-target emotional expression) were employed as three non-targets.

Individuals participated in Experiments 4b and 4c after completing the practice block and then were informed which images would be displayed more often. After a short break participants performed a test block of 600 trials. The stimulus contingencies for each experiment are displayed in Table 3.2.

Table 3.2

The number of trials for the Redundant Targets (IE), the Emotional Expression Target (E), the Identity Target (I) and three Nontarget (NTs) in Experiments 4a, 4b, 4c

	Stimuli					
Experiments	E+I	I	E	NT1	NT2	NT3
4a	100	100	100	100	100	100
4b	150	75	75	100	100	100
4c	100	100	100	150	75	75

Analysis of data

First, data analysis described in section 2.3 was performed for each experiment. Then a one-way ANOVA was carried out to examine the effect of ISCB and NRCB on violations of the Independent Race Model inequality.

3.2.2 Results

In all three experiments participants produced more errors in response to the single targets relative to redundant targets. The highest error rate was for “no-go” trials to a non-target face (NT1) containing both identity and emotion distractors (Table 3.3). Participants tended to have a liberal response bias (β = 0.19, 0.3 and 0.54) and good discrimination (d′ =3.54, 3.31 and 3.41). The differences in error rates between the experiments were not significant ($F(2, 42) = 1.94$, $p > .12$, $\eta^2 = 0.06$). There was a significant main effect of Target ($F(2, 84) = 11.6$, $p < .05$, $\eta^2 = 0.79$). Pairwise Bonferronni-corrected comparisons showed that errors for the non-target face (NT1) were reliably higher compared to all other stimuli ($p < .05$). There was no interaction between Target and Experiment (4a-4c) ($F(4, 84) = 1.92$, $p > .05$, $\eta^2 = 0.1$).

Table 3.3

Error rates (in %) for Redundant Targets (IE), Identity (I), Emotional Expression (E) Targets and non-target faces NT1, NT2, NT3 in Experiments 4a, 4b and 4c

		Experiments		
Stimuli	Trials	4a	4b	4c
IE	“Go”	0.48	1.45	0.02
I		1.6	1.85	1.01
E		0.6	1.47	0.24
NT1	“No-go”	4.81	4.80	5.7
NT 2		1.1	1.67	1.01
NT 3		1.2	1.40	0.7

A redundant target effect was found in all three experiments (Table 3.4).

Table 3.4

Mean RTs for Redundant Targets (IE), the Identity (I) and Emotional Expression (E) Targets in Experiments 4a-4c

Experiments	M (SD)		
	E+P	I	E
2a	484 (57)	548 (64)	592 (82)
2b	455 (39)	518 (42)	560 (55)
2c	465 (40)	529 (44)	548 (55)

A mixed design ANOVA with Experiment as a between-subjects factor and Target (redundant, identity and emotional expression targets) as the within-subject factor was carried out to examine whether RTs for redundant targets were shorter than for single target identity and emotional expression trials. There was a main effect of Target ($F(2, 84) = 18.8$, $p < .001$, $\eta_2 = 0.83$). Pairwise Bonferroni-corrected comparisons showed that RTs for redundant targets were faster than for either single target (Table 10) for all experiments ($p < .001$). There was no main effect of Experiment ($F(2, 42) = 1.55$, $p > 0.2$, $\eta_2 = 0.12$), and no interaction between Experiment and Target ($F(4, 84) = 1.75$, $p > .05$, $\eta_2 = 0.07$).

All three experiments showed significant violations of the Independent Race Model inequality. In Experiments 4a and 4b the Independent race Model inequality was violated at percentiles 0.05 – 0.35 (all $p < .05$). In Experiment 4c violations were found at percentiles 0.05-0.45 (all $p < .05$). The group CDFs for redundant targets and the sum of target identity and emotional expression targets in Experiments 4a-4c are displayed in Figure 3.4.

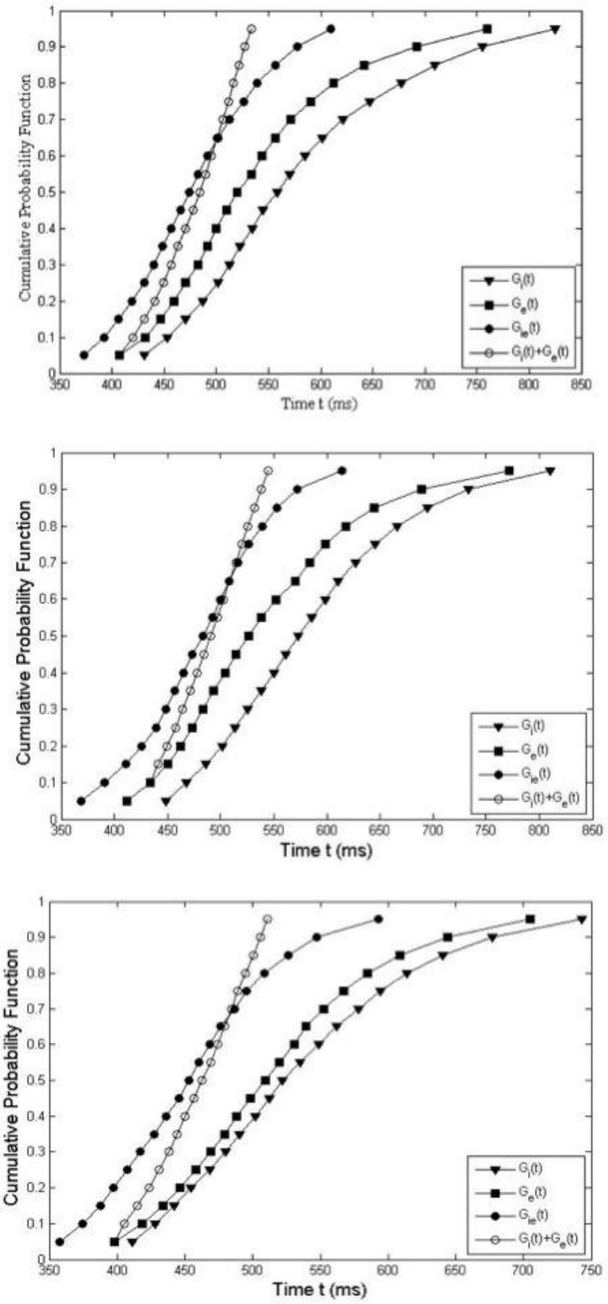

Figure 3.4 .CDFs for Redundant Targets (IE), the sum of distributions of the Emotional Expression and Identity targets (I + E) and single targets (E) and (I) in Experiments 4a (top), 4b (middle) and 4c.

The capacity coefficients in Experiments 4a-4c displayed in Figure 3.5 clearly demonstrated superiority effect for the face containing redundant targets in a range of time bins from 425 ms to 525ms for all experimental settings.

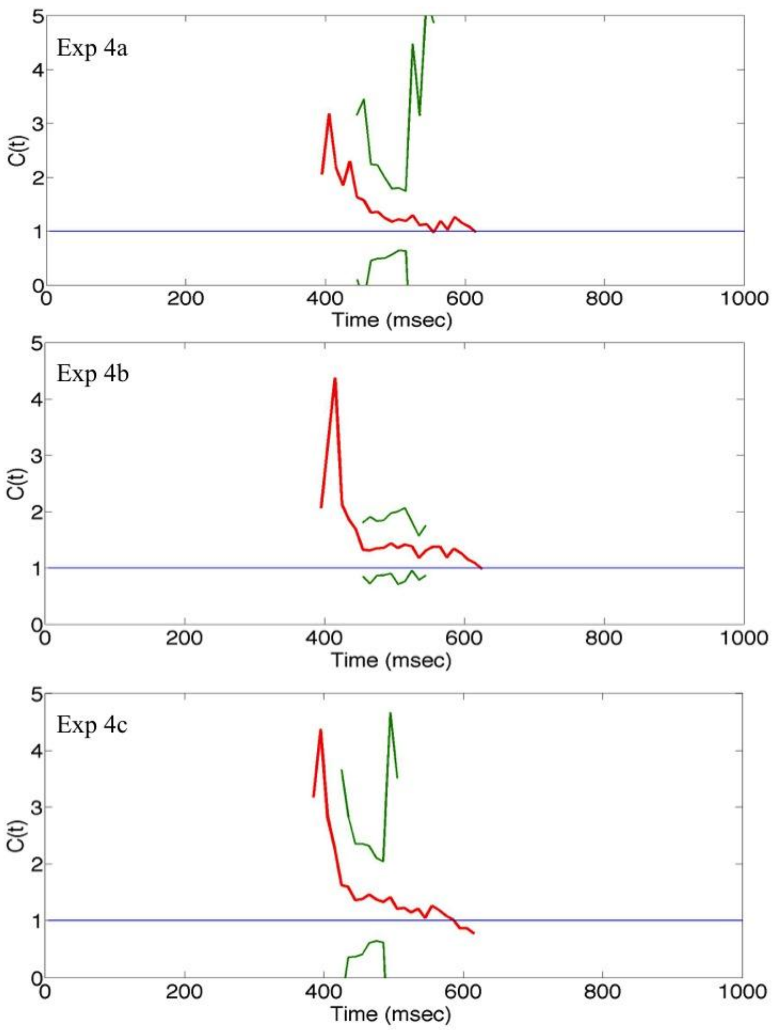

Figure 3.5. Group capacity coefficient (lower panel) in Experiments 4a-4c. The horizontal line at C(t) = 1 (in blue) indicates the reference value for unlimited capacity. The capacity coefficients are depicted in red; the confident intervals for capacity coefficients are in green

A univariate one-way ANOVA with Experiment as the between subject factor was used to test whether there were differences in the size of the redundancy gain across Experiments 4a-4c (Table 3.5). The size of the redundancy gain was calculated by subtracting of RTs for redundant targets from RTs for the fastest of the single targets at each percentile. There was no effect of Experiment on the size of the redundancy gain (F (2, 44) = .46).

Table 3.5

The size of the redundancy gains and standard deviation (in brackets) in Experiments 4a, 4b and 4c

	Experiments		
	4a	4b	4c
The size of redundancy gain, ms	63.81 (22.8)	60.2 (27.48)	64.31 (30.55)

3.2.3 Discussion

Experiments 4a-4c demonstrated that manipulations of inter-stimulus and non-target contingencies did not affect the redundancy gains between facial identity and emotional expression. Experiment 4a showed a reliable violation of the race inequality using a design that lacked biased contingencies. A similar result was obtained when contingency was biased in favor of redundant target trials (Experiment 4b) and non-target trials (Experiment 4c). Moreover, there were no differences between the size of the violations in Experiments 4a-4c. These results contradict The Interactive Race Model (Mordkoff & Yantis, 1991). The maintenance of significant violations of The Independent Race Model across all the sub-experiments is consistent with a coactivation account. The similarity between patterns of the capacity coefficients in Experiments 4a-4c further support the coactivation account for processing of identity and emotional expression in faces.

Notably, participants in Experiment 4b - in which the redundant targets had a higher probability of occurrence compared with either single target - were less accurate than in Experiment 4a. According to the Interactive Race Model (Mordkoff & Yantis, 1991), the positive inter-stimulus contingency should improve accuracy in response to redundant targets. However, this was not the case. This provides additional support for the coactivation account and again counters the inter-stimulus contingency proposal.

In all sub-experiments a non-target face containing both distractors (NT1) elicited more false alarms than the other stimuli. Although the percentage of errors was not very high, this finding suggests that participants cannot ignore the task irrelevant information completely. On the other hand, this effect was observed in a “go-no/go” task, but not in a “two-choice’ task (Experiment 1). Given that participants showed different response biases in Experiment 1 and 4, this might partly reflect a difference in a non-decision process in these tasks (Grice, Canham, & Boroughs, 1984; Grice & Reed, 1992; Mordkoff & Yantis, 1991; Perea et al., 2002).

The capacity analysis reveals similar patterns of capacity coefficients for experiments 4a-4c.

3. 3 Pictorial versus structural coding of facial identity and emotional expression (Experiment 5)

Although Experiments 1, 2 and 4 here demonstrated significant redundancy gains when participants responded to both structural identity and emotional expression in faces, it remains unclear what information was used for the task. It is possible, for example, that participants remembered pictorial properties of specific targets and distinguished faces on the basis of these cues (Bruce & Young, 1986) It is not necessarily the case that responses were based on the true extraction of facial identity and emotion information. Now many previous studies on face perception have shown that recognition of the structural properties of faces can be dramatically disrupted when faces are displayed upside-down in comparison with up-right orientation (Freire, Lee, & Symons, 2000; Leder & Bruce, 2000; Searcy & Bartlett, 1996).

The specific effect of inversion on identity processing has been attributed to the disruption of coding the configural relations between facial features (e.g., the distances between eyes, nose and mouth; Searcy & Bartlett, 1996; though see Sekuler, Gaspar, Gold, & Bennett, 2004, for an alternative view), and a similar argument can be made for emotional expression processing (Sekuler, Gaspar, Gold, & Bennett, 2004). For instance, McKelvie (1995) reported that inversion reduced accuracy for discriminating sad, fear, anger and disgust, with sad expressions being identified as neutral.

In Experiment 5, I tested for redundancy gains with inverted faces. If the redundancy gains depended on structural encoding of facial configurations, then the gains should be eliminated here. On the other hand, since the pictorial cues remain the same when faces are upright and inverted, then gains in Experiment 5 based on pictorial cues should match those we have observed earlier.

3.3.1 Method

Participants

Twelve undergraduate students (three males) aged between 21 and 26 years participated in this study. They received credits for participation. All participants reported normal or corrected-to-normal vision.

Stimuli and Apparatus

A set of inverted images from Experiment 1 was employed (Set 7 in Appendix A). This set included sad and happy faces that gave a maximum opportunity to process the inverted faces.

Design and Procedure

Design and procedure was identical to Experiment 1 except that faces were inverted.

3.3.2 Results and discussion

The overall percentage of errors was 24.5. The participants were less accurate in responding to emotional expression than to redundant and identity targets (Figure 3.5). False alarms to one of the inverted non-target NT3 (Appendix 1) occurred on 50.2% of all trials. Participants showed low sensitivity to images containing targets (d′ = 1.31).

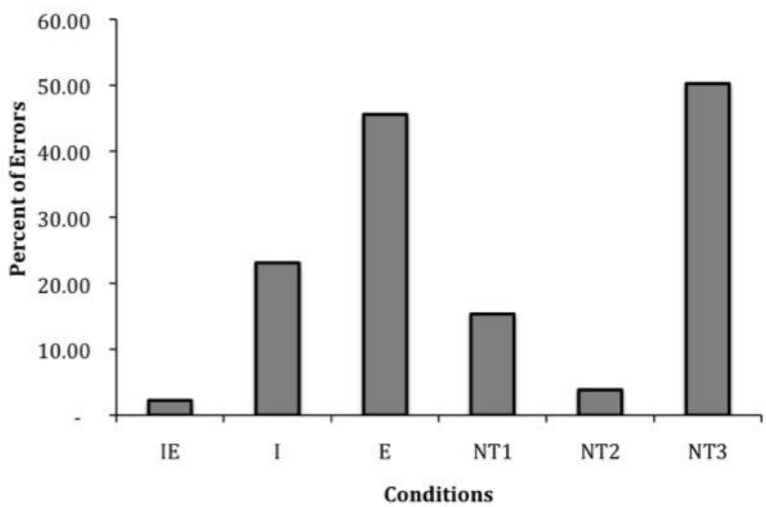

Figure 3.6. Error rates (in %) for Redundant Targets (IE), the Identity Target (I), the Emotional Expression Target (E) and three Nontargets (NTs) in Experiment 5.

A one-way repeated-measures ANOVA with Conditions (IE, I, E, NT1, NT2, NT3) as a within subject factor was conducted to assess if accuracy differed across the conditions. There was a main effect of condition on accuracy ($F(5,55) = 6.55$, $p = .001$, $\eta_2 = .61$). Pairwise comparisons within the main effect of conditions (corrected using a Bonferroni adjustments) indicated that there were reliable differences between redundant targets (IE) and both the non-target 3 (NT3) ($p < .05$), and the emotional expression target (E) ($p < .05$). Mean RTs for all the conditions in Experiment 5 are displayed in Table 3.6.

Table 3.6

Mean RTs for Redundant Targets (IE), the Emotional Expression (E) and Identity (I) Targets, and three Nontarget faces (NTs) in Experiment 5

	Conditions					
	IE	I	E	NT1	NT2	NT3
Mean RT, ms (SD)	961.5 (133.6)	798.9 (158.3)	931.1 (293.0)	832.3 (173.0)	788.0 (142.8)	884.6 (201.6)

A one-way repeated-measures ANOVA with Target (redundant, identity and emotional expression targets) as a within subject factor was carried out for RTs. There was a main effect of Target on RT ($F(2, 20) = 5.1$, $p < .05$, $\eta_2 = .57$). Pairwise Bonferroni-correted comparisons showed that participants were faster in responding to the identity target compared with both the redundant target ($p = .001$), and the emotional expression target ($p < .05$) (Table 12).

Two mixed design ANOVAs were conducted with Experiment (Experiment 1 and 5) as a between subject factor and Condition (redundant, identity, emotional expression targets and three non-targets) as a within subject factor for accuracy and RTs. For accuracy there were main effects of Experiment ($F(1,22) = 48.5$, $p < .001$, $\eta_2 = .91$) and Condition ($F(5, 110) = 5.4$, $p < .001$, $\eta_2 = .74$), and a reliable interaction ($F(5, 110) = 5.2$, $p < .05$, $\eta_2 = .77$). For RTs there were main effects of Experiment ($F(1,22) = 19.98$, $p < .001$, $\eta_2 = .86$) and Condition ($F(5,110) = 2.54$, $p < .05$, $\eta_2 = .42$), and an interaction ($F(5,110) = 12.8$, $p < .001$, $\eta_2 = .67$). Pairwise comparisons using Bonferroni adjustments showed that in Experiment 1 RTs for redundant targets ($M = 961.5$, $SD = 133.6$) were slower than RTs to the same targets in Experiment 5 ($M = 798.9$, $SD = 158.3$) ($p < .05$).

The manipulation of inversion in Experiment 5 produced longer RTs and reduced response accuracy and decreasing sensitivity for target signals. This finding is in a line with previous studies on inverted faces (Freire et al., 2000; McKelvie, 1995; Searcy & Bartlett, 1996). Notably, the image containing redundant targets and the image NT3 had similarly shaped faces (Appendix A). When the faces were inverted this similarity might be a cause of poor accuracy on NT3 because inversion impairs the recognition of internal facial features (Sekuler et al., 2004).

It could be argued that the low performance on the discrimination task here minimized any opportunity for redundancy gains to arise. For example, if participants could not discriminate facial emotion, than naturally the emotion would not facilitate responses to target identity. However, while accuracy did decrease here, it remained considerably higher than expected by chance responses to one of the 6 stimuli (16.7%). Hence there was some opportunity for facial emotion still to affect responses to face identity, but we found no evidence for this.

Taken together, the result showing poor discrimination of target signals and higher error rates in response to both targets and non-targets suggest that structural encoding (sensitive to face inversion) contributes to the redundancy gain here, and that effects are not solely dependent on pictorial encoding (common to upright and inverted faces).

3.4 Discussion of Chapter III

The experiments reported in this chapter demonstrated redundancy gains in the processing of facial identity and emotional expression. In Experiment 1, 3 and 4, there was evidence for violation of the Miller (1982) inequality consistent with coactivation of identity and emotion information in faces. These violations occurred with different face identities and with the emotional expressions for sadness and anger. The data contradict independent processing models for identity and emotion. Experiment 4 further showed that the effects were not dependent on inter-stimulus contingencies and non-target associations, going against the Interactive Race Model (Mordkoff & Yantis, 1991) account of the data. Results of the capacity analysis further support the co-activation account by demonstrating that capacity of processing is increased with increasing number of targets. This effect was consistent across Experiments 1,2 and 4a-4c suggesting that manipulation in personal identity and stimuli contingency do not affect the processing capacity. However, processing of identity and neutral expression was found to be of limited capacity. The last result is in a line with results the Miller test that showed no redundancy effect in processing identity and neutral expression. Taken together, these results suggest that processing of faces where target information has distinct features is more beneficial compared to neutral faces.

The main conclusion here is that facial identity and emotion information are processed together and both contributed in a non-independent manner to target detection.

Experiment 5 tested whether performance was dependent on pictorial or structural coding of faces by examining target detection when faces were inverted. The effects of redundancy on RTs were eliminated in this case. The effects were also eliminated in Experiment 3 where face identity was combined with a neutral facial emotion to create the redundant target. These last results suggest that the redundancy gains were not due to the memory of pictorial properties of the stimuli, and there needs to be a specific expressed emotion in order for facial information to be processed coactively. In contrast to facially expressed emotions such as sadness and anger, neutral facial expressions may vary across individuals and may be difficult to extract as a common category from different faces – as a consequence redundancy gains are difficult to find.

An important aspect of the chapter is that the redundancy effect was robust for different facial identities and emotional expressions. There are at least two features that might contribute to this. First, we used a task where both the structural identity and the expressed emotion were integrated in a single stimulus. Previously, similar results have been obtained in studies examining the relation between processing the color and shape of a single stimulus (Mordkoff & Yantis, 1991). In a task requiring participants to detect two targets (e.g. the color green and the shape X), the redundant targets display (green X) was processed faster than either single target, and violations of the Independent Race Model were observed (Experiment 1-3, Mordkoff & Yantis, 1991). In contrast, when participants performed a task requiring the detection of a shape and color belonging to different objects, the data supported independent processing (Experiment 4 and 5, Mordkoff & Yantis, 1991). Second, in the present study the effect of differences in the discriminability of identity and emotional expression was controlled. The effect of discriminability on the processing of identity and emotional expression has previously been demonstrated in studies of Garner interference (Ganel & Goshen-Gottstein, 2004; Melara, Rao, & Tong, 2002). For instance, Ganel and Goshen-Gottshtein (2004) showed that when the discriminability of identity and expression judgements were equated, Garner interference occurred in both directions. In contrast, in studies where discriminability was not controlled, either no interference (Etcoff, 1984) or asymmetric interference (Schweinberger & Soukup, 1998) has occurred.

The present results suggest that the redundant target effect is caused by an interaction between facial identity and emotional expression. This raises the question of the level of processing at which this interaction occurs. The Coactivation Model (Miller, 1982) proposes that the interaction between stimuli leading to a super-redundancy gain occurs prior to a decision about target presence, but, in this case, after identity and emotional expression have been separately coded. In contrast, the Interactive Race model (Raab, 1962) suggests that information about facial identity and emotional expression may be exchanged at early perceptual levels (inter-stimulus crosstalk) or at a decisional stage (non-target response bias). There are also suggestions that coactivation for redundant targets occurs at late motor-related stages (Giray & Ulrich, 1993; Li, Wu, & Touge, 2010). EEG-studies (Q. Li et al., 2010; Schroger & Widmann, 1998), examining the processing of bimodal (audio and visual) stimuli, indicate that RT gains for redundant targets are located neither at early, sensory-specific nor at motor stages, but at intermediate, central stage of processing, consistent with the coactivation view. It is interesting to note here that the redundancy effect in Experiments 1 and 2, using a task with two responses, was not different from that in Experiment 4, which required only a single response. This suggests that the interaction is unlikely to occur at late motor stage. Whether the effect arises at an early or more intermediate processing stages remains to be tested.

The present results can be contrasted with a strictly modular account of processing facial identities and emotions, as suggested in cognitive models of face perception (Bruce & Young, 1986). The data refute this, since they show that an independent processing model cannot account for the magnitude of the redundancy gain we observe at the very fastest responses that are produced on a trial. The data show that, at some point along the processing stream, facial identity and expression interact. This raises the question what mechanism may underlie the interaction? I speculate here that the most likely mechanism of the enhanced response for the redundant target information in faces may link to match-to-template mechanism similar to the template-matching selection mechanism (Duncan & Humphreys, 1992) or the Houghton-Tipper model (1994). When participants learn the target identity and emotional expression, the cognitive system creates templates containing facial features (or their combination) that specify the object of the target for action. When viewed faces are matched against the templates, faces containing both targets has as twice more chance for response ‘target present’ compared to faces containing either single target. However, the greater probability of matching to the template cannot explain faster responding for the redundant target faces. The crucial assumption here is that information from both the target identity template and the target emotional expression template may be combined to produce a qualitatively new template containing integrated information about targets.

Containing a very distinguish information compared to either single template the new template may enhance processing of redundant faces at the perceptual level (presumably, by top-down modulation). Although the mechanism of the facilitation effect described above is hypothetical and need further investigation, it seems to be plausible to explain the coactivation in processing of identity and emotional expression in faces.

Chapter IV

Neural network supporting interaction between processing of facial identity and emotional expression (Experiment 6)

The results of Chapter III demonstrate that the presence of both identity and emotional expression cues can facilitate recognition performance. This facilitation effect did not depend on a particular facial expression or identity or an irrelevant information in faces and pictorial properties of a face image. These findings are difficult to explain from both the cognitive (Bruce & Young, 1986) and the neural (Haxby et al., 2000) models assuming independent processing of identity and emotional expression in faces.

As was discussed in section 1.2.2, the model of distributed system for face perception (Haxby & Gobbini, 2000) proposed two separate neural pathways (the dorsal pathway for processing changeable aspects of faces and the ventral pathway for processing of invariant facial cues) that are distinguished anatomically and functionally. One possibility that the model does not consider is that processing of both identity and emotion may increase the coupling between areas within a pathway. For instance, it was demonstrated that viewing famous and emotional faces increased coupling between brain areas of the ventral pathway (Fairhall & Ishai, 2007). From this perspective, enhanced processing of redundant targets may be caused by synchronized activity between areas in the core system such as the OFA and the FFA, or the OFA and the STS making processing of combined features in the redundant target face more efficient. Moreover, attending to both facial identity and emotional expression may elicit distinct distributed neural network as compared to either single dimension, in particular, with synchronized activity between the FFA and the pSTS. The assumption is mainly based on results of previous neuroimaging studies showing functional relation between these two areas (Fox & Barton, 2007; Turk-Browne et al., 2010; Vuilleumier, Richardson, Armony, Driver, & Dolan, 2004) and behavioral studies showed interaction between identity and emotion in faces (Ganel & Goshen-Gottstein, 2004; Yankouskaya, Booth, & Humphreys, 2012).

Another possible neural mechanism for the redundant target effect in faces may link to synchronized activity in regions of the extended system that may modulate the overall responses of the core system, such as anterior temporal cortex (Kriegeskorte et al., 2007), the temporoparietal junction (Leibenluft, Gobbini, Harrison, & Haxby, 2004), the amygdala and the orbitofrontal cortex (LoPresti et al., 2008). For example, LoPresti et al. (2008) examined working memory for identity and emotion using a delayed match-to-sample task that required them to match either the emotional expression or the identity of a face after a 10 s delay. Analysis of the sustained neural activity during the delay time revealed that the orbitofrontal cortex, the amygdala and the hippocampus were involved in activation during the identity matching blocks and the emotional expression matching blocks (LoPresti et al., 2008).

Calder and Young (2005) proposed an alternative PCA framework for processing of facial identity and emotional expression in which perceptual representations for both identity and emotional expressions are coded by single representation system. PCA is a statistical tool that converts a set of observations of many correlated variables into a set of values of linearly uncorrelated variables called principal components (PCs). PCA in face processing was shown as reliable technique for extracting and categorizing facial cues, that code facial identity, emotional expression, racial cues and gender (Burton & Bruce, 1993; Calder et al., 2001; Deffenbacher, Vetter, Johanson, & O'Toole, 1998; Hancock et al., 2000; O'Toole, Abdi, et al., 2007). Although it has been demonstrated that perceptual extraction of identity and emotional expression cues in faces may be based on different components, there is partial overlapping of the components (Calder et al., 2001). Furthermore, Calder and Young (2005) suggested that '…independent coding of facial identity and facial expression can be achieved by a single multidimensional system in which the independence is partial (statistical) rather than absolute'. Given the idea of a single PCA framework for coding identity and emotional expression in faces, the redundant target effect found in Experiments 1-5 in the present study may reflect overlapping principal components for coding both identity and emotional expression in faces. Alternatively, a face containing both target identity and target emotional expression may activate areas in the brain that are involved in common representational system for coding these facial dimensions, but also depended on a task demands. For example, single-cell recording studies show that the STS and the anterior inferotemporal cortex (AIT) contain cells responsive to both identity and emotional expression (Hasselmo et al., 1989; Rolls, Baylis, Hasselmo, & Nalwa, 1989; M. P. Young & Yamane, 1992). Given that in the present study three conditions (target identity, target emotional expression and both targets) were used, the redundant target effect may reflect to activation of cell population responsive to both targets as compared to either single target.

The assumptions above are tested in Experiment 6. Functional neuroimaging data were collected while participants performed a divided attention task required to monitor each displayed face for target identity and target emotional expression and to make decisions about target presence or target absence. Then behavioural data were tested for interaction. Neuroimaging data from individuals who demonstrated an interaction between the processing of the two facial dimensions were entered in further analysis.

4.1 Method

Participants

Seventeen right-handed participants (ten females; mean age 23.6 years) with normal or corrected-to-normal vision and no history of neurological disorders participated in this study. After neuroimaging data quality check, data from one participant were discarded from further analysis due to no redundancy gains were found in behavioral data. This experiment was carried out in accord with the ethical guidelines of the British Psychological Society. Each participant gave informed consent at the start.

Stimuli

Stimuli Set 1 was employed in this study. The presentation of stimuli, experimental control and data acquisition was controlled using Cogent 2000 and Cogent Graphics developed by the Cogent 2000 team at the FIL and the ICN (http://www.vislab.ucl.ac.uk/cogent_2000.php).

Design and procedure

The design was similar to Experiment 1 (Chapter 3). Participants were presented with a set of selected photographs of faces that varied in identity and emotion and instructed to respond “target present” as quickly and accurately as possible when they saw a target person and/or a target emotional expression. When they saw neither the target person nor the target emotional expression, participants were required to respond “target absent”. The order of the trials was random. Prior to scanning, participants completed an initial practice block of 18 trials during which they were given a feedback on their accuracy and reaction time (RT) after each trial. Six runs were carried out during the scan of 60 trials (10 events per face) in each run (in total, there were 360 trials). Each face was presented for 500-ms after a fixation cross (500-ms) and followed by a black blank screen of random duration (3.5-7 sec). Participants responded “target present” or “target absent” using the index or middle fingers, respectively.

Image acquisition

MRI data were acquired using a Phillips 3T Achieva system placed in the Birmingham Univercity Neuroimaging Centre using an 8 channel phase array head coil. For each participant, structural images were also acquired using a T1-weighted sequence (FOV = 232 mm, TR/TE/ Flip = 8.4 msec/5.0 msec/308, in plane matrix = 1 x 1 mm, slice thickness = 1 mm, 170 sagital slices) and functional images with an EPI sequence (TR/TE/Flip angle = 2400 msec/40 msec/80 degree, FOV = 250 mm, matrix = 128 x 128). Each functional image comprised 41 contiguous 3-mm axial slices with no gap, oriented parallel to the inferior edge of the occipital and temporal lobes. A total of 606 functional images were acquired in one scanning runs with a repetition time of 2.4 sec.

Data analysis

Behavioural data analysis. Analysis of the behavioral data was identical to previous experiment (see detailed explanation in section 2.3).

Neuroimaging data analysis Functional images were analysed using SPM8 software (Wellcome Department of Imaging Neuroscience, London, UK; www.fil.ion.ucl. ac.uk/spm). The first four volumes were discarded to allow for T1 equilibration. All images were realigned and unwarped, corrected for slice timing, co-registered with T1 scan and spatially normalized to the Montreal Neurological Institute

(MNI) standard brain and re-sampled to obtain images with a voxel size of 3mm×3mm×3mm, and then smoothed with an 6-mm FWHM isotropic Gaussian kernel.

Two analyses were carried out: univariate using General Linear Model (GLM) and MVPA using conn (Whitfield-Gabrieli & Nieto-Castanon, 2012). For the univariate analysis: first, individual onsets and time series were concatenated across sessions, and the single-subject hemodynamic responses were modelled by convolving delta-stick functions aligned to the onset of each condition with a first-order canonical hemodynamic response function (K. J. Friston, Stephan, Lund, Morcom, & Kiebel, 2005). Stimuli onsets were defined relative to the acquisition of the middle slice. The resulting time series were then used as regressors in a voxelwise, fixed-effects general linear model with sessions as a covariate for each subject. The model included regressors for 3 target trials (I+E, I, E), for the 3 non-target faces and for the incorrect trials. Movement parameters derived from the realignment corrections (3 translations, 3 rotations) and a set of harmonic functions capturing low frequencies changes (1/128 Hz) in the BOLD signal typically associated with scanner or physiological noise were entered as covariates of no interest. Effect size maps were generated for the six conditions for each participant, across sessions. Second, the individuals' maps were used to perform a second level group analysis treating subjects as random variables.

MVPA was conducted with the Functional Connectivity toolbox (conn) (Whitfield-Gabrieli & Nieto-Castanon, 2012). The conn software uses SPM files for data definition and access. An additional pre-processing step for SPM-preprocessed data was included using CompCor method (Behzadi et al., 2007) implemented in conn for removing physiological and movement confounds.

The individual time-series for the three conditions containing targets were entered in the individual's level analysis. In this first analysis multivariate pattern analysis of whole-brain connectome for each condition are computed assessing the connectivity pattern between each voxel and the rest of the brain. First, for each voxel conn creates a MxN correlation matrix where M is number of subjects x number of conditions (16 x 3 = 48 in the present study), and N is a number of voxels in the brain. Second, conn performs singular value decomposition (SVD) of this matrix and obtains a set of K 'principal components' (a NxK matrix of 'spatial' components) as well as a set of K 'principal component scores' (a MxK matrix of component scores). The first 'spatial component', Nx1 vector (a spatial map), and the 'principal component scores' of interest are a simple Mx1 vector (a single number for each subject/condition; representing how much each participant and each condition is loaded on the observed spatial component map). These latter numbers are the ones that will be later entered into a second-level analysis. By definition these numbers have maximal between-subjects/conditions variance (there is no other normed linear combination of the columns of the original MxN matrix that results in a set of numbers with higher variance than our first principal component scores), and they have zero mean.

Conn repeats the voxel-to-voxel MVPA analyses for every voxel in the brain (resulting with 48 'principal component score' maps (16 participants * 3 conditions), where the value at any specific voxel represents the principal component score value as discussed above). Then conn performs the second-level analyses jointly across all voxels entering these maps into desired between-subjects/conditions analyses. Thus, 16 individual connectivity maps for each of the three conditions were entered to the second level analyses where participants are treated as random variables. The change in magnitude and extent of temporal connectivity between the conditions are thresholded using a family wise error correction (FWE) correction of $P_{FWE} < 0.05$ for the whole-brain volume with a minimum cluster extent of 50 contiguous voxels.

Regions that are significant in the resulting voxel-level analyses indicate condition-related differences in connectivity between those areas and the rest of the brain. Post hoc analyses using each of these areas as seeds were performed to characterize what specific aspects of the connectivity between these areas and the rest of the brain differ between conditions.

To re-iterate, the steps and logic for the neuroimaging analysis was as follows (the same structure is kept in the result section):

1. Exploring all relevant areas in the brain involved in the task the activation for faces was contrasted with a baseline. This contrast was performed using GLM (three faces containing targets and three nontarget faces were contrasted against baseline (mean signal) generated in SPM.
2. Examine the cortical areas responding to target present vs. absent condition, the following contrasts were carried out using GLM: [2]IE > [-1]I + [-1]E; [1]IE > [-1]I; [1]IE > [-1]E; [1]IE + [1]I + [1]E > [-1]NT1 + [-1]NT2 + [-1]NT3. The reversed contrast was also tested one was also performed.
3. Test the redundant targets-related differences in connectivity, the individual principal components maps obtained by the voxel-to-voxel MVPA were entered in the second level (random effect) analysis as a contrast [2]IE versus [-1]I + [-1]E. Note that here the scores for the first principal component representing correlation patterns was compared. As PCA sign is meaningless, positive or negative effects in the contrast has no meaningful sense. Here the

two-sides t-test has been used to account for both the positive and negative scores (Whitfield-Gabrieli & Nieto-Castanon, 2012).

4. Post Hoc seed-to-voxel analysis was performed (the areas that significantly different connected to the rest of the brain for the redundant targets were entered as seeds) to characterize the difference in connectivity between redundant targets and both single targets.
5. The same analysis as in 3 was performed for contrasts IE versus I, IE versus E and I versus E.

4.2 Results

4.2.1Behavioural results

The overall percent of correct answers was 97.6%. A one-way repeated-measures ANOVA showed that difference between the errors for either condition was not reliable ($F(5,75) = 1.9$, $p > .05$, $p\eta 2 = .11$).

The results of the RTE analysis revealed the overall redundancy effect: the redundant condition was faster ($M = 851.5.3$, $SD = 63.9$) than the fastest (in this case the identity target) single target ($M = 928.5$, $SD = 85.6$) condition (Figure 4.1, b). A one-way repeated-measures ANOVA with Bonferroni correction for multiple comparisons showed a reliable difference between the mean RTs for redundant targets and both the identity-defined target and the emotional expression target ($M = 990.4$, $SD = 104.9$) [$F(5, 75) = 10.2$, $p < .001$, $p\eta 2 = .45$; $t(15) = 3.5$, $p < .003$, $d = 0.88$; $t(15) = 8.8$, $p < .001$, $d = 0.52$, respectively]. This result showed that participants benefited and were about 70 msec faster when the face depicted two targets compared to only one.

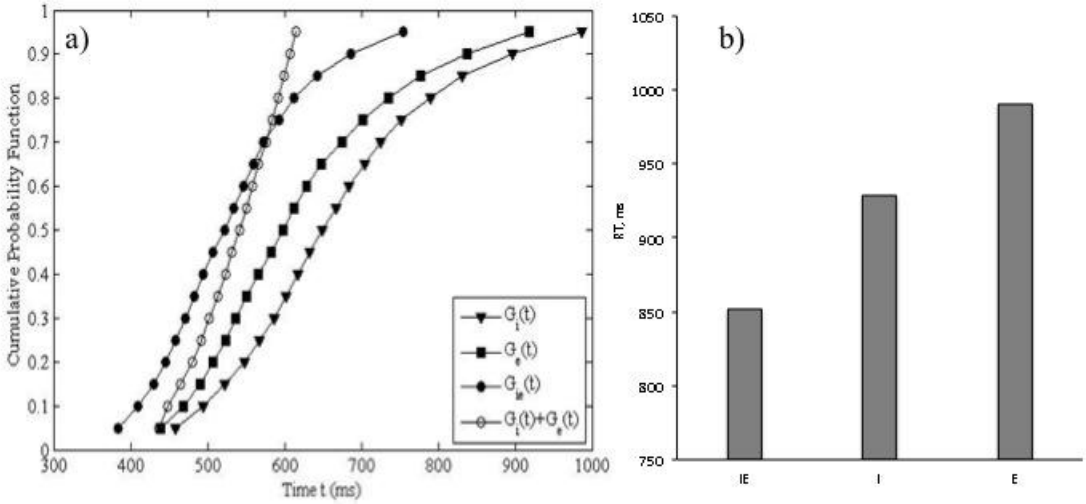

Figure 4.1 a) CDFs for redundant targets $G_{(IE)}$, the sum of distributions of emotional expression and identity targets $G_{(I)}+G_{(E)}$ and single targets $G_{(E)}$ and $G_{(I)}$; b) Mean RTs for the redundant targets (IE), the identity target (I), the emotional expression target (E)

The Miller test for inequality was used to test for inter-dependence between dimensions. The CDFs for redundant targets exceed the CDFs for the sum of the emotional expression target and the identity target at the first six quintiles (all $p < .05$) (Figure 4.1, a). This effect was reliable for the first four quantiles points (all $p < 0.05$). This means that participants were integrating information from identity and emotion prior to reaching a decision on any single dimension.

4.2.2 Neuroimaging results

4.2.2.1 Univariate analysis

Viewing faces relative to baseline elicited a large neural network that including areas commonly reported in the literature for face processing (Figure 4.2), this included bilateral responses in extrastraite visual cortex extending to the ventral stream and the

FFG and to the dorsal stream to the STS. As expected we also observed effects in left motor associated regions, due to the response given on each trial.

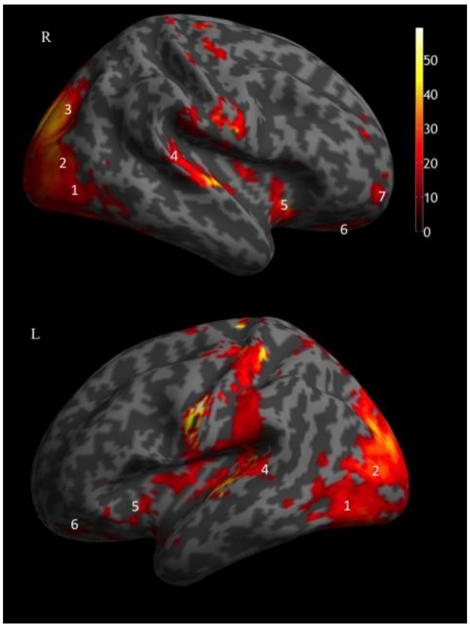

Figure 4.2. Neural network for processing faces (defined by contrast faces > baseline for the group of 16 participants). SPM (uncorrected, p < 0.001, with min of 50 voxels) rendered on a SPM canonical cortical surface. 1 – the FFG, 2 – the lateral Occipital Cortex, 3 – the middle and superior Occipital Cortex, 4 - the STS, 5- the IFC, 6, 7 – the inferior Frontal Cortex (infFC) and the OFC

The different target conditions (contrasts [2]IE > [-1]I + [-1]E; [1]IE > [-1]I; [1]IE > [-1]E;[1]I > [-1]E) did not elicit any above threshold differential response (p < 0.001 uncorrected with k > 50). The effect of faces contained target on brain activity compared to non-target faces was examined. The areas identified by this contrast comprised the left and right supramarginal gyrus and the right STS reliable activated at cluster level (Table 4.1, Fig. 4.3). The opposite contrast (non-targets vs. targets) showed no significant activations.

Table 4.1

Clusters activated for faces containing targets as compared to non-target faces*

Anatomical labels	Z-scores	No of voxels	MNI-coordinated		
			x	y	z
r-STS	4.26	87	54	-43	7
r-Supramarginal gyrus	4.05	69	57	-34	37
l-Supramarginal gyrus	3.86	82	-63	-40	25

*All clusters reported here are significant at $p < 0.05$, FWE-corrected

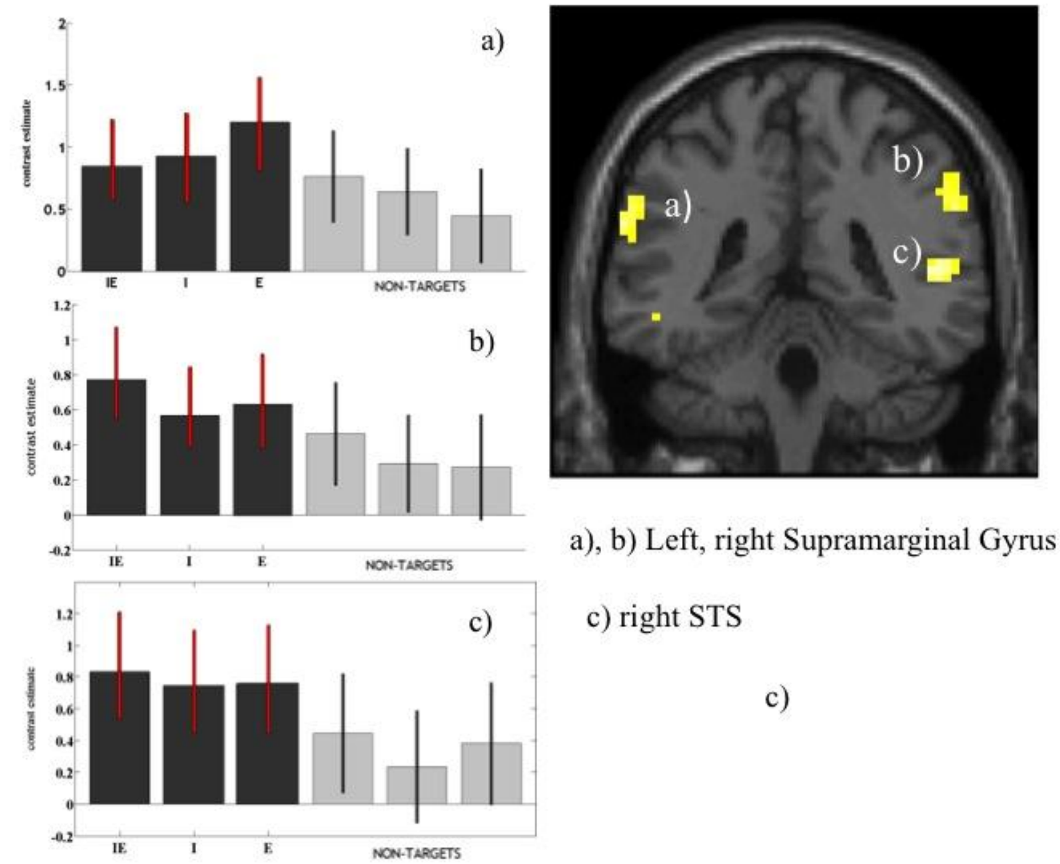

Figure 4.3. Brain areas activated for faces containing targets as compared to non-target faces. IE – redundant targets, I – the identity target, E – the emotional expression target. (FWE-corrected SPM at the cluster level, with min of 50 voxels showing Z > 3.86, overlaid on a SPM canonical single subject T1 weighted image)

The different target conditions (contrasts [2]IE > [-1]I + [-1]E; [1]IE > [-1]I; [1]IE > [-1]E;[1]I > [-1]E) did not elicit any above threshold differential response ($p < 0.001$ uncorrected with $k > 50$).

4.2.2.2 MVPA

I first tested for the difference between neural connectivity for the redundant target and both single targets using a two-side t-test for a contrast [2] IE versus [-1] I + [-1] E. Note that this analysis is performed on the ‘principal component score’ maps where the value at any specific voxel represents the principal component score value highlighting voxels that show reliable different connectivity pattern between the tested conditions (see for more detailed explanation in the Method section, 4.1). Figure 4.4 show that bilateral medial prefrontal and right inferior frontal cortices and hippocampus were differently connected to the rest of the brain during redundant target condition as compared to both single targets (Table 4.2).

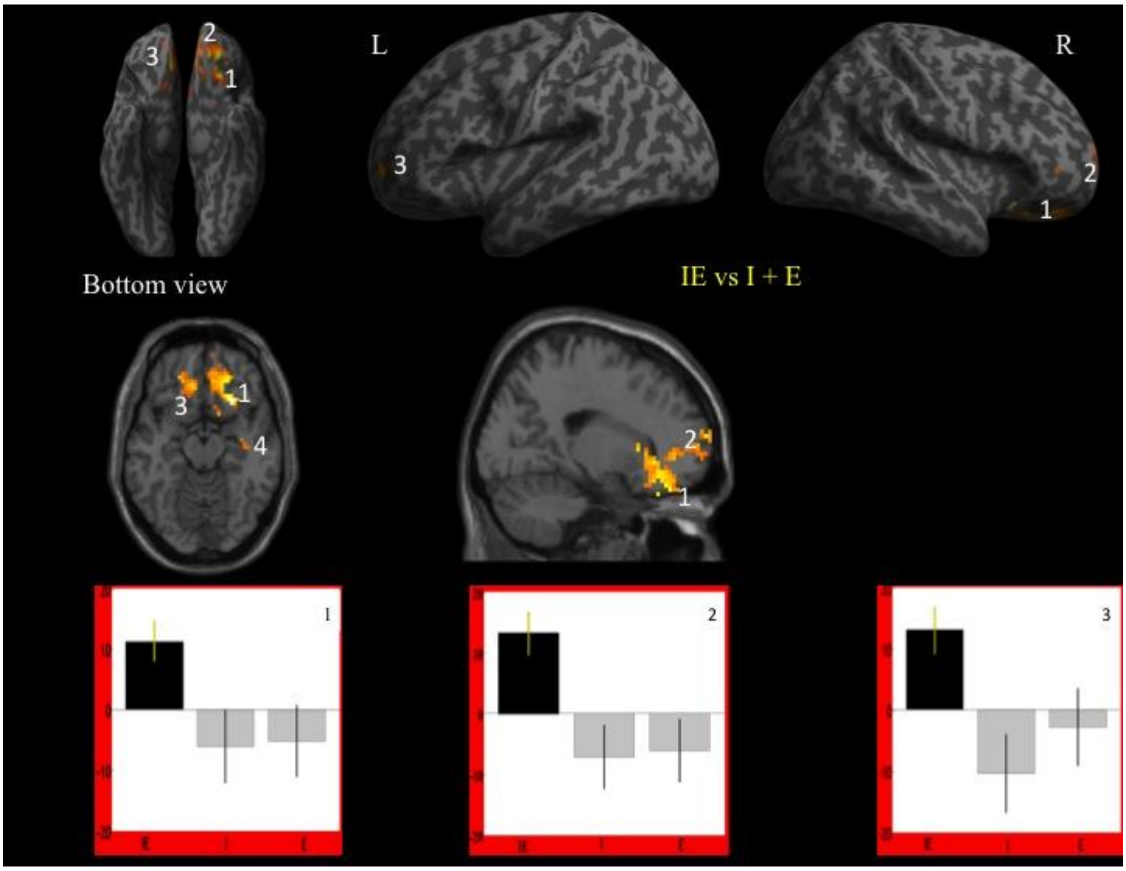

Figure 4.4. Clusters of voxels that were differently connected to the rest of the brain during the redundant targets as compared to both single targets (FWE-corrected at the cluster level, with min of 50 voxels) rendered on a SPM canonical cortical surface (upper row), overlaid on a SPM canonical single subject T1 weighted image (middle row). These clusters include voxels in the right Orbitofrontal Cortex (rOFC) (1), the right Inferior Frontal Cortex (infFC) (2), left Orbitofrontal Cortex (lOFC) (3) and the

right hippocampus (rHp) (4). The differences between single target conditions (pictures 1- 3 in the lower row) are not significant (all $p > 0.05$).

Result of the two-side *t*-test displayed in Figure 4.4 indicates that the data from the redundant targets condition shows significantly different 'principal component score' values than those coming from the two single target conditions at three clusters: in the left and right Orbitofrontal Cortex, and in the right Inferior Frontal Cortex (Table 4.2).

Table 4.2

Clusters associated with redundant targets (IE) as compared to both single targets (I + E*

Cluster	Hemisphere	N of voxels	Z-scores	MNI coordinates		
				x	y	z
OFC	r	162	4.49	27	20	-14
OFC	l	155	4.12	-21	38	-05
InfFC	l	126	4.03	-36	-28	+37
Hp	r	51	3.23	24	-28	+10

*$p < 0.05$, FWE-corrected at the cluster level, with min of 50 voxels

To explore which specific aspects of the connectivity between these clusters and the rest of the brain was different between the redundant and single targets condition, a post hoc analysis was performed. The clusters that showed the highest connectivity for the redundant targets at group level (Fig. 4.4) were entered as a seeds in the seed-to-voxel analysis perform with conn. A mask image containing all voxels in the clusters was created and entered as multiple ROIs in the first level analysis. First, conn calculates mean time series for each ROI and correlates this averaged time series with BOLD time series at each voxel for each condition that resulted in 144 individual temporal connectivity maps (48 maps for each ROI). Before averaging individual voxel data, the waveform of each brain voxel was filtered using a bandpass filter (0.0083/s < f < Inf) to reduce the effect of low-frequency drift and high-frequency noise. These maps were then included in a second-level random-effects analysis. The magnitude and extent of temporal connectivity between the conditions were thresholded using FWE correction of $p < 0.05$ for the whole-brain volume with a minimum cluster extent of 50 contiguous voxels. For each ROI two-side t-test was performed for contrast [2]IE > [-1]I + [-1]E. A result of the group level analysis is displayed in Figure 4.5.

Results of the seed-to-voxel analysis show that compared to both single targets, during the processing of the redundant targets condition there was an increase in coupling between the right OFC (Figure 4.5) and bilateral clusters in the medial and the inferior occipital regions (see the MNI coordinates Table 4.3). There were no reliable differences in functional connectivity between redundant targets and both single targets for the left OFC, the right InfFC and rHP entered as seeds in the seed-to-voxel analysis. The reversed contrast ([1]I + [1]E > [-2]IE) does not show reliable differences at cluster level or at pick voxel level.

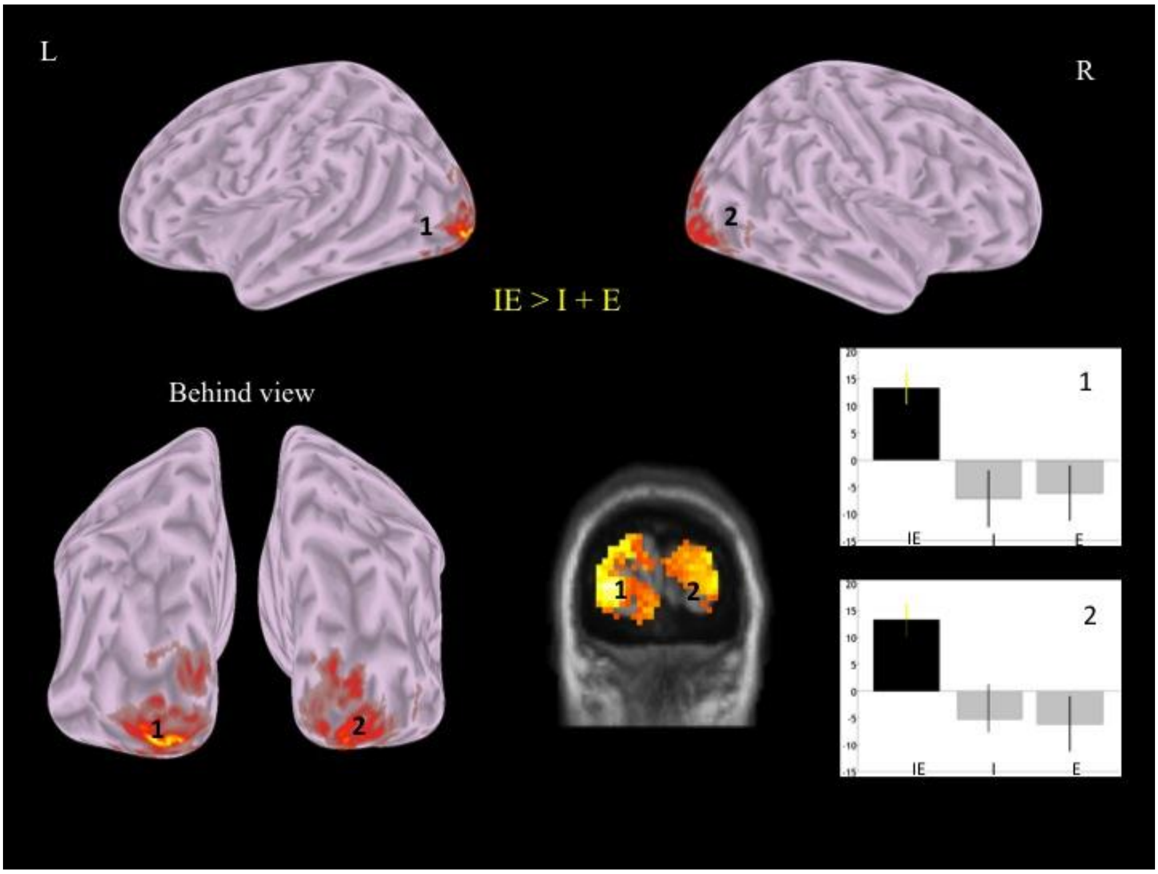

Figure 4.5. Result of the seed-to-voxel analysis (contrast [2]IE > [-1]I + [-1]E) (FWE-corrected SPMs at the cluster level with min of 50 voxels showing Z > 4.67) rendered on a SPM canonical cortical surface, and overlaid on a SPM canonical single subject T1 weighted image

Table 4.3

Seed-to-voxels functional connectivity for the redundant targets (IE) as compared to both single targets (I + E) with rOFC as a seed

Cluster	Hemisphere	Z-scores*	No of voxels	MNI coordinates

				x	y	z
mOcG and Inf OcG	r	4.67	471	33	-94	-08
mOcG and InfOcG	l	4.91	611	-21	-100	-08

*significant at cluster level ($p < 0.05$, FWE-corrected)

To examine further what specific neural connectivity associated with the redundancy effect in comparison to each signal target condition, three contrasts were performed on the individual principal component score maps: IE versus I (Figure 4.6 and Table 4.4) and IE versus E (Figure 4.7 and Table 4.5), and I versus E.

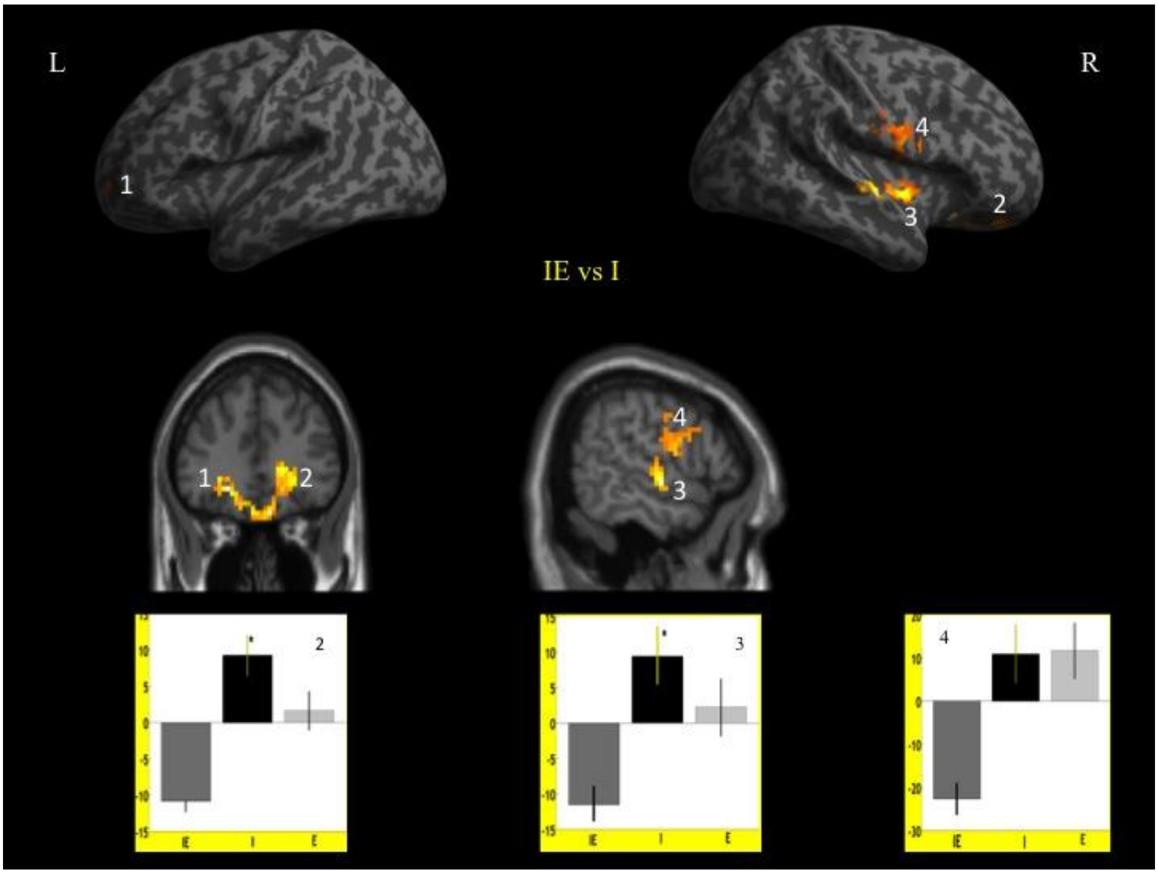

Figure 4.6. Clusters of voxels ($p < 0.05$, FWE-corrected at the cluster level, with min of 50 voxels) that connected differently to the rest of the brain for the redundant targets as compared to the identity target. Rendered on a SPM canonical cortical surface (upper row), overlaid on a SPM canonical single subject T1 weighted image (middle row). 1 and 2- the left and right Orbitofrontal Cortex; 3 – the right middle Superior Temporal Sulcus (rSTS); 4 – the right Precentral Gyrus. * - the difference between I and E is significant ($p < 0.05$)

Regions within the bilateral OFC, mid STS and pre-central sulcus change their connectivity pattern during redundant target vs. identity single target (contrast IE versus I, Figure 4.6 and Table 4.4). Note that the bilateral OFC partially overlapped the one observed when comparing the IE to I + E. Post hoc seed-to-voxels analyses were performed. Regions depicted in Table 4.4 were entered as seeds. Results of these analyses at group level (for contrast IE > I) are displayed in Figure 4.8 and Table 4.6. I observed that during the redundant condition there was also an increased coupling between bilateral OFC and bilateral superior parietal cortices (pre-cuneus) in comparison to the single identity condition. No other reliable differences were observed.

Table 4.4

Clusters associated with redundant targets (IE) as compared to the identity target (I)***

Clusters	Hemisphere	Z-scores	N of voxels	MNI coordinates		
OFC	r	4.48	199	24	25	-8
OFC	l	4.21	114	-21	38	-5
mSTS	r	4.23	132	60	-10	-5

*$p < 0.05$, FWE-corrected at the cluster level, with min of 50 voxels

**The cluster in the Precentral Gyrus was excluded from further analysis because there was no reliable difference between principal component scores for the identity and emotional expression targets

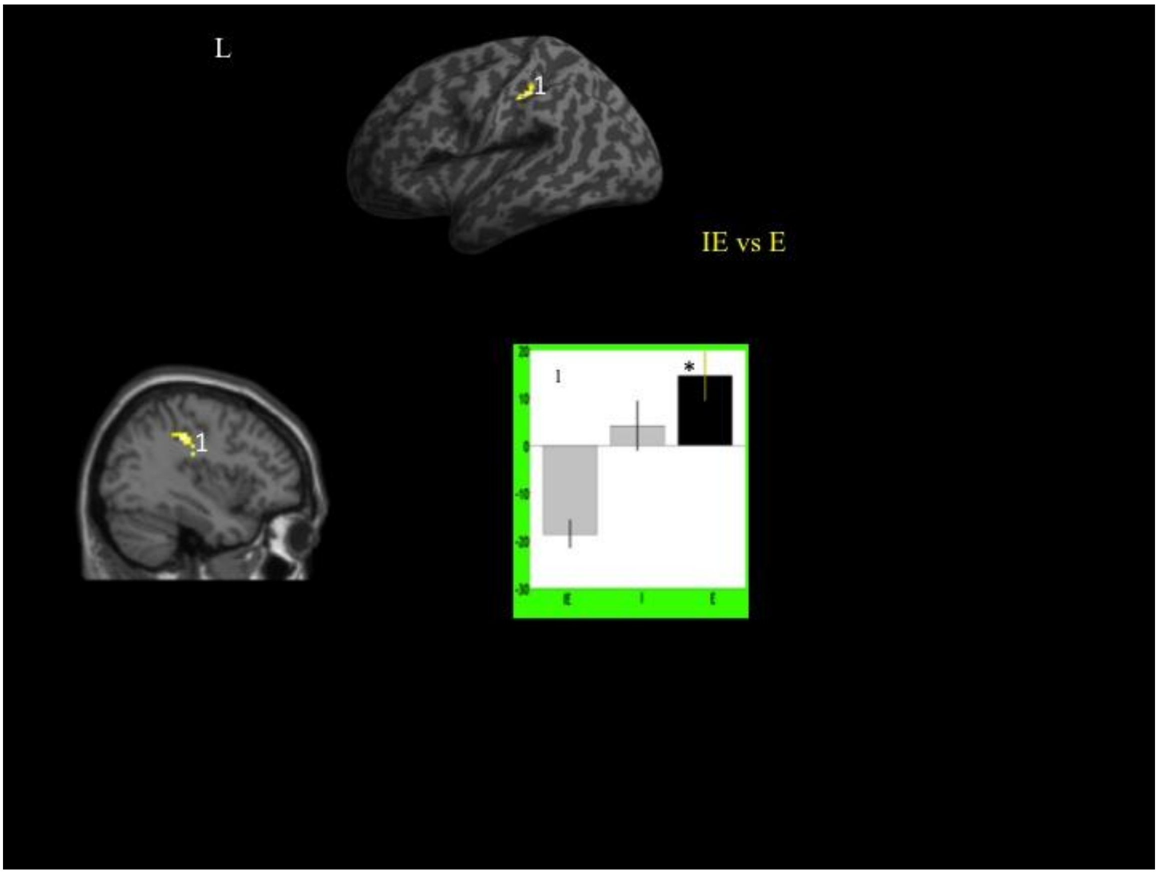

Figure 4.7. Clusters of voxels connected differently to the rest of the brain for the redundant targets as compared to the emotional expression target (FWE-corrected at the cluster level, with min of 50 voxels). Rendered on a SPM canonical cortical surface (on the top), overlaid on a SPM canonical single subject T1 weighted image. 1 - the left Inferior Parietal Sulcus (IPS) (*the difference between I and E is significant (p < 0.05))

Table 4.5

Clusters of voxel associated with redundant targets (IE) as compared to the emotional expression target (E)*

Cluster	Hemisphere	Z-score	N of voxels	MNI coordinates		
				x	y	z
Inferior Parietal Sulcus	l	4.11	52	-36	-31	37

*$p < 0.05$, FWE-corrected at the cluster level, with min of 50 voxels

To characterize the differences in connectivity between redundant targets and the identity target (contrast IE versus I, Figure 4.6) post hoc seed-to-voxels analyses were performed. Regions depicted in Table 4.4 were entered as seeds. Results of these analyses at group level (for contrast IE > I) are displayed in Figure 4.8 and Table 4.6. Note, results of the seed-to-voxel analysis for the m STS (Table 4.4) did not show any significant voxels for the contrast [1]IE > [-1]I and the reversed contrast [1]I > [-1]IE) and have not been displayed in Figure 4.8. The reversed contrasts ([1]I > [-1]IE for both seeds (lOFC and rOFC) also revealed no significant differences even at lower threshold.

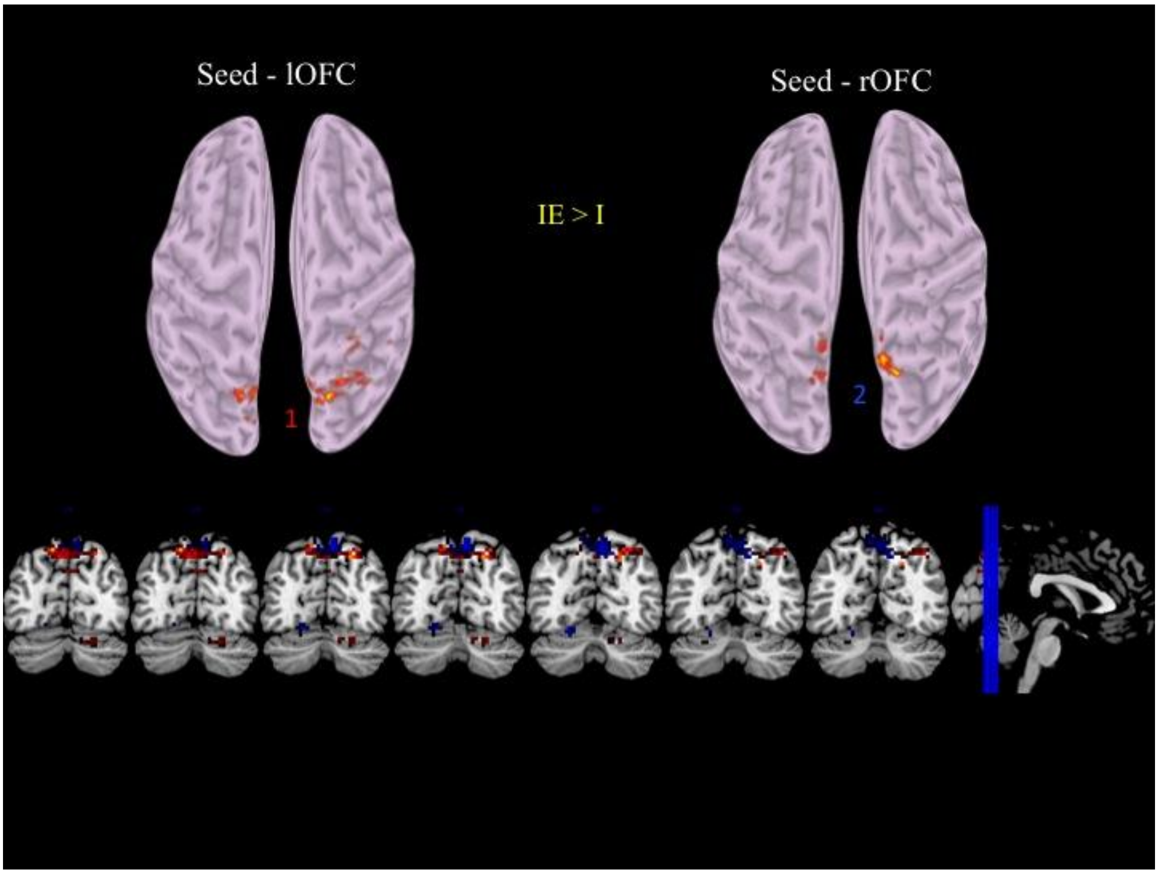

Figure 4.8 Results of the seed-to-voxels analyses (contrast [1]IE > [-1]I) ($p < 0.05$, FWE-corrected SPMs at the cluster level, with min of 50 voxels (see Table 4.6) rendered on a SPM canonical cortical surface (upper row). The lower row: multislices show the functional connectivity for the lOFC (in red) and rOFC (in blue). Masks for both seed-to-voxels connectivity analyses were created in conn and overlaid on the ch2better.nii.gz template in MRIcron. 1 – Precuneus (posterior part), 2 – Precuneus (anterior part)

Table 4.6

Seed-to-voxels functional connectivity for the redundant targets (IE) as compared the identity target (I)*

Seed	Cluster	Z-scores*	No of voxels	MNI coordinates		
				x	y	z
lOFC	Precuneus	4.21	212	24	-70	55
rOFC	Precuneus	4.07	141	06	-70	49

*$p < 0.05$, FWE-corrected at the cluster level, with min of 50 voxels

To characterize the differences in connectivity between redundant targets and the emotional expression target (contrast IE versus E, Figure 4.7) post hoc seed-to-voxels analyses were performed. Region depicted in Table 4.5 was entered as seeds (the left IPS). The analysis at the group level (for contrast IE > E) revealed no significant differences between redundant targets and the emotional expression target even when the threshold was low (p<0.01, uncorrected). However, the reversed contrast ([1]E > [-1]IE) showed reliable correlation between the seed (the left IPS) and the dorsal part of the anterior cingulate cortex (pACC) (Figure 4.9 and Table 4.7). No other reliable effects were observed.

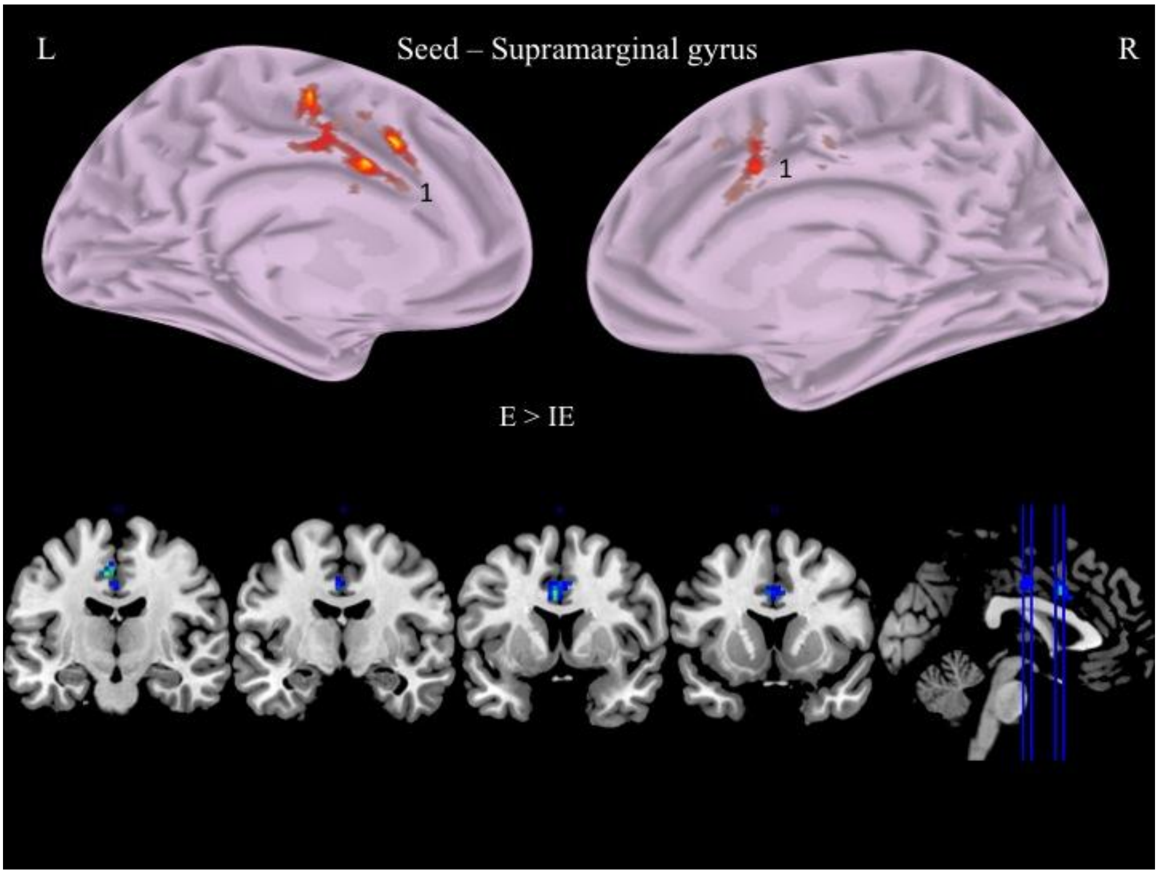

Figure 4.9. Result of the seed-to-voxels analyses (contrast [1]E > [-1]IE) ($p < 0.05$, FWE-corrected SPMs at the cluster level, with min of 50 voxels (see Table 4.7) rendered on a SPM canonical cortical surface (upper row). The lower row: multislices show the functional connectivity for the left IPS. A mask for two-sides *t*-test for the seed-to-voxels connectivity analyses was created in conn and overlaid on the ch2better.nii.gz template in MRIcron. 1 – the dorsal anterior cingulate cortex

Table 4.7

Seed-to-voxels functional connectivity for the emotional expression target (E) as compared the redundant target (IE)*

Seed	Cluster	Z-scores*	No of voxels	MNI coordinates		
				x	y	z
l-IPS	dACC	4.63	193	05	-13	46

*$p < 0.05$, FWE-corrected at the cluster level, with min of 50 voxels

Finally, the differences in connectomes between two single targets (contrast I versus E) did not reach level of significance at pick level or at cluster level.

4.3 Discussion

The goal of this study was to use neuroimaging data to gain insight into the neural network supporting the behavioural interaction between processing of identity and emotional expression in faces. I replicated the presence of a strong redundant gain in behaviour. The imaging data show that redundant target was associated with different neural coupling. Specifically during redundant targets there was increase connections of the medial OFC with the posterior occipital and superior parietal cortices as compared to a single target. The discussion that follows is divided to three parts: behavioural and univariate analyses; the neural mechanisms for the redundant target effect in faces; and neural connectivity for the processing of identity and emotional expression in faces.

Behavioural and univariate analyses. The behavioural data replicate results of Experiments 1, 2, 4 and indicated that the redundancy effect is determined by co-active processing of target identity and target emotional expression in faces (Fig. 4.1).

The univariate analysis using GLM showed, as expected, that a large network of regions was active while participants were performing the task. Of these three areas responded more to faces containing targets as compared to non-target faces: the right and the left SMG and the right STS. Taking into account that functional role of the SMG in face processing has been linked to encoding of newly learned faces (M. L. Phillips et al., 1998) and to associating faces with other information (such as name) (Campanella et al., 2001), it is conceivable here that the SMG-activation may reflect the way of learning the targets. Moreover, there is evidence of involving the pSTS in discriminating identity when irrelevant variations in expression needed to be discounted (Fox, Hanif, Iaria, Duchaine, & Barton, 2011). Though this later region did not show different response depending on the target type.

The univariate analysis failure to detect any difference between faces that depended on the type of target information may be due to the fact that three target faces present partly overlapped task-relevant information, and, therefore, may have engaged overlapping neural networks. It is also possible that the repeated presentation of the same stimuli across the experiment have led to strong fMRI adaptation effect which masked or washed out any specific neuronal effects related to the redundancy gain. On the other hand, this result may indicate that the redundant target effect is not mediated via change in activation in amplitude in one single regions, but is rather associated with change in cross-talk across regions, as will be discussed next.

Neural mechanism for the redundant target effect in faces. The key methodological approach in this study was the use of PCA-based method to identify functional connectivity differences between the target-containing faces.

Here MVPA demonstrated that compared to both single targets the redundant target face elicits stronger functional connectivity between the Orbitofrontal cortex and the medial/inferior regions in the occipital lobe. An involvement of the Orbitofrontal cortex (OFC) in a face processing is well established (Hasselmo et al., 1989; Kringelbach, 2005; Kringelbach & Rolls, 2003; Rolls et al., 1989; Rolls & Grabenhorst, 2008; Rolls, Hornak, Wade, & McGrath, 1994; Summerfield & Egner, 2009; Summerfield et al., 2006) . For example, Rolls (1996) suggested that the orbitofrontal cortex played a role in evaluating both identity and emotional expression information in faces. Kringelbach and Rolls (2003) reported activation in the orbitofrontal cortex during a face discrimination task, and suggested that some part of the orbitofrontal cortex responded selectively to face expression when it indicated that behaviour should change (i.e. choosing a correct target emotional expression). Interestingly, Haxby et al. (1996) reported that face recognition and face encoding tasks activate different parts of the orbitofrontal cortex: the recognition task elicits activation in the middle part of the OFC, while the encoding task reflects to activation of the posterior part of the left OFC. In the present study the MNI coordinates for the OFC are similar to coordinates reported in Haxby et al.'s (1996) study for the encoding task.

An involvement of the middle part of the occipital cortex and the inferior occipital gyrus in face processing is also known (Fairhall & Ishai, 2007; Gobbini & Haxby, 2007; Palermo & Rhodes, 2007; Rhodes, Michie, Hughes, & Byatt, 2009). It has to be noted that part of the inferior occipital gyrus is the functionally defined occipital face area (OFA) (Gauthier & Nelson, 2001; Pitcher, Duchaine, Walsh, Yovel, & Kanwisher, 2011; Rolls et al., 1989; Rotshtein et al., 2007; Vuilleumier et al., 2004). These regions have been shown to perform computational stage of face processing such as discrimination faces from objects, representation of facial features (the eyes, nose and mouth) and spacing between facial features (Rhodes, Ewing, et al., 2009; Rhodes, Michie, et al., 2009; Rotshtein et al., 2007).

Here the coupling of neural activity between the OFC and OcC for the redundant target face as compared to both single targets suggests that the redundant target effect reflects the interaction between these regions (Varela, Lachaux, Rodriguez, & Martinerie, 2001). Moreover, the two-side *t*-test for the seed-to-voxels analysis shows that the interaction is of positive sign (i.e., increasing of neural activity in the OFC is associated with increasing neural coupling with the OcC). What mechanisms may underlie this interaction? Although the involvement of OFC and OcC in face processing is established, these regions are outside of the core face network and the functional connectivity between these regions has not been studied. However, Bar and colleagues have argued for an important role for OFC in visual processing (Bar et al., 2006; Kveraga, Ghuman, & Bar, 2007). Kveraga et al. (2007) evaluated synchrony between OFC and occipital cortex using MEG data. Causality analysis in this study indicated that the direction of information flow was from the occipital cortex to the OFC and from the OFC to the temporal cortex and that the OFC-temporal interaction might be reciprocal.

There is also evidence that the orbitofrontal cortex (OFC) might be specifically involved in top-down visual processing (Bar et al., 2006; Bar et al., 2001; Rolls & Grabenhorst, 2008). Bar et al. (2001) compared cortical activity for trials in which objects were successfully recognized with trials where the same objects were recognized incorrectly. The results showed that correct object recognition was associated with increased activity within the OFC while there was a differential activity in the occipito-temporal regions. Interestingly, using the same task with MEG, which provides better temporal resolution for the measurement cortical activity, Bar et al. (2006) reported differential activation in the OFC 50 ms before it developed in the occipito-temporal cortex. Furthermore, using trial-by-trial covariance analysis of the MEG data, Bar et al. (2006) demonstrated strong synchronized activity between occipital visual regions and the OFC at a relatively early stage after stimulus onset (approximately at 80 ms). Using Dynamic Causal Modeling and Bayesian model selection the authors found both intrinsic and modulatory effective connectivities among the left orbitofrontal cortex (OFC) in addition to the right fusiform face area (FFA) and right occipital face area (OFA). The authors conclude that the orbitofrontal cortex plays a crucial role in the top-down processing of faces by regulating the activities of the occipital face area. Notably, it was found that for the OFC, only the left hemisphere showed greater activity when subjects detected a face (J. Li et al., 2010).

Taken together, the results of MVPA here and previous findings suggests that possible mechanism of the enhanced performance for the face containing both the target identity and target expression is mediated by reciprocal interaction between the OFC and the OcC. First, the OFC receives facial codes from OcC that it then uses to generate predictions regarding the identification of either target. Due to the greater match of the redundant targets to any template for the targets, compared with the single target conditions, top-down modulation from the OFC may then facilitate recognition of the redundant target. The idea that the human brain utilizes predictive coding to facilitate the processing of a stimulus it is not novel (Bubic, von Cramon, & Schubotz, 2010; K. Friston, 2010; Rao & Ballard, 1999) and has been implemented in a number of studies on sensory perception to explain processing of stimuli in different modality (Apps & Tsakiris, 2013; Pennartz, van Wingerden, & Vinck, 2011; Zelano, Mohanty, & Gottfried, 2011). In addition, since correct recognition of a target is shown to be associated with a reward (Rolls & Grabenhorst, 2008), the OFC may facilitate processing of the redundant targets as being associated with higher reward compared to the single targets. The mechanism described here is hypothetical and needs further investigation.

In contrast to studies that reported involvement of the left OFC in face processing rather than the right OFC, the data here indicate of involvement of both the right and left OFC in processing of faces. The lateralization of the connectivity for the OFC in right hemisphere is consistent with the general role of the right hemisphere in the processing of nonverbal information (Kapur et al., 1994; Tulving, Markowitsch, Kapur, Habib, & Houle, 1994). Activation in the left OFC may be due to the fact that people tend to use verbal strategies to organize and to learn a wide variety of stimuli, including nonverbal ones (e.g. naming faces). On the other hand, the right OFC may be specifically involved in integrative processing of information (Kringelbach, 2005).

The neural representation of redundant targets involves the OFC that correspond to extended systems in Haxby and Gobbini (2011) model associated with processing different aspects of faces. The observation that areas outside the well established core face processing network does not contradict the model (Haxby & Gobbini, 2011), but adds to it by demonstrating the importance of regions that are part of the extended network in processing and integrating information from faces.

Neural connectivity for processing of identity and emotional expression in faces. There is one more finding that is of a potential interest for exploring the neural mechanism for processing of identity and emotional expression in faces. The OFC showed also increase coupling with the superior parietal cortex when redundant target compared to the identity target alone. The left IPS showed increase coupling with the middle cingugate cortex during the emotional target compared to the redundant target. It could be that larger recruitment of sensory simulation network (Adolphs, 2002a, 2002b) is recruited to support the emotional target detection when compared to the redundant target conditions.

Following the model postulated a single multidimensional system for coding of identity and emotional expression in faces (Calder & Young, 2005), the results indicate largely overlapping representational systems for processing the two facial dimensions. Moreover, if the coding of facial identity and emotional expression reflect separate modules as assumed by the Face Recognition Model and the Distributed Neural Network Model, MVPA should have revealed the difference for the contrast I > E. The absence of reliable differences between I and E conditions (faces that are of different identity and different emotional expression) here suggests that there are largely overlapping connectomes for these faces. This also supports the idea about single multidimensional representational system for processing both identity and emotion in faces, but contradict the proposal about largely different sets of PCs for both dimensions in faces (Calder & Young, 2005) (though inference based on null results should be made with caution).

The seed-to-voxels analyses showed that the difference in connectivity between redundant targets and the identity target reflected the functional coupling between the

OFC and the precuneus. Although the precuneus was reported in many neuroimaging studies on face processing, its specific role in face processing is still unclear (Fox & Barton, 2007; Fusar-Poli et al., 2009; J. Li et al., 2010). In recent meta-analysis bilateral precuneus (in both hemispheres) was reported to be actively involved in processing of emotional information in faces (Fusar-Poli et al., 2009). This contrast compares between faces that had the same identity but display different expression. The functional connectivity between the OFC and the precuneus observed might suggest that the added benefit for the redundant target was arising from information on the target emotional expression that was fed forward to the OFC. The MVPA showed that the IPS had different connectivity to the rest of the brain for the face containing the target emotional expression only compared to the redundant face. This difference reflects the functional connectivity between the IPS and the dorsal part of anterior cingulate cortex (dACC). Greater activity of the dACC was found in a resolving conflict task with ambiguous stimuli, and it was suggested that dACC plays a role in directing attention to task-relevant cues (Orr & Weissman, 2009; Weissman, Gopalakrishnan, Hazlett, & Woldorff, 2005).

The finding that the redundancy effect in in faces is supported by neural coupling between the Orbitifrontal Cortex and the Occipital cortex further supports the idea discussed in Chapter III that the interaction between facial identity and emotional expression is not reflect later motor response or very early perceptual processing.

The present results make a theoretical contribution to the field by demonstrating that changes in neural coupling between the OcC and OFC are involved when identity and emotion information both map onto target representation.

Chapter V. Interactions between identity and emotion in own and other-race faces: the modulatory effect of experience (Experiment 7)

Experiments 1- 6 presented in Chapters III and IV demonstrate strong facilitation effect sin processing identity and emotional expression in faces. It was shown that: (i) there is a redundancy gain when both cues are presented which does not depend on a particular identity or emotional expressions or pictorial properties of images, (ii) combination of identity with neutral expression eliminates the facilitation effect. However, in all these experiments the stimuli were faces for the same race as the participants. It is well established that own-race (own ethnicity) faces are well-learned stimuli (Ackerman et al., 2006; Hugenberg, 2005; Levin, 2000; Meissner & Brigham, 2001; Walker, Silvert, Hewstone, & Nobre, 2008), the extensive experience with one's own race may result in visual expertise in processing faces of individuals within that group (Ackerman et al., 2006). However, despite over twenty years of research, it remains unclear exactly how the processing of own- and other-race faces differ. This raises the question whether there are qualitative differences in the processing of identity and emotion in faces belonging to own- vs. other races. This was examined here.

There are several lines of evidence indicating that expertise in face processing is a skill that develops over many years of practice (Bukach, Bub, Gauthier, & Tarr, 2006; Bukach, Cottle, Ubiwa, & Miller, 2012; Bukach, Gauthier, & Tarr, 2006; Gauthier & Nelson, 2001), and typically leads to advantages in face processing for members of our own group compared to members of other racial groups (Bukach, Gauthier, et al., 2006; Levin, 2000). Moreover, it has been demonstrated that the number and length of social contacts with other-race people lead to reduced own-race face advantage in individuals with more experience with other race faces (Bukach et al., 2012).

A number of research suggested that the own race bias affects both identity and expression processing. The results of previous studies have shown that people recognize faces of their own race more accurately than they recognize faces of other race groups (Hugenberg, 2005; Kito & Lee, 2002; Kubota & Ito, 2007). These results extend beyond face recognition memory to also affect the detection and perceptual matching of faces. Walker & Tanaka (2003) show that participants were better at discriminating between own race morphed faces than other race. The authors argued that an own-race advantage arises at an earlier stage of perceptual encoding (see also Kubota & Ito, 2007). In support this it has been shown that facial identity of own-race faces are processed more configurally compared with other race faces (Cassidy et al., 2011). Taken together, these findings indicate that own race expertise may affect qualitatively the way face identity is processed.

The robustness of the effect of face race on emotional expression recognition has also been confirmed by number of studies (Elfenbein & Ambady, 2002; Hugenberg & Bodenhausen, 2004; Kito & Lee, 2002). For instance, Kito and Lee (2004) report reduced accuracy in recognizing expressions depicted by other race faces compared with own race. A meta-analysis of emotion recognition (Elfenbein & Ambady, 2002) performed on large group of participants (22,000 in total) provided evidence for an in-group advantage in understanding of emotion: participants were generally more accurate in recognizing emotions expressed by members of their own culture compared to recognizing emotions expressed by members of a different cultural group. The authors suggested that the in-group advantage might be due to group differences in decoding ability (Elfenbein & Ambady, 2002).

Recently, Karnadewi & Lipp (2011) have used the Garner task to investigate whether the processing of race and of emotional expression interact. Participants were presented with sixteen photographs depicting eight different individuals posing a happy or an angry expression, and the task was to judge as quickly and accurately as possible either the emotional expression of the face or whether the face was European or African American. Similar to the results described above with unfamiliar own race faces (Ganel & Goshen-Gottstein, 2004; Schweinberger & Soukup, 1998), The results showed asymmetrical interaction, in which race affected the categorization of emotional expressions whereas emotional expressions had no effect on the categorization of faces by race (Karnadewi & Lipp, 2011). However, it should be noted that racial groups can be discriminated rapidly from local face cues (e.g., skin color) and this may be critical to the observation of asymmetrical interference effects from race on judgments of emotional expression.

To sum up, it is clear that the processing of identity and expression information from own race faces is superior to the processing of this information from other race faces. However, it is unclear whether the relatively poor processes of the different facial dimensions (e.g. expression and identity) of other race faces are linked. Furthermore, in is unknown whether the differences in processing own versus other race are primarily quantitative or are mediated by qualitatively different cognitive mechanisms. These issues are addressed to Experiment 7.

The main prediction for Experiment 7 is that there should be an interactive processing of identity and expression for own-race faces for each racial group, replicating results of Experiment 1, 2, 4. The question is what happens when faces belong to other racial (ethnic) groups. If the interaction between facial identity and expression depends to some degree on experience, then the reduced expertise with other race faces would be associated with diminished integrative processing of identity and expression for other race faces. Furthermore, variable level of experience with members of other race should positively correlate with the extent of the redundancy gain, as a marker for integrative identity and expression processing.

To test the prediction, three experiments (7a, 7b, 7c) with three different ethnic groups (European, African and Asian) were carried out. Each group of participants performed the divided attention task for three sets of stimuli (own and two other-race faces). The effect of own- and other-race faces was assessed using the procedure described in section 2.3.

5.1 Method

Participants

Three groups of twelve students from the University of Birmingham participated in Experiments 7a, 7b, 7c. The first group (participated in Experiment 7a) consisted of European individuals (i.e. Caucasian), in the second group (participated in Experiment 7b) were African individuals and in the third group were Asian individuals (participated in Experiment 7c). Twenty-seven participants were UK born (12 European, 8 African, and 7 Asian). Participants were aged between 19 and 23 years and they received credit for participation. There was no significant age difference between the groups ($F(2,6) = 0.89$, n.s.). This experiment was carried out in accordance with the ethical guidelines of the British Psychological Society. Each participant gave informed consent at the start and was free to withdraw at any stage, although none did.

Stimuli and Apparatus

Three sets of 6 female portrait photographs were employed, 18 all together for the three ethnic groups. All face images were sourced from The NimStim Face Stimuli Set (Tottenham et al., 2002). In each set of same ethnicity faces, five different identities presented five different expressions, with the target identity presented twice to give a total of 6 faces (Appendix A, sets 4, 5, 6). The expression used were sad as the target expression and happy, surprise, neutral and angry as the non-targets. The recognition of facial expression in all of the photographs used in the present study was rated at least 80% or more (Tottenham et al., 2002). Based on the speed for ‘different’ responses discriminating between two faces, the face identities and emotional expressions were chosen (eliminating any strong preferences for one expression or identity over others, so that the discrimination along the two critical dimensions was approximately matched). The images selection procedure is described in section 2.2.1.

Design and procedure

Before performing the experiment, participants completed two self-report questionnaires regarding (i) the quantity of social-contact (Cronbach's $\alpha = 0.87$), and (ii) experience in individuating different race groups (Cronbach's $\alpha = 0.94$) (Walker et al., 2008). All items were rated on a 5-point scale, where 1 = low contact and 5 = high contact (Appendix C).). These questionnaire included questions such as ‘I often see other-race people at social events I attend” (The quantity of social contact),

‘How often have you had other-race persons on your team during sports or your group during other activities?’ (individuating experience).

For the identity and expression judgments a “target present/target absent” task was employed (see in detail in section 2.2). Each participant performed the task separately for the three sets of face images (European, African and Asian). The order of the face sets was counter-balanced across participants. Participants were asked to respond as quickly and accurately as possible when the target identity and/or the emotional expression were displayed by pressing a button “target present” on the keyboard, and press a button ‘target absent’ when a displayed face contains no target. Prior to being presented with each set of faces participants completed an initial practice block of 18 trials during which they were given a feedback on their accuracy after each trial. The practice trials insured that all participants were able to perform the target detection task with all the three set of faces with an accuracy level above 95%. After a short break participants then performed a test block of 120 trials for each set of faces. In total, participants performed 360 trials in the test blocks.

The stimulus presentation and instructions for the participants were the same as in Experiment 1 (detailed description is in section 2.2).

Analysis of data

The number of errors and response times for the correct ‘go’ trials were analyzed.

The procedures for estimating the redundancy gain effect, testing the independent race vs. the co-activation model and performing the capacity analysis were identical to Experiments 1-4 and are described in section 2.2.

Computing correlations between experience with other race and the redundant gain: scores for each self-report questionnaire were calculated along with the size of the redundancy gain for each participant. As there were three different ethnic groups, first it was assessed whether participants differed in their reported experience with one or the other group. The self report questionnaires assess i) the quantity of visual encounters with other race faces and ii) the amount of experience with individuals from other race. For each participant a score on each of these measures was computed. The results (see below) showed that participants reported similar levels of encounters and interactions with both other race groups, which were either high or low. Therefore, the results of the two other race groups were collapsed for these analyses. The size of redundancy gain was obtained by subtracting the mean RT for the image containing both targets from the mean RT for fastest of the single target trials. In cases where the RT for the single target was shorter than RTs for the redundant target image, the size of the redundancy gain was marked as negative. These values were computed for each set of ethnic faces separately. The RG for the other race was averaged across the two other ethnic groups.

Multiple regression analyses were employed to examine whether experience with another race can predict the size of the RG, and specifically whether it was driven by the number of contacts and individuating experiences participants had with other-race people. In total, four measures were computed for each participant: two summed scores for each of the self-report questionnaires and three values for the size of redundancy gains (one for the own-race set of images and two for the other-race sets of images).

5.2 Results

5.2.1 Accuracy and RT performance in Experiments 7a-7c

Accuracy performance

The accuracy of performance (errors in %) for own and other-race images in each experiment is displayed in Figure 5.1.

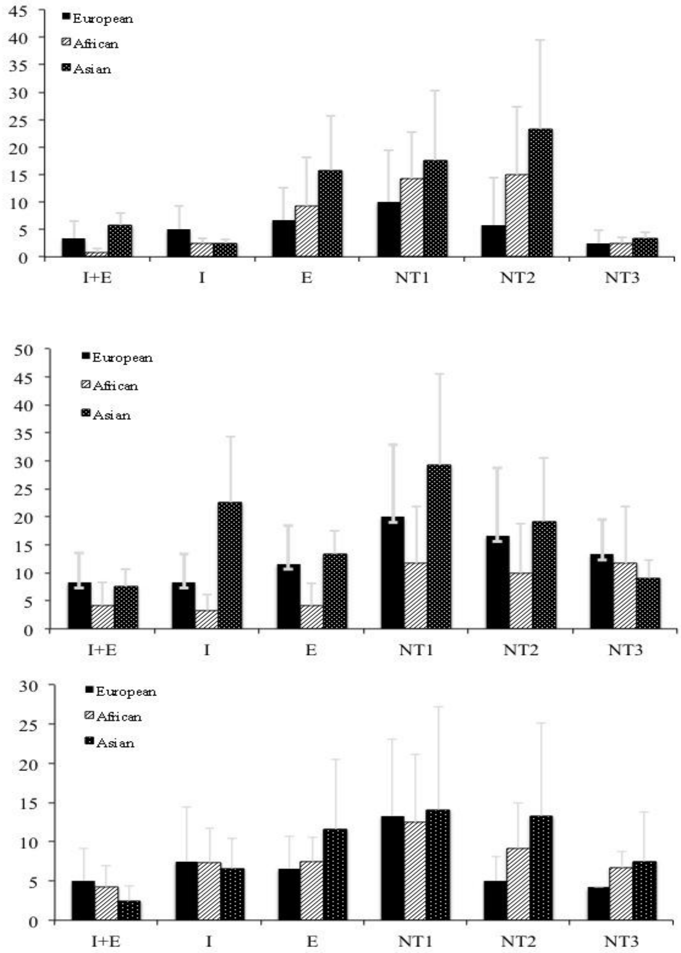

Figure 5.1. The percentage of error (standard deviation in brackets) for the Redundant Targets (IE), the Identity (I) and Emotional Expression (E) Targets, and three Nontarget faces (NTs) in Experiment 7a (top), 7b (middle) and 7c

A mixed design ANOVA with stimuli (the redundant target, the identity target, the emotional expression target and the three non-targets) and sets of faces (European, African and Asian) as within subjects factors and group (European, African and Asian participants) as a between subject factor was used to examine performance accuracy. There was a main effect of stimulus ($F(5,165) = 4.9$, $p < .001$, $p\mu^2 = 0.13$). A Bonferonni test for multiple comparisons showed that the participants were less accurate in responding to the non-target face with a surprised expression ($p < .05$) compared to all other expressions. There were no other differences within the stimulus conditions. There was also an interaction of stimuli*sets of faces ($F(10, 330) = 3.3$, $p < .05$ $p\mu^2 = 0.091$). However, Bonferonni adjustments for multiple comparisons revealed no reliable differences between the stimuli across each set of faces (European, African, Asian) (all $p > .05$). There were no differences between the ethnic groups ($F(2,33) = 1.8$, $p > .05$) nor an interaction of face sets*group ($F(2,66) = 1.7$, $p > .05$). Overall, the overall response accuracy was high most errors were false alarms and these were highest with the non-target stimulus expressing a surprise emotion. More importantly there were no reliable differences in error rate between the different target present trials, and no effects of the ethnicity of participants.

RT performance

Mean RTs for correct responses and SEM for images containing a target for each group of participants are displayed in Figure 5.2.

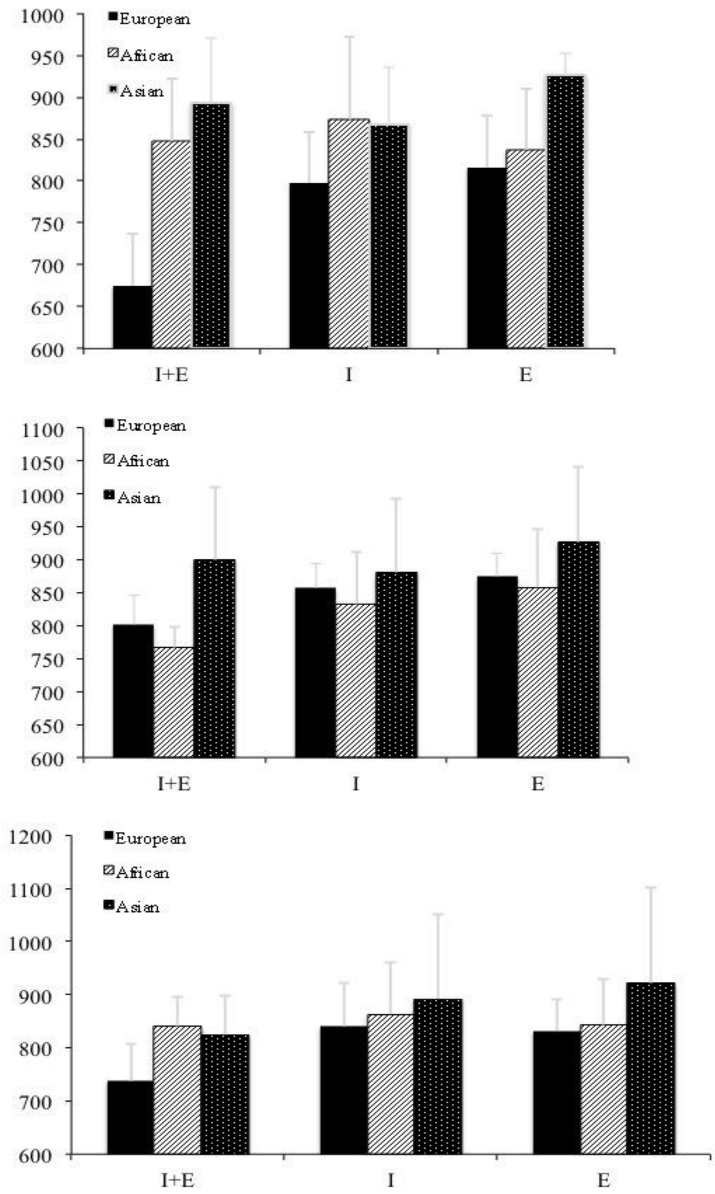

Figure 5.2. Mean RTs for responses to the Redundant Targets (IE), the Identity (I) and Emotional Expression (E) Targets in Experiments 7a (top), 7b (middle) and 7c

A mixed design ANOVA was conducted with stimuli (redundant targets, the identity target, the emotional expression target) and sets of faces (European, African and Asian) as within subject factors and Experiment (7a, 7b, 7c) as a between subject factor.

There was a main effect of stimulus ($F(2,66) = 14.4$, $p < .001$, $p\mu^2 = 0.3$). Simple effect analyses showed that RTs for the redundant targets were reliably shorter (see Fig. 5.2) than for the identity target ($t(107) = 7.9$, $p < .001$, $d = 0.76$) and the emotional expression target ($t(107) = 9.2$, $p < .001$, $d = 0.66$). RTs for the identity target did not differ reliably from those for the emotion target ($p > .05$). There was no main effect of group ($F(2, 33) = 0.7$) but there was a main effect of face set ($F(2,66) = 47.5$, $p < .001$, $p\mu^2 = 0.59$). RTs for the European faces were faster than for the African and Asian faces (all $p < .001$), and RTs for African faces was reliably faster than for Asian faces (all $p < .05$).

Most importantly there was a three-way interaction between stimulus, set and group ($F(8,132) = 3.9$, $p < .001$, $p\mu^2 = 0.19$). To reveal the sources of this interaction we computed a separate ANOVA for each group of participants. A reliable interaction occurred between stimulus and face set for the European and African groups ($F(4,44) = 13.6$, $p < .001$, $p\mu^2 = 0.56$, $F(4,44) = 8.7$, $p < .001$, $p\mu^2 = 0.44$, respectively). African and European participants were faster in responding to a redundant target face in the set of own-race faces compared to the set of other-race faces and they also showed overall less difference between single and redundant targets for other-race faces compared to the own-race faces. No reliable interaction of stimulus*set was observed for Asian participants ($F(4,44) = 2.1$, $p > .05$, $p\mu^2 = 0.16$), though they tended to show a similar pattern, with larger redundancy gain for Asian faces compared with the African and European faces (see Fig. 5.2).

5.2.2 The redundant target effect in own and other-race faces in Experiments 7a-7c

The redundancy gain effect was examined using the 'favoured dimension' test (Biederman & Checkosky, 1970) see section 2.2 for more details). Figure 5.3 shows the mean redundancy gains for each group of participants for each racial set of faces.

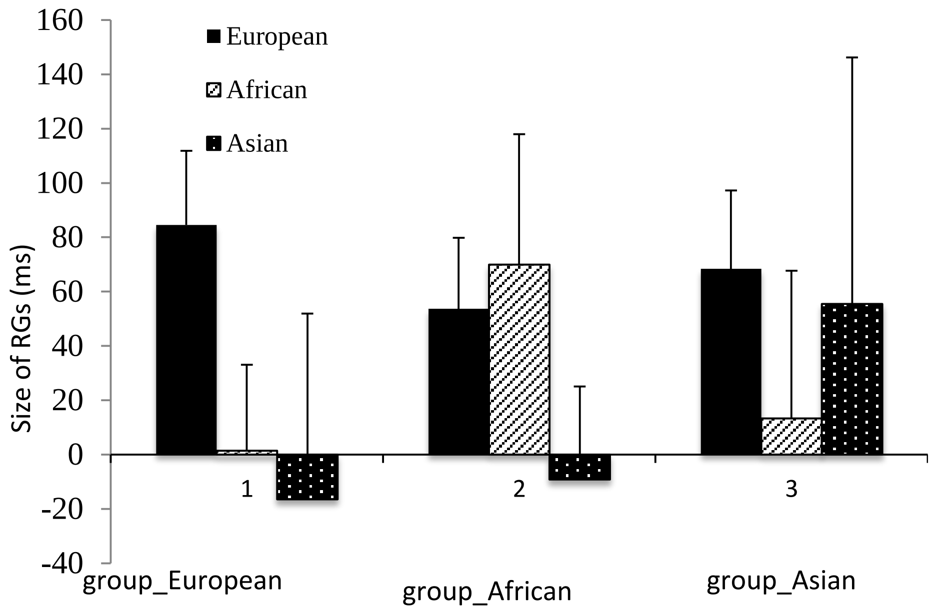

Figure 5.3. Mean size of the redundancy gains (ms) and SEM for groups of European, African and Asian participants across the three stimulus sets. The negative value means that the RT for the single target was shorter than RTs for redundant targets image (no redundancy gain).

To examine the effect of race of face on the size of the redundancy gains for European, African and Asian participants, a mixed design ANOVA was conducted with race of face (European, African, Asian) as a within-subject factor and group of participants as a between-subject factor. There was no main effect of group ($F(2,33) = 1.1$, $p = .36$, $p\mu^2 = 0.06$), but there was a main effect of face set ethnicity ($F(2,66) = 3.23$, $p < .05$, $p\mu^2 = 0.089$) and more importantly a reliable interaction between the face sets and group ($F(4,66) = 3.74$, $p = .008$, $p\mu^2 = 0.19$).

To unravel the sources of this interaction, I computed separate analyses for each participant group. For the group of European participants the size of the redundancy gain was greater for own-race faces (see Fig. 5.3) compared to African faces ($t(11) = 9.18$, $p < .001$, $d = 0.31$) and Asian faces ($t(11) = 8.35$, $p < .001$, $d = 0.11$). There were no reliable differences between the sizes of the redundancy gains for African and Asian faces ($t(11) = 1.9$, $p > .05$, $d = 0.35$).

For the African participants the size of the redundancy gain was greater for African faces as compared to Asian faces ($t(11) = 3.6$, $p = .004$, $d = 0.17$). The size of redundancy gains for their own-race (African) faces did not differ significantly from those for European faces (all $p > .05$).

The group of Asian participants showed no reliable differences in the size of the redundancy gain for own-race faces as compared to European faces ($t(11) = 0.9$) and African faces ($t(11) = 1.1$, $p = .29$, $d = 0.23$). However, the size of the redundancy gain for European faces was greater than for African faces ($t(11) = 2.4$, $p = .033$, $d = 54$) for this group.

5.2.3 Testing the independent race vs. the co-activation model

To assess whether the redundancy gain effects reported above reflect the Independent Race Model or a Co-activation model for the processing of identity and expression, I tested whether the inequality assumption of the independence model was reliably violated (see section 2.3). Graphic representation of CDFs for redundant targets, the identity target, the emotional expression target and the sum of the CDF for two single targets for each experiment are displayed in Figures 5.4 - 5.6. Paired-samples t-tests were performed on the mean RT for the redundant targets and the sum of the identity target and the emotion targets for each set of stimulus at each quantile point in each experiment, to examine whether the differences were reliable and violated the Miller inequality assumption.

5.2.3.1 Experiment 7a

CDF for the redundant target was to the left of the sum of the single-target CDFs for own-race faces (Figure 5.4, top panel) indicating violation of the Miller (1986) inequality. These violations were statistically significant for first nine quantiles (all $p < .05$). In contrast, redundant targets CDFs for African and Asian faces (Figure 5.4, middle and low respectively) did not show any violation that was confirmed by paired-samples t-test (all $p > .05$).

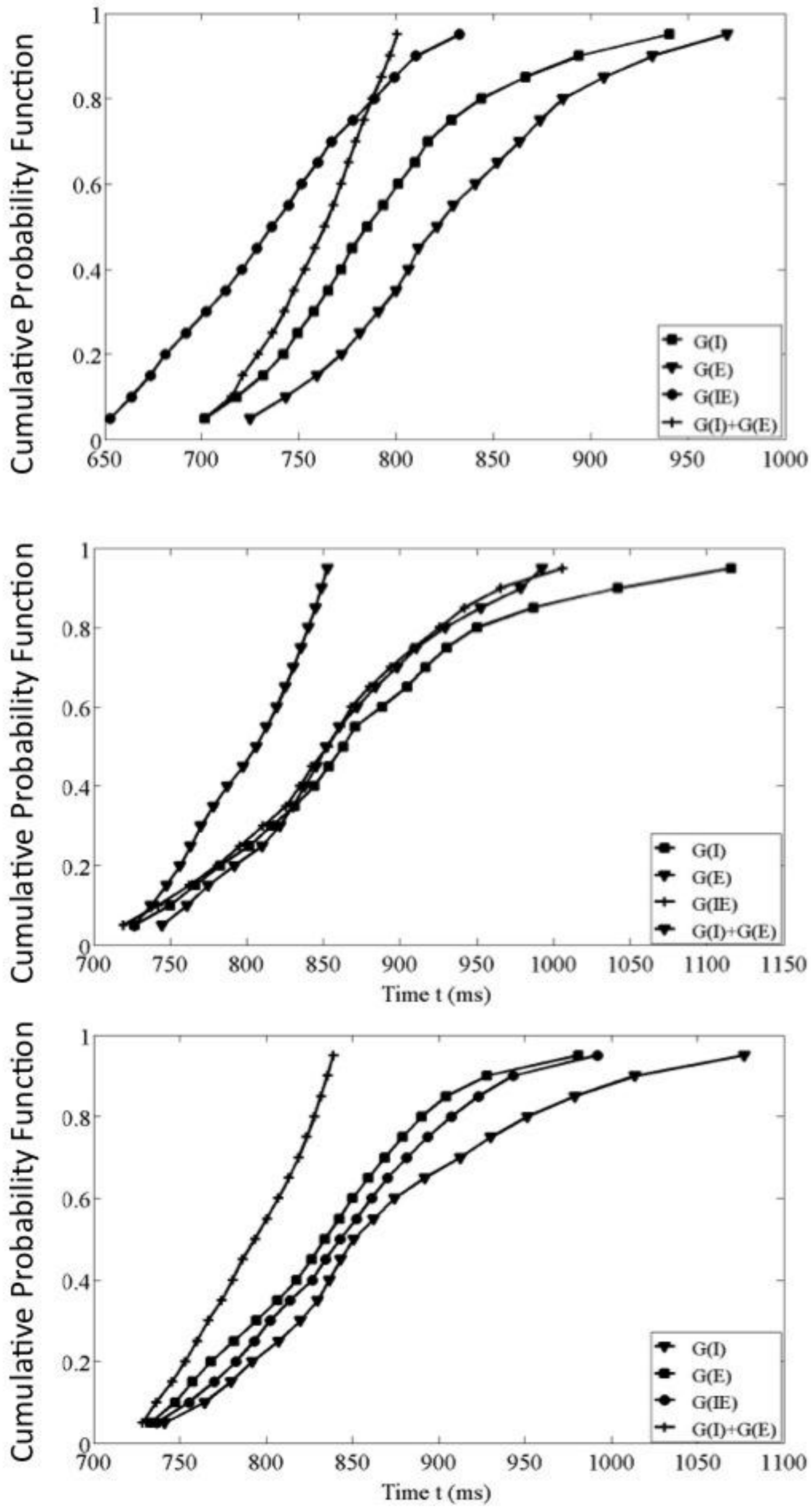

Figure 5.4. CDFs for own race faces (top), African faces (middle), Asian faces (low) in Experiment 7a. I - Target Identity, E - Target Emotional Expression, IE - Redundant Targets, I+E - the sum of RT distributions for I and E.

5.2.3.2 Experiment 7b

The redundant targets CDFs for own-race and European faces were to the left of the sum of the single-target CDFs (Figure 5.5, top and middle panels respectively). These violations were statistically significant at eight quantiles for own-race faces (all $p < .05$) and at two quantiles (all $p < .05$) for European faces. There were no quantile points at which the redundant targets CDF exceeded the sum of the single-target CDFs for Asian faces (Figure 5.5, low panel).

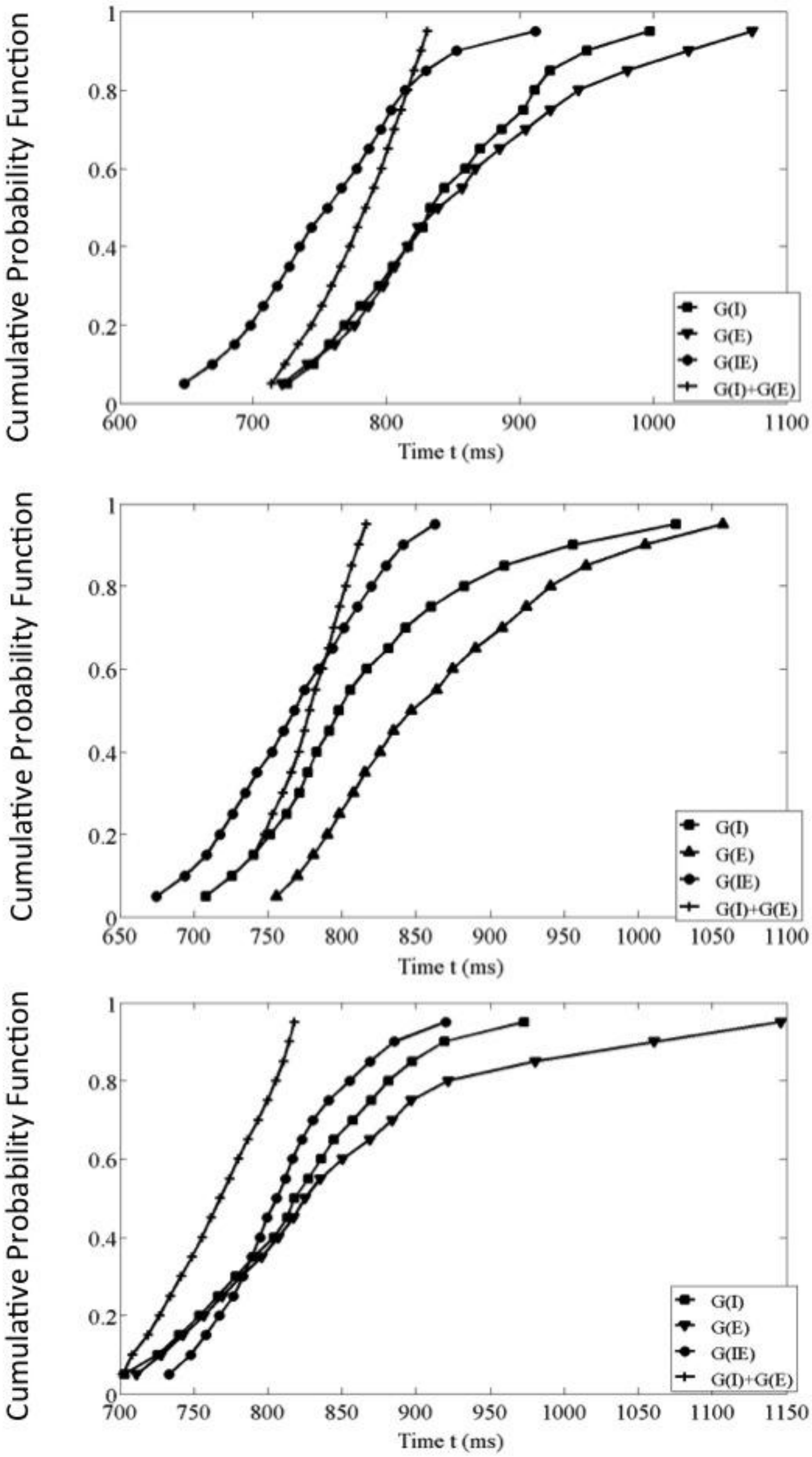

Figure 5.5. CDFs for own race faces (top), European faces (middle), Asian faces (low) in Experiment 7b. I - Target Identity, E -Target Emotional Expression, IE - Redundant Targets, I+E -the sum of RT distributions for I and E.

5.2.3.3.Experiment 7c

The redundant targets CDF for own-race faces was to the left of the sum of the single-target CDFs (Figure 5.6, top panel). These violations were statistically significant at five quantiles (all $p < .05$). Similar results were obtained in this group for European-race faces (Figure 4.3, middle panel), here these violations were reliable at four quantiles (all $p < .05$). There were no quantile points at which the redundant targets CDF exceeded the sum of the single-target CDFs for African faces (Figure 5.6, low panel).

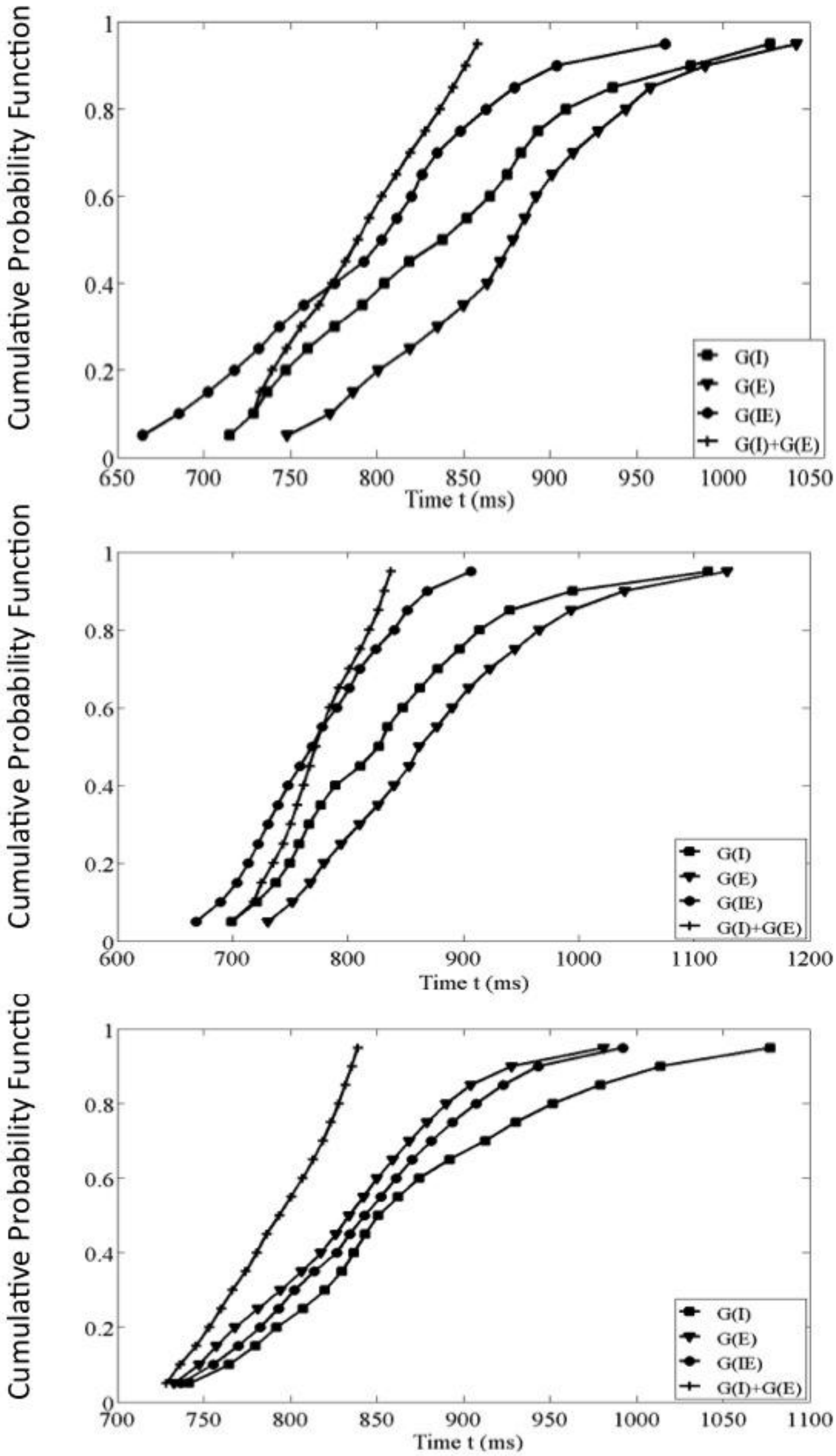

Figure 5.6. CDFs for own race faces (top), European faces (middle), African faces (low) in Experiment 7c. I - Target Identity, E -Target Emotional Expression, IE - Redundant Targets, I+E -the sum of RT distributions for I and E.

5.2.4 Examining capacity processing

Capacity coefficients were calculated for each experiment separately (Experiments 7a-7c) and presented in Figures 5.7-5.9.

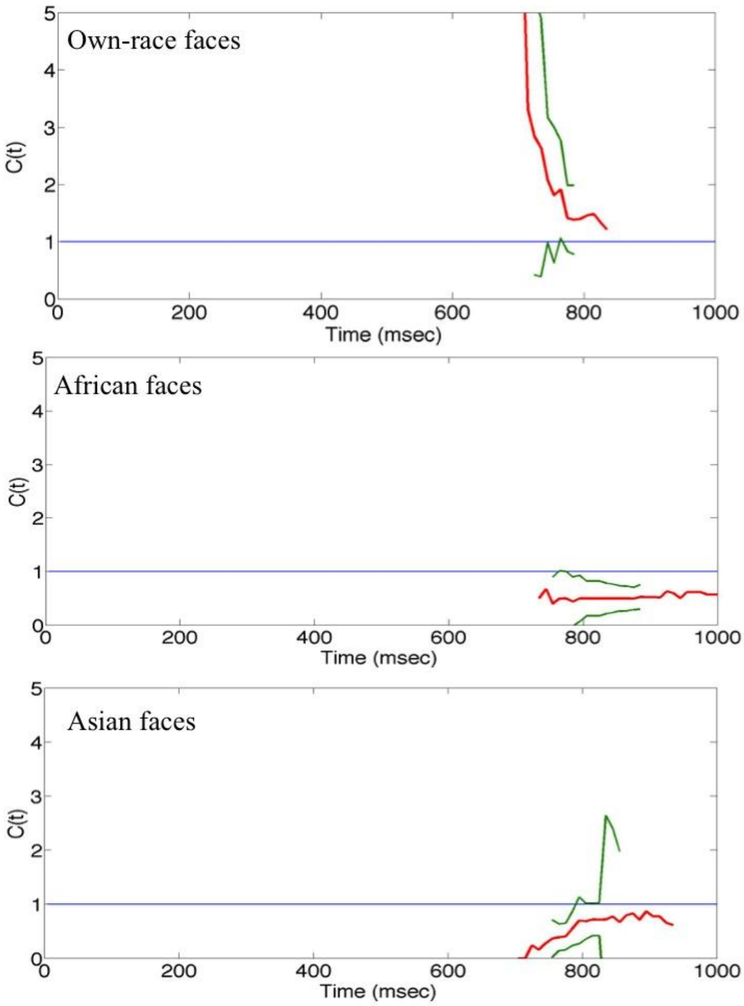

Figure 5.7. Group capacity coefficient in Experiment 7a (European participants). The horizontal line at C(t) = 1 (in blue) indicates the reference value for unlimited capacity. The capacity coefficients are depicted in red; the confident interval for capacity coefficient in green.

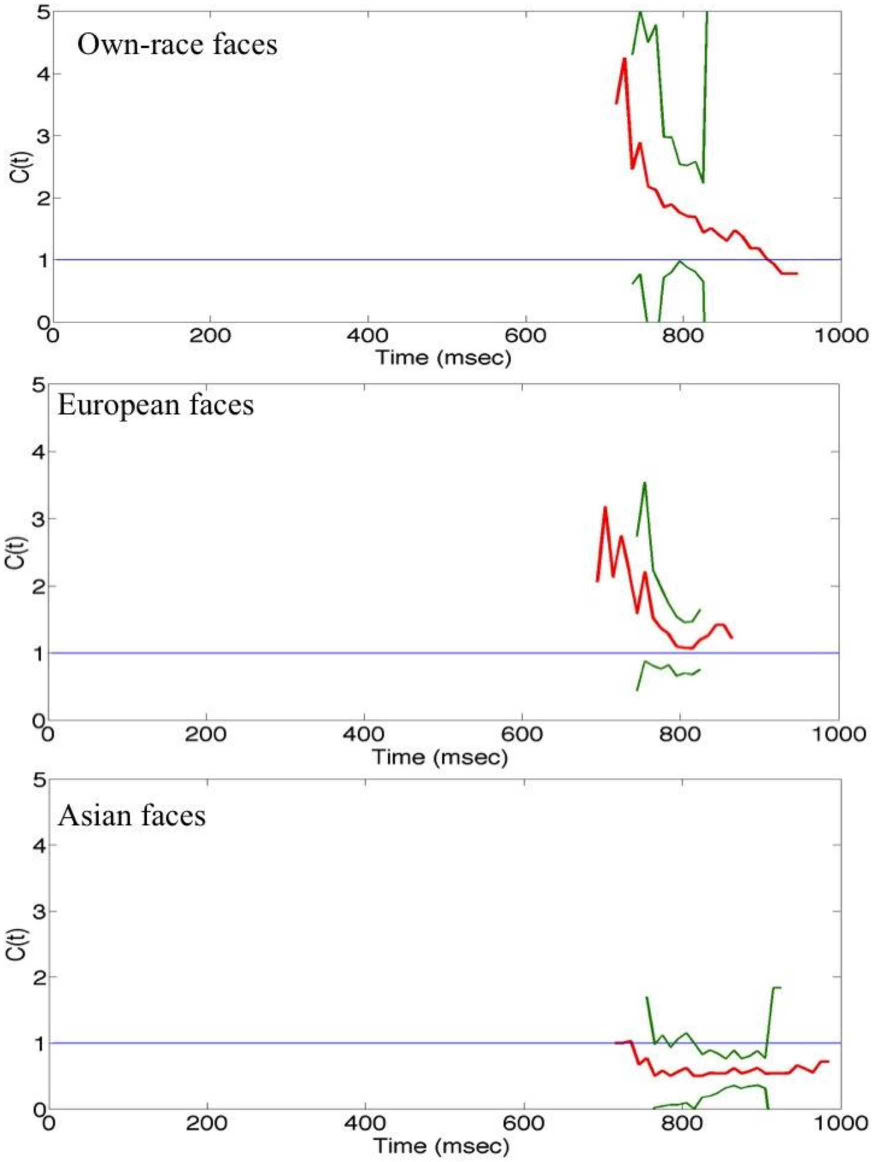

Figure 5.8. Group capacity coefficient in Experiment 7b (African participants). The horizontal line at C(t) = 1 (in blue) indicates the reference value for unlimited capacity. The capacity coefficients are depicted in red; the confident interval for capacity coefficient in green.

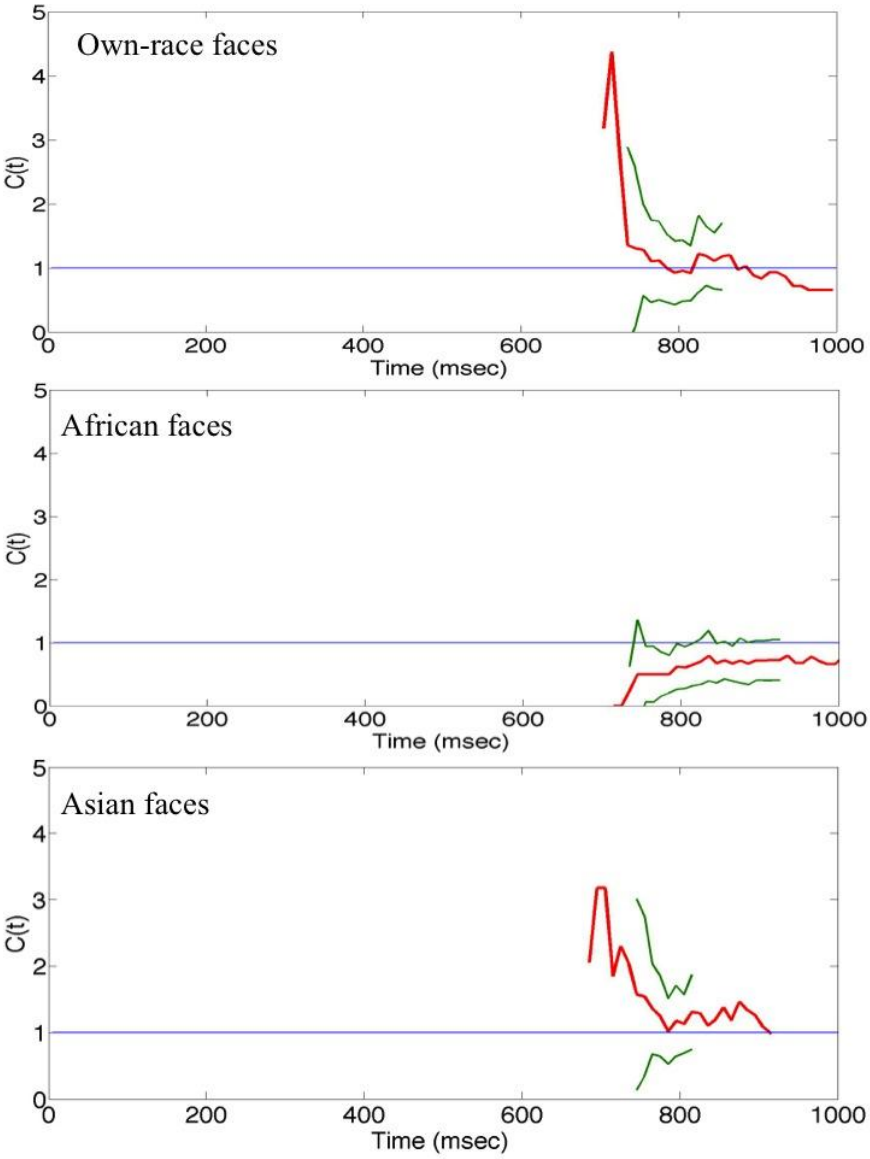

Figure 5.9. Group capacity coefficient in Experiment 7c (Asian participants). The horizontal line at C(t) = 1 (in blue) indicates the reference value for unlimited capacity. The capacity coefficients are depicted in red; the confident interval for capacity coefficient in green.

Collectively, Figures 5.7-5.9 demonstrate super capacity for processing of identity and emotional expression in own-race faces and limited capacity in other-race faces, excluding European faces which are processed with super capacity in both group of

African and Asian participants. The super capacity corresponds to time bins from 680 ms to about 820 ms. The overall limited capacity coefficient (averaged across time bins) for processing of other-race faces in each experiment is close to 0.5 (Figures 5.7-5.9).

5.2.5 Redundant gain effect and social experience

Averaged scores for the quantity of social contact and individual experience with other-race people for three experiments are displayed in Table 5.1.

Table 5.1

Mean scores for Self-report questionnaires in Experiments 7a-7c

Questionnaires	Experiments 7a M (SD)	Experiments 7b M (SD)	Experiments 7c M (SD)
Quantity of social contact*	14.9 (8.1)	27.0 (5.7)	23.85 (10.1)
Individual experience**	32.2 (14.9)	38.5 (10.9)	39.8 (11.4)

*Max scores = 30; min scores =6;

** Max scores = 50; min scores = 10

Multiple regression analyses tested whether the quantity of social contact, and the amount of individual experience with other-race people, predicted the size of the redundancy gains for own- and other-race faces. Prior to running the analyses it was tested if there were differences in number of well-known other race people for each group of participants (Experiments 7a-7c). In the first three questions in the ‘Quantity of social contact' questionnaire, participants report the number of well-known European, African and Asian people. In each experiment the number of well-known other race people reported was examined using a paired-sample t-test (e.g. in Experiment 7a the number of well known European, African and Asian people was compared) (Table 5.2). As expected, the number of well-known own-race people was reliably higher in all experiments (all $p < .05$) (Table 2). In contrast, none of the three groups showed a reliable difference between the number of well known members from the two other races ($t(11) < 1.3$, $p > 0.1$). Thus, because of the numbers of known people of two other races were approximately equal, for the multiple regression analysis we used averaged redundancy gain scores for the other race.

Table 5.2

Means number (standard deviation in brackets) of well-known own and other-race people in Experiments 7a-7c

Experiment	Number of well-known own and other race people		
	European	African	Asian
7a	**6.8* (2.1)**	3.2 (1.3)	2.9 (0.6)
7b	9.3 (3.4)	**16.7 (4.1)**	7.8 (4.2)
7c	5.1 (2.2)	5.3 (2.5)	**11.4 (4.9)**

* In bold for own race people

The multiple regression analysis was carried with all 36 participants, the aim was to test whether the size of redundancy gains in other race faces can be predicted the number of social contact and amount of individual experience. The scores for The Quantity of social contact and The Individual experience questionnaires were entered in each analysis as predictors. No multivariate outliers were identified by using the

Mahalanobois' distance (6.7). The correlations between the two questionnaires and the dependent variable, redundancy gains, were positive and small to moderate, ranging from .11 (The Quantity of social contact and RGs for own-race faces) to .47 (The Quantity of social contact and RGs for other-race faces). This indicates that redundancy gains for other race faces were related to the degree of contact/experience an individual had experienced. Table 5.3 summarizes the results of two regression analyses.

Table 5.3

Summary of multiple regression analyses for the size of redundancy gains for Own and Other-Race faces (N = 36)

Sets of faces	Variables	B	SE (B)	Β	t	Sig. (p)
Own-race	The Quantity of social contact	.044	.62	.012	0.68	.91
	Individual experience	.75	.56	.24	1.3	.22
Other-race	The Quantity of social contact	1.6	.32	.59	4.5	.000
	Individual experience	.47	.30	.21	1.4	.119

Note
R^2 for own-race faces = 0.058
R^2 for other-race faces = 0.517

The regression analysis (Table 5.3) showed that self reported experience with members of the other races significantly predicted the size of the redundancy gain, explaining 51.7% of the variaance. Furthermore, the results suggest that the most important factor predicting the RG is the 'Quantity of social contact' score ($F(2,35) = 17.7$, $p < .001$). To ensure that these results were specific to the amount of experience with other races and were not driven by specific properties of the participants (e.g., participants not only knowing more members of other races may also be more sociable), I computed the same analyses but now trying to predict the redundancy gains of the participant's own race from the two self-reported questionnaires. The result of the regression for own-race faces indicated that number of social contacts and amount of individual experience with members f of another racial group did not reliably predict the size of the redundancy gains for own-race faces (R2 = .058, $F(2,35) = 1.02$, n.s.).

5.3 Discussion of Chapter V

Experiment 7 aims to test whether experience with faces from specific ethnic groups affects interactions between the processing of facial identity and expression. Redundancy gains in the processing of own-race faces were found for all three groups of participants. This finding confirmed and generalized previous results of Experiments 1, 2, 4 and 6. Interestingly, the redundancy gain from combined identity and expression targets was reduced for other race faces, dependent on the experience the participant had with other race faces. Furthermore, evidence for the integration of emotion and identity information from faces was asymmetric. European participants only showed this for own race faces. African and Asian participants showed it for their own race faces and for European faces, but they did not show it respectively for Asian and African (both other-race) faces.

The capacity analysis demonstrates that processing of identity and emotional expression in own-race faces has super capacity, indicating that the observed responses for the redundant target face are greater than predicted by the combined single targets. This means that adding information to own race faces results in positive dependency that facilitated performance. This finding further supporting our prediction about co-active processing for own-race faces (Townsend & Eidels, 2011; Townsend & Nozawa, 1995). In contrast, adding information to other-race faces is cause the negative dependency indicating that processing of identity and emotional expression in other-race faces is operating at limited capacity. The negative dependency is held true for European participants, but not for African and Asian groups where responses for European faces are positive dependent. This finding is similar to that revealed by testing the Independent Race Model and will be discussed below.

The overall larger redundancy gain for own race faces fits well with previous reports demonstrating superior identity and expression processing for own race compared with other race faces (Elfenbein & Ambady, 2002; Hayward, Rhodes, & Schwaninger, 2008; Levin, 2000). Interestingly, while redundancy gains occurred for African and Asian participants presented with European faces, the reverse was not the case. This asymmetry may reflect the fact that the study took place in UK where the majority of the population is of Europe origin, plus 15 out of 24 participants in both the Asian and African groups were born and grew up in the UK and reported substantive contact with European people from their childhood. Thus the asymmetric contact may have determined the selective cross-race redundancy gains for African and Asian participants. Similar conclusions were drawn from the study by Hancock and Rhodes (2010) where Chinese and Caucasian participants varying in contact with other-race faces were tested for both recognition and configural coding of own and other-race faces. The number and length of social contacts with other-race people also appeared to be important, correlating with the redundancy gains for other race faces. This is consistent with participants processing own- and other-race faces in a similar manner once they have gained sufficient experience with other race faces (Bukach, Bub, et al., 2006; Bukach et al., 2012; Gauthier & Nelson, 2001).

The size of the redundancy gains were more strongly linked to the number of social contacts than to the rated quality of other-race contact involving personal face-to-face communication. Recently, Bukash et al. (2012) have reported a strong negative correlation between self-reports of individuating experience and the other-race effect when holistic processing of faces was examined in both Caucasian and African participants (participants performed composite tasks to assess holistic processing for same-race and other-race faces in separate sessions). A weak relation between individuating experience with other-race people and the size of redundancy gains in the present study may thus reflect methodological differences between the studies. For example, in contrast to the task used in Bukash et al. (2012), here participants were asked to divide their attention between two facial dimensions rather than attend to view faces. Future work needs to assess whether holistic processing of facial features is key to enabling the qualitative experience in individuating other race faces to moderate the processing of other-race faces.

The own-face advantage in Experiment 7 was found for RT performance, but not for accuracy. However it should be noted that error rates were low and mainly reflected to responses for face stimuli containing no targets. There was no evidence that RT performance in this study came at the cost of response accuracy.

As discussed in the section 2.1, the redundancy gain effect can be explained by two models of processing, the Independent Race-model (Raab, 1962) and the Co-activation model (Miller, 1982). The Independent Race Model holds that at no point in the cumulative distribution functions should the probability of a response to redundant targets exceed the sum of the probabilities for responses to either single target. In contrast, according to the coactivation account, responses to the redundant targets can be made before either single target generates enough activation to produce a response. Critically here violations of the Miller inequality were observed once faces were familiar (for own-race faces for all participants; for European faces for African and Asian participants). It could be argued that the European faces were similar more discriminable, and thus were more liable to yield race-model violations. However, this seems unlikely given that the redundancy gains were moderated by contact. The results suggest that some degree of familiarity with the properties of the faces within particular racial groups is needed before information about identity and expression becomes integrated as faces are processed. In the absence of this experience, however, facial identity and emotional expressions are processed independently. Results of the capacity analysis further support this finding by demonstrating that own-race faces and European faces which is common for this country are processed with super capacity, but processing of other-race faces is of limited capacity. A possible explanation for this finding may be linked to qualitative differences between processing of the same and other-race faces at neural and perceptual level of face processing. For example, Golby, Gabrieli, Chiao & Eberhardt (2001) found that the FFA was less active in response to other race faces than to own race faces; Vizoli, Rousselet and Caldara (2010) using EEG reported strong repetition effect to the same race and the same identity faces on N170 component, but not for other race faces. Michel, Rossion, Han, Chung & Caldera (2006) demonstrated that own-race faces are processed more holistically and configurally than other race faces (see also Tanaka, Kiefer & Bukash, 2004); Levin et al. (2000) argued that there are qualitative differences between own and cross-race faces in facial features encoding. Notably, in recent study Stahl et al (2010) using ERPs, showed an effect of face expertise on the P2 component sensitive to second-order relationship in faces. This explanation is supported by our capacity analysis. Super capacity here may link to a degree of familiarity (expertise) in faces: the more familiar the face are, the less resources are needed to process them. Conversely, unfamiliar faces demand more resources and increasing workload leads to slower responses for faces containing two targets.

Taken together these findings suggest that the effect of expertise in processing faces from different races facilitates the pooling of information from the face – for example to form stronger facial configurations for face identification and to facilitate the integration of identity and emotion here. Converging evidence supporting the argument for identity and expression being pooled, in line with the Co-activation account (see Experiments 1-4). Interestingly, the overall capacity coefficient for other-race faces (excluding European faces) is 0.5. Similar result was obtained in Experiment 3 for processing of identity and neutral expression. However, in contrast to Experiment 3 where neutral expression might act as a very limited resource of information, other-race faces here contain distinct features for both identity and emotional expression and, therefore, cannot be explained by luck of information to be processed on the channels.

The main limitation of the present study is that the groups of African and Asian participants consisted of both native and British born people. To investigate further the processing of identity and emotional expression in other-race faces it would be interesting to test groups of native and British people separately. In addition, the redundancy gain for own-race faces in this study was smaller overall in the Asian participants (redundancy gains were significant only across the first 4 quantiles) compared to the European and African groups (significant across 9 and 11 quantiles respectively). The possible reason for this may be related to images used in the Asian face set. The images were photographs of Malaysian people, but the sample of participants consisted of Chinese (7 participants), Malaysian (2 participants), Japanese

(2 participants), Philippino (1 participant) individuals. Though Malaysian faces are similar to Chinese and Japanese faces, there might be subtle differences that affect RTs and made integrative processing of identity and expression sub-optimal.

Thus, the present results provide strong evidence (from violations of the independent race model) that face identity and expression are not processed independently. In addition, the data indicate that the integration of identity and expression is modulated by experience with different race faces; experience leads to stronger integration of different types of facial information.

Chapter VI

Interaction between facial identity and emotional expression across lifespan

It is estimated that by 2026 people aged over 65 years will outnumber 16-24 year-olds by two to one (Office for National Statistics, 2009). The shift in proportion of the older age group has profound implications for employers, in particular, in public service where 42.1% of employees are aged between 30-60, and call into the question of how to manage old workers. Managing older workers requires understanding of how older individuals differ from younger employees, in particular, what neural functions are preserved and enhanced with age. The current research contribute to the understanding by demonstrating whether the interactive processing in faces is preserved with age and showing the direction for further research that may be potentially important for providing workers with efficient training.

Previous experiments in this thesis demonstrated a strong facilitation effect in processing of facial identity and emotional expression in young adults (mean age 25 years). This raises the question whether this facilitation effect will be preserved across the lifespan. Answer this question is important for us to develop a deeper understanding the nature of the facilitation effect and its dynamics of the normal aging process. This question is examined in Experiment 8.

Over the past 15 years, a considerable amount of research has been performed in order to better understand the changes in cognitive function that can occur as a result of the normal aging process. There is strong evidence of a decline in the sensory-motor reaction, information processing speed and selectivity in older people as compared to young (Allen, Madden, Groth, & Crozier, 1992; Owsley, Sekuler, & Boldt, 1981; Plude

& Hoyer, 1986; Rensink, 2002; Rogers & Fisk, 1991)(see Madden, 2001; Craik & Salthouse, 2000 for a review). Perhaps the most pronounced age–related decline has been found in tasks when participants are required to divide their attention between two sources of visual information (Allen, Madden, & Crozier, 1991; Allen et al., 1992; Hartley & Little, 1999; Somberg & Salthouse, 1982; Verhaeghen, Steitz, Sliwinski, & Cerella, 2003). These age-related impairments in dual task performance have been linked to conepts such as slowed mental speed (Salthouse, 1996), decreases in mental workspace (Verhaeghen, Marcoen, & Goossens, 1993) and reduced mental energy (Rogers, 2000 for a review), and/or changes in processing resolution including an impaired ability to distinguish relevant from irrelevant stimuli (Allen et al., 1991; Allen et al., 1992), reduced inhibitory processing (Wheatley, Scialfa, Boot, Kramer, & Alexander, 2012) and sensory decline (Owsley et al., 1981). At a neural level, cognitive decline has been associated with age-related atrophy in white matter (Marner, Nyengaard, Tang, & Pakkenberg, 2003) as well as decline in specific regions of cortex (e.g., frontal cortex, (Grady et al., 1994).

However, despite the age-related deficits in divided attention, there are data indicating that the ability to integrate information from two signals from the same or different modalities is spared with increased age (Bucur, Allen, Sanders, Ruthruff, & Murphy, 2005; Bucur, Madden, & Allen, 2005; Laurienti, Burdette, Maldjian, & Wallace, 2006; Linnet & Roser, 2011). Evidence that older participants can even benefit more than young adults from combining information from two sources comes from studies using the redundant target paradigm. In this paradigm, either double targets (e.g., a shape and a colour) or single targets (shape or colour) are randomly presented, and participants are asked to respond to the presentation of one target as quickly and accurately as possible. For example, Laurienti et al. (2006) examined the speed of discrimination responses of older and young individuals to the presentation of simple visual (a red or blue circle), auditory (the word red or blue) and combined visual–auditory stimuli. RTs were faster to targets with combined attributes and this 'redundant target effect' was greater for older adults than for younger adults (see also Allen et al., 1992; Bucur et al., 2005). These studies suggest that, although the processing of single targets may decline elderly individuals, there is a benefit from target redundancy. The enhanced performance has been linked to the greater ability of older participants to exploit the redundant cues as an effective compensatory strategy to overcome sensory deficits with single stimuli (Laurienti et al., 2006). For example, if ageing is associated with increased levels of 'noise' in perceptual processing, then the presence of a redundant target may be beneficial if the additional signal information reduces the effects of the noise (Allen et al., 1992). This raises the question whether the benefits from redundant targets is preserved for more complex and ecologically valid stimuli such as faces.

There is considerable evidence that older adults are impaired relative to younger adults in the recognition of familiar as well as unfamiliar faces (Bartlett, Strater, & Fulton, 1991; Boutet & Faubert, 2006; Calder et al., 2003; Daniel & Bentin, 2012; Lott, Haegerstrom-Portnoy, Schneck, & Brabyn, 2005). For example, Daniel and Bentin (2012) argued that older participants had problems integrating face features into global structures and demonstrated enhanced dependence on configural information in faces. The authors suggested that age-related perceptual changes could also be responsible for the slower and less accurate subordinate categorization found in older relative to younger participants (Daniel & Bentin, 2012). A deficit in elderly participants has also found for the recognition of emotional expressions in faces. Some studies have reported that the effect of aging was limited to a subset of emotions, namely sadness (Moreno, Borod, Welkowitz, & Alpert, 1993), sadness and anger (L. H. Phillips, MacLean, & Allen, 2002), or sadness, anger, and fear (Calder et al., 2003; Orgeta & Phillips, 2008), with the result that older participants are biased for positive emotional expressions.

To date, though, there have been no studies examining whether there is impaired integration of different types of facial property in older observers. In Experiment 8, I examined this issue by testing whether interactions between the processing of face identity and facial emotion are impaired in older participants. Participants were given a divided attention task in which they were required to detect as a target a particular facial identity or emotion, and, on redundant signal trials, both the target identity and emotion were present (see Section 2.2 for detailed description of the task).

In Experiments 1-4 (Chapter III), where participants were young adult, the results showed strong facilitation effect for faces containing both the target identity and emotion (a redundant target display). Here I evaluate whether there is matching evidence for the interactive processing of facial identity and emotion in elderly participants. To test this, I examined the detection of face identity and emotion targets in three groups of participants aged between 20-30, 40 -50 and 60-70 years, with target faces carrying either the critical identity, the emotion or both the identity and the emotion. To weight the results against finding redundancy gains and to minimize biases found for processing positive emotions in older participants, the emotion target was a sad expression.

6.1 Method

Participants

Three groups of twelve individuals participated in this study. The first group was consisted of young participants (aged 20-30), the second group – of middle-aged individuals (aged 40-50) and the third group – of older participants (60-70 years old). The young participants were University of Birmingham undergraduate students; the middle-aged group was recruited from the staff of University of Birmingham; the older group was consisted of individuals enrolled in School of Psychology participants' scheme. All participants had normal or corrected to normal vision. This experiment was carried out in accord with the ethical guidelines of the British Psychological Society. Each participant gave informed consent at the start.

Stimuli and Apparatus

In this experiment set 1 was employed (Appendix A). The presentation of stimuli was controlled using Cogent 2000 and Cogent Graphics developed by the Cogent 2000 team at the FIL and the ICN (http://www.vislab.ucl.ac.uk/cogent_2000.php).

Design and procedure

A "go/no-go" task was employed. Half of the trials used stimuli containing at least one target attribute (target identity, target emotional expression, or both targets; 'go' trials). On the other half of the trials, the stimuli did not convey any target attribute ("no-go" trials) (see section 2.2 for details).

Prior the main task participants completed an initial practice block of 18 trials during which they were given a feedback on their accuracy and reaction time (RT) after each trial. After a short break participants performed four blocks of 60 trials with short break between blocks. In total, participants performed 240 trials in test blocks. Each trial started with the presentation of a fixation cross at the center of the screen for 500 ms. Images were presented successively in random order with random interstimuli intervals from 500 ms to 2 sec. On “go” trials the image was displayed until a response was made. On “no-go” trials the stimulus was displayed 2000 ms.

Analysis of data

RTs for correct responses only were entered in statistical analysis. The first analysis looked whether the three groups of participants were different in accuracy and RT performance.

The second analysis determined whether redundant targets trials were responded to more quickly than single target trials using the favored dimension test (Biederman & Checkosky, 1970) (see section 2.2).

The next analyses assessed whether the Independent Race Model inequality was violated (Miller, 1982) and what capacity correspond to the processing (section 2.2 for details).

6.2 Results

6.2.1 Accuracy performance

The accuracy performance across thee groups of participants is displayed in Table 6.1.

Table 6.1

The mean percentage of errors for Redundant Targets (IE), the Identity Target (I), the Emotional Expression Target (E), and the 3 Non-target faces (NTs) for groups of young, middle-aged and older participants

Group of participants	Stimuli					
	IE	I	E	NT1	NT2	NT3
Young	0.2	0.3	0.3	0.6	0.5	0.5
Middle aged	0.1	0.2	0.4	0.3	1.3	1.6
Older	0	0.4	0.6	0.3	3.4	2.2
Total	0.3	0.9	1.3	1.2	5.2	4.3

It is important to note that accuracy was very high across all groups, over 99% accuracy on ‘go’ trials and 96% on ‘no go’ trials. Group comparisons for accuracy performance were made with 3(groups) X 6 (conditions) repeated measures analysis of variance (ANOVA). There was a main effect of stimuli ($F(5,165) = 11.3$, $p < .001$, $p\mu^2 =0.025$), in which participants made more errors on ‘no go’ than ‘go’ trials (Table 6.1); a main effect of group ($F(2,33) = 4.0$, $p < .05$, $p\mu^2 = 0.02$), showing that error rate increased with age; and an interaction of stimuli*group ($F(10,165) = 3.3$, $p = .001$, $p\mu^2 =0.017$). Simple effects, revealed that the interaction was mostly driven by the responses to the ‘no go’ trials with the young participants being more accurate in withholding their response to non-target stimuli (see Table 1) as compared to older participants ($p < .05$). There were no reliable differences in accuracy performance between young and middle aged participants, and middle aged and older groups (all $p > .05$).

6.2.2 RT performance

Mean RTs and standard deviations for stimuli containing targets for three groups of participants are displayed in Figure 6.1.

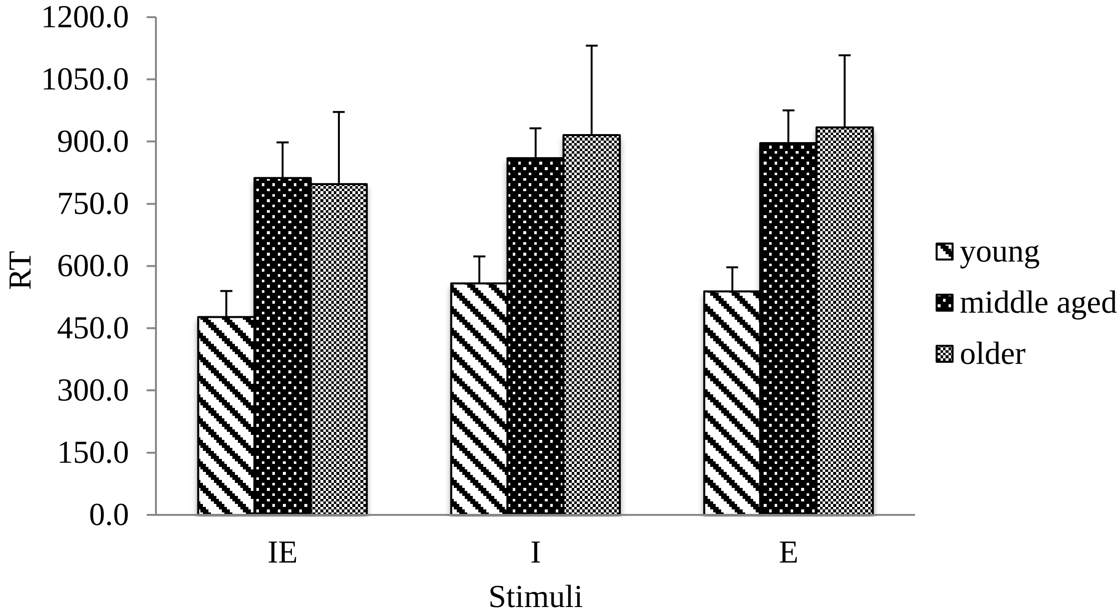

Figure 6.1. Mean RTs for images containing both targets (IE), the identity target (I), the emotional expression target (E) for groups of young, middle aged and older participants

There was no evidence for accuracy/RT trade off (Appendix D). Group comparisons for reaction time performance were carried out using a 3 (conditions containing targets) X 3 (groups) ANOVA. As expected the age group had a reliable effect on response times ($F(2,33) = 33.13$, $p < .001$, $p\mu^2 = 0.066$), with younger participants being faster than both the middle aged and older groups on all conditions (all $t(22) > 5.5$, $ps < 0.001$, $ds > .52$), though the middle aged and the older groups showed no reliable RT differences ($ps > .05$). In line with previous reports, the target type also had an effect on RT ($F(2,64) = 32.8$, $p < .001$, $p\mu^2 = 0.06$), such that RT on the redundant target condition (IE) were faster than both of the single target conditions (IE vs. I: $t(35) = 9.3$, $p < .001$, $d = 0.96$; IE vs E: $t(35) = 10.8$, $p < .001$, $d = 0.97$). This effect was reliable in all three groups: (IE vs. I + E: young, middle, elderly).

More interestingly an interaction between age group and stimulus type ($F(4,64) = 5.4$, $p = .001$, $p\mu^2 = 0.021$) is also observed. Inspection of the results in Figure 6.1 suggests that the redundancy effect was higher with increased age, thus the older the participants the more they benefited from having a redundant target. However, because comparing mean RTs does not account for the nature of the redundant target effect, I will test this observation more systematically below.

To ensure that results here were not caused by general age-related slowing, which might produce spurious interactions between age group and the experimental conditions (Faust, Balota, Spieler, & Ferraro, 1999) I also examined the effects after converted each individual's RTs to log-transformed scores. Using the log-transformation here was driven by data obtained in Experiment 8 which showed proportional relations for all conditions across three groups (Appendix E) and high individual variability in responses to the same stimuli that might bias against using z-score transformations (Faust et al., 1999). Salthouse (1988) suggested that an interaction of Task X Age that remains statistically significant after log-transformation of raw RTs is the result of age effects beyond more general influences of task complexity and general slowing, because a logarithmic transformation represents equal ratios as equal intervals.

The new transformed scores were then used in a mixed design ANOVA with targets (IE, I, E) as within-subjects factor and age group (young, middle aged and older) as a between subjects factor. This analysis revealed a very similar results to the non-transformed data: a main effect of group ($F(2,32) = 43.8$, $p < .001$, $p\mu^2 = 0.068$) and of stimuli ($F(2,64) = 43.7$, $p < .001$, $p\mu^2 = 0.05$) and an interaction of stimuli*group ($F(4,64) = 5.6$, $p = .001$, $p\mu^2 = 0.021$). There were no other effects ($F < 1.0$). Similar to the ANOVA on the non-transformed data, patterns for the three stimuli were obtained after examination main effects using independent sample t-tests.

6.2.3 Redundancy gains

All three groups showed faster responses for displays containing both targets compared to displays containing either single target (Figure 6.1). To better understand this effect I computed the redundancy gain for each participant by subtracting the RT of the redundant target from each single target, separately. The redundancy gain was then estimated conservatively based on smallest of the two subtractions. These data were entered into a one-way ANOVA on non-transformed data and used to test for the size of redundancy gains among young, middle-aged and older participants.

In line with the interaction I reported above, the size of redundancy gains was reliably different across these groups ($F(2,33) = 5.1$, $p = .012$, $p\mu^2 = 0.024$) with larger size for the old group as compared to the middle-aged group ($t(22) = 2.8$, $p < .05$, $d = 0.75$) (Figure 6.2).

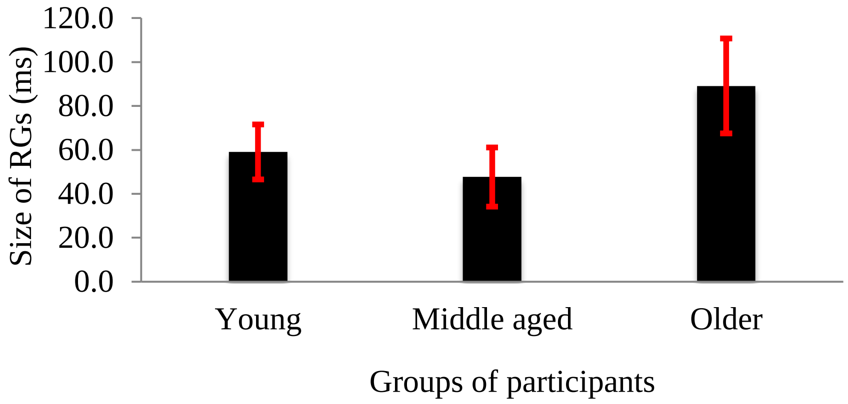

Figure 6.2. Size of redundancy gains (and SEM) in groups of young, middle-aged and older participants

The same analysis using log-transformed data revealed quite similar results for the main effect of group ($F(2,33) = 5.35$, $p = .01$, $p\mu^2 = 0.027$). However, post hoc (Bonferroni) comparisons showed that, in contrast to the non-transformed data, the size of the redundancy gain in both younger and older participants was reliably greater than in the middle-aged group ($t(22) = 3.0$, $p = .048$, $d = 0.52$, and $t(22) = 2.7$, $p < .05$, $d = 0.74$). Similar to non-transformed data no difference in the size of the redundancy gain was found for comparisons between young and older participants $t(22) = 0.4$).

6.2.4 Testing for independence in processing of identity and emotional expression in faces

To test whether redundancy gains were determined by statistical facilitation or coactive processing of identity and emotional expression, the Miller test (1982) was performed for each RT quantile point in the three groups. Groups' CDFs are displayed in Figure 6.3.

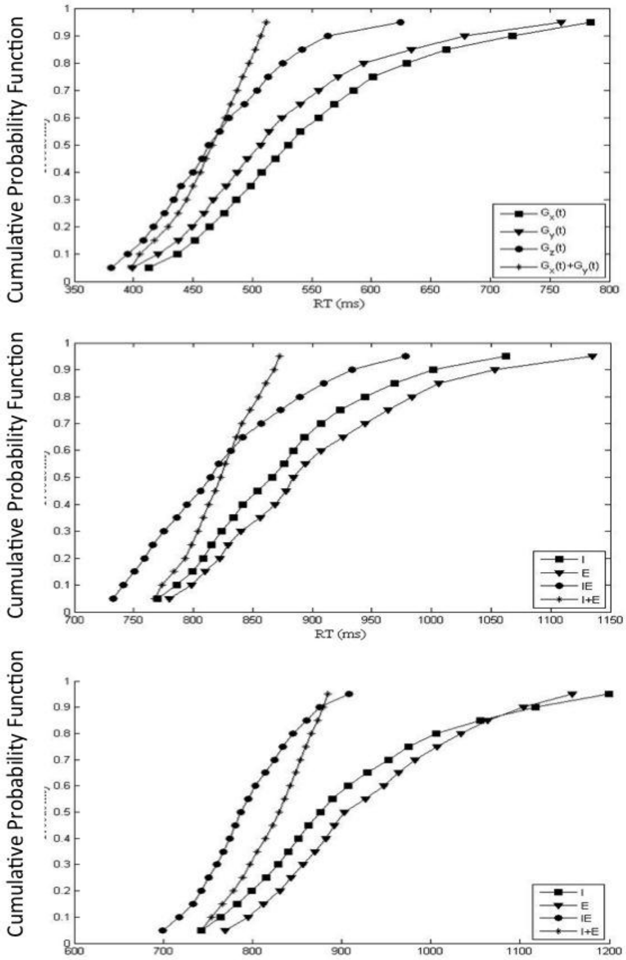

Figure 6.3. CDFs for redundant targets (IE), the sum of distributions of emotional expression and identity targets (I+E) and single targets (E) and (I) in groups of young (top panel), middle aged (middle panel) and older (lower panel) participants

A paired sample t-test was performed for means RT for the image containing both targets and the sum of two images either containing single target at each quantile points to test whether the probability of the two-targets display reliably exceeded the summed RT distribution. In the group of young participants responses for the redundant targets were reliably faster at 6 quantiles; in the middle-aged group – at 7 quantiles; in the older group – at 13 quantiles .

To visualise the results above, I plotted the difference between reaction times predicted by the Race Model and obtained reaction times for each group (Figure 6.4). The curves were obtained by subtracting CDFs for each quantile point predicted by the Race Model (I+E) from CDF of corresponding quantiles for redundant targets (IE). The race model predicts that at no-point the redundant target should be faster than the fastest response for each single target, and hence its prediction is that RT difference between redundant and single target should be zero or smaller. Slower RTs for the single targets (I or E) compared with the redundant target (IE) in specific time windows will show a positive difference which violates the race model predictions.

The data presented in Figure 6.4 demonstrate that the time window over which the older group benefited from the redundant targets is larger than in young and the middle-aged group (part of curves that are above the horizontal solid line): for the young group the time window is 50 ms (440-390 ms) whilst for the middle-age is 75 ms (840-765 ms) and for the older group is 201 ms (900-699 ms). Also, the magnitude of the enhancement is reliably greater for the older group ($F(2,33) = 8.92$, $p < 0.05$, $p\mu^2 = 0.053$); than for the young group ($t(22) = 4.2$, $p < 0.05$, $d = 0.54$) and the middle-aged group ($t(22) = 2.8$, $p = 0.045$, $d = 0.21$).

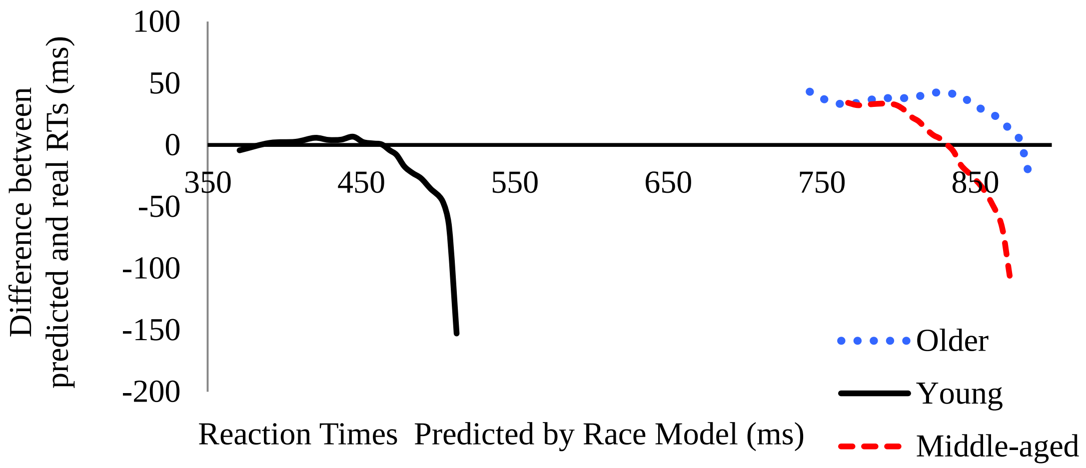

Figure 6.4. Differences between RTs predicted by the Race Model (solid horizontal line) and obtained RTs for young, middle-aged and older groups

The results of the capacity analysis (Figure 6.5) support the results of Miller test for young, middle-aged and older group. Older participants show a higher pick capacity coefficient and are super capacity over more time bins than middle-aged and younger adult. The super capacity for the young group corresponds to time bins from 425 ms to about 475 ms, for the middle aged group – from 760 ms to 840 ms, and for the older group from 760 ms to 940 ms. The overall capacity coefficient (averaged across time bins) is 1.3, 1.8 and 2.4 for the young, middle-aged and older group respectively. Result of the between group ANOVA indicated that this difference is significant ($F(1,2) = 4.6$, $p < 0.05$, $p\mu^2 = 0.35$), and overall capacity for the older people is reliably large compared to the young group (($t(22) = 3.6$, $p = .004$, $d = 0.19$) and middle-aged group (($t(22) = 2.3$, $p < 0.05$, $d = 0.14$). The difference between young and middle-aged groups was not significant ($t(22) = 1.4$, $p < 0.05$).

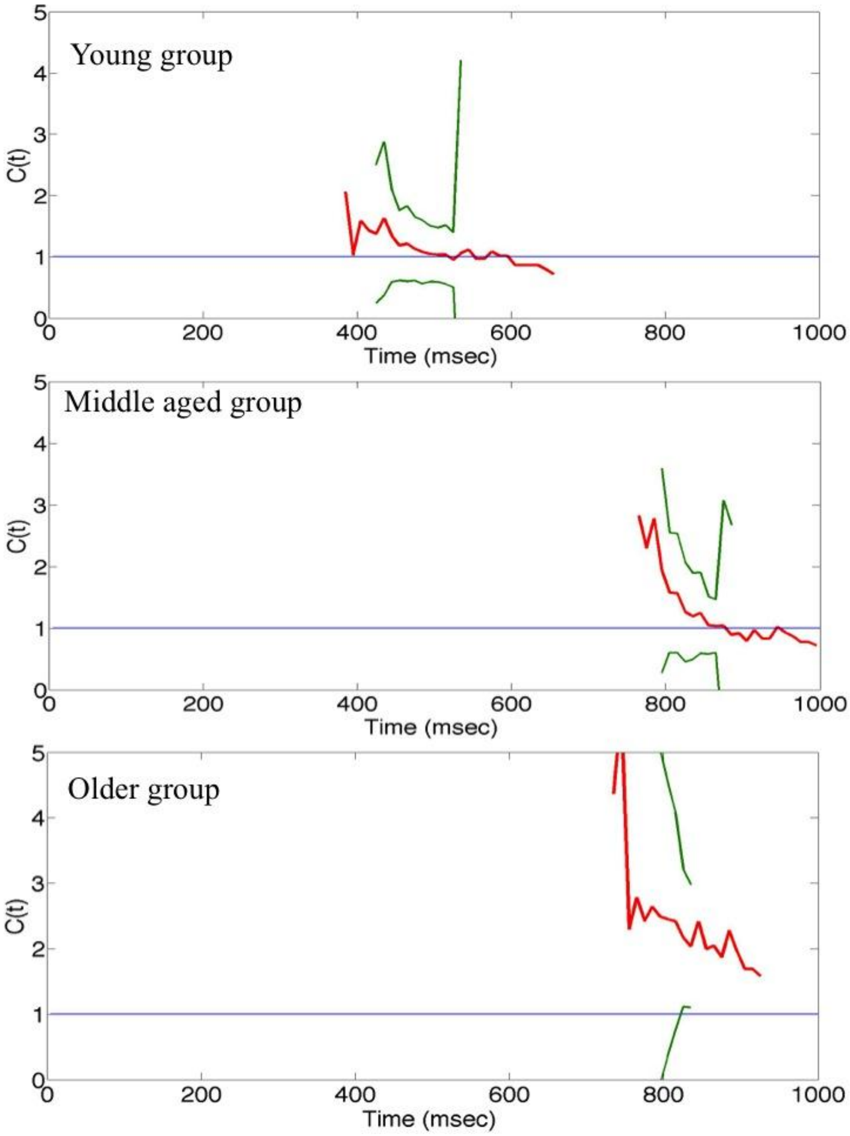

Figure 6.5. The results of group capacity analysis for young (top panel), middle aged (middle panel) and older participants

6.3 Discussion

Experiment 8 examined the effect of aging on interaction between processing of identity and emotional expression in faces. The results demonstrate that older adults can benefit more than younger adults from the combination of facial identity and emotion and this benefit is not due entirely to statistical facilitation that might be associated with independent processing of features for facial identity and emotion. The results of the Miller test (1982) provide clear evidence of enhanced responses to the redundant targets, present at all ages but more markedly so in the older participants. This finding is consistent with the results of previous studies showing the faster responding for two targets as compared to either single target in elderly participants (Bucur, Allen, et al., 2005; Bucur, Madden, et al., 2005; Diederich, Colonius, & Schomburg, 2008; Laurienti et al., 2006).

There are two questions that may be raised with regard to this finding. The first reflects the possibility that the greater benefit from redundant targets in the elderly may occur at expense of accuracy. However, there was no evidence that older participants traded-off the accuracy of performance with redundant targets.

The second question links to enhanced effects of redundancy in the elderly. Does this enhancement result from general slowing with age? Data here suggest that faster responding for displays containing both the target identity and emotion is unlikely to be due to general slowing, as the differences were apparent even when the data were log transformed, when effects of overall processing speed should reduce (Norton, McBain, & Chen, 2009; Plude & Hoyer, 1986; Somberg & Salthouse, 1982).

One other explanation of the enhanced performance in responding to redundant targets in the elderly is that it reflects declines in ignoring irrelevant information as individuals age (Allen et al., 1992; Allen, Weber, & Madden, 1994b). For example, Allen et al. (1994) emphasized that older participants have difficulties with ignoring irrelevant information rather than any difficulty associated with activating or selecting targets. If age increases the ‘internal noise’ in information processing (Allen et al., 1994b), then it is plausible to think that redundant targets contain no internal noise, while the single target stimuli contain ‘noise’ along the other dimension (the “noise” of the emotional expression for identity targets and of identity information for expression targets).

Previously, the most pronounced evidence for enhanced integrative processing in elderly participants comes from studies using multisensory signals (Bucur, Allen, et al., 2005; Bucur, Madden, et al., 2005; Diederich et al., 2008; Laurienti et al., 2006), and there are only few studies examining the integration of unisensory (visual) signals in aging using the Race Model test (Bucur, Madden, et al., 2005). The results of these last studies are inconsistent. For example, there was no evidence for co-activation in the visual redundant target task for either young or older participants in the study of Laurienti et al. (2006). On the other hand, enhanced integrative processing in the elderly compared to young individuals was reported by Bucur, Madden, et al.(2005). Bucur, Madden et al. (2005) explained their results as a compensation for a decline in attentional selection, reflecting attention to targets and enhanced coactivation. Data here also suggest that better performance for the redundant targets here results from attentional allocation to both identity and emotional expression cues. However, given that face processing is highly dependent on the integrated processing of facial features, it can even be argued that the enhanced redundancy gains in older participants stem from their greater life experience, given that experience with faces does affect their recognition (Bukach, Gauthier, et al., 2006; Gauthier & Nelson, 2001). This conclusion contradicts studies which have reported a decline in face recognition with age (Bartlett et al., 1991; Habak, Wilkinson, & Wilson, 2008; Kiffel, Campanella, & Bruyer, 2005; Lott et al., 2005). However, the majority of studies here have examined recognition memory for faces, and this might reflect worsening memory with age rather than a deterioration in perceptual processing. In contrast, the task in Experiment 8 placed few demands on memory and instead required detailed attention to configural (second-order relations). The great redundancy gain in the elderly may thus result from more efficient integration of the second-order feature relations defining facial identity and emotional expression cues in faces. This explanation is in a line with the finding that older adults have spared function for processing of second-order relation in faces (Boutet & Faubert, 2006). Moreover, the results of capacity analysis here further support the assumption about more efficient integration of facial cues in the elderly. In terms of workload, older participants here were able to do up to 2.4 times as much work as predicted from the single target distributions during the redundant targets presentation. In contrast, the amount of work for the redundant targets in the young group is as twice less (= 1.3). This result contradicts commonly reported age-related decreasing performance in cognitive tasks when workload is increased (Cerella, 1985; Fulton & Bartlett, 1991; Madden, 1985; Madden, Pierce, & Allen, 1992). On the other hand, it is in a line with recent studies demonstrated larger super capacity processing (Hugenschmidt et al., 2010) and enhanced performance during multisensory simulation (Laurienti et al., 2006) in older adults as compared to young adults. Although a precise mechanisms of this facilitation effect in older population is unknown, the data here indicate that redundant information reduces the impact of workload on performance, and this effect reflects not only simple objects (Laurienti et al., 2006), but also complex stimuli like human faces.

A number of studies have reported faster RTs and higher accuracy for older participants when recognizing positive as compared to negative emotional expressions

(Calder et al., 2003; Kiffel et al., 2005; Orgeta & Phillips, 2008). In Experiment 8 the identity target only (Person 1) was accompanied with a happy emotional expression (non-target emotion), while both the redundant target (Person 1 expressing sadness) and the emotional expression target only (Person 2 expressing sadness) contained a negative emotional expression. The ‘positive expression bias’ predicts that the older group would show better performance for the identity target as compared to the emotional expression target, and there should also be a reduced redundant target effect. However, there were no reliable differences between RTs for the identity and emotional expression targets and an increased redundancy effect, contradicting the ‘positive emotion’ bias account of performance. I did however find that, the size of redundancy gain in middle-age participants was smaller as compared to both the young and the older groups when the log-transformed data were considered. Although the difference between RTs predicted by the Race Model and the observed RTs gradually increased with age (Figure 6.2) this finding needs further investigation to examine what factors may reduce in middle age.

Taken together, Experiment 8 provides strong evidence that facial identity and emotional expression are processed interactively and this interaction remains intact with age and, indeed, older people demonstrated a greater enhancement in performance for redundant information in faces when compared with young and middle-aged individuals. This effect does not reflect general age-related slowing but may be resulted from experience-dependent increases in the efficiency of combining identity and emotional expression cues in faces, and/or from increased distribution of attention to both identity and expression properties of faces.

Chapter 7

General Discussion

The current thesis has been concerned with the cognitive and neural mechanisms involved in integrative processing of facial identity and emotional expression. In particular I assessed whether these two facial dimensions were processed in an integrative or separate manner, what conditions could modulate the relation between identity and emotion in faces, which neural network supported the relation and whether the integration was preserved with age. In order to answer the above questions, the study concentrated on examining the interaction between processing of identity and emotional expression in faces at behavioural and neural levels.

7.1 Summary of empirical chapters

The first empirical chapter (Chapter III) examined the presence of redundancy gains when people respond to target face identities and emotional expressions, and tested whether the data were fitted the Independent Race model (Raab, 1962) or the Coactivation Model (Miller, 1986) .The analysis provides a strict assessment of whether discrimination performance can be accounted for by independent processing of the critical, target-defining properties. As it was shown in Experiments 1-3, the data contradict independent processing models for identity and emotion. Experiment 4 further showed that the effects were not dependent on inter-stimulus contingencies and non-target associations, going against an Interactive Race Model (Mordkoff & Yantis, 1991) account of the data. The main conclusion here is that facial identity and emotion information are processed together and both contributed interactively in a non-independent manner to target detection. Experiment 5 tested whether performance was dependent on pictorial or structural coding of faces by examining target detection when faces were inverted. The effects of redundancy on RTs were eliminated in this case. The result suggests that the redundancy gains were not due to the memory of pictorial properties of the stimuli.

Chapter IV (Experiment 6) examined the neural networks supporting the redundant target effect in faces. A univariate analysis revealed three areas in the brain that were significantly activated for faces containing targets as compared to non-target faces: the right and left SMG and the right STS. Involvement of the SMG and the rSTS in target/non-target discrimination may be linked to learning the targets in the task. However, the mass-voxel univariate analysis did not detect any brain regions that responded more strongly to any target faces. This suggests that the redundancy gain was not due to change of in the general levels of activation in specific regions, but maybe more to changes of connections between regions. Therefore in the next step I used multivariate pattern analysis (MVPA) to compute coupling between regions as different target faces were presented.

The result of the MVPA indicated that the data from the redundant targets condition were associated with different connectivity patterns compared with the two single target conditions. Specifically coupling of three clusters with other brain regions was affected by the presence of the redundant target: the left and right Orbitofrontal Cortex and the right Inferior Frontal Cortex. To explore what specific aspects of the connectivity changes between these clusters and the rest of the brain differed between the redundant and single targets, post hoc analyses in which the clusters were entered as seeds in a seed-to-voxel analysis were performed. The seed-to-voxel analysis demonstrates that the left OFC reliably increased its coupling with the Middle and Inferior Occipital Cortex during redundant target compared with the single targets conditions. The interaction between the two regions was positive sign (i.e., increasing of neural activity in the OFC was associated with increasing neural activity in the OcC). The seed-to-voxel analyses with the other two clusters (the right OFC and the IFG) revealed no above threshold patterns of connectivity associated with the redundant target as opposed to the single targets. This could mean that, while connectivity pattern with the right OFC and the IFG changed depending on processing of identity and emotion targets in the faces, connectivity to other regions that mutually exchange information did not reliably overlap across the participants.

I next examined changes of the connectivity maps for each single target. No reliable difference between the connectivity maps associated with either single target (contrast I versus E) was found. In contrast, differences in functional connectivity for the redundant targets as compared to the identity target (contrast IE versus I) were associated with the OFC in both hemispheres (as above) and the middle right STS. The difference between neural connectivity for the redundant targets as compared to the emotional expression target (contrast IE versus E) was associated with the left Supramarginal Gyrus that showed an increase coupling with the dorsal anterior cingulate cortex for the emotional expression target as compared to redundant targets (contrast E > ID in seed-to-voxel analysis). Taken together, the results indicate that the redundant target in faces affects the functional connectivity between the OFC and the Occipital Cortex.

Chapter V (Experiments 7a-7c) tested whether experience with a set of faces, manipulated through the ethnicity (race) of the observer relative to the faces, affected the way identity and expression processing interact. The data demonstrated that the redundancy gain was reduced for other race faces and was depended on experience.

Furthermore, the results indicated a qualitative difference between processing own-race and other race faces that varied with experience: when an observer has experience with faces, emotion and identity information is processed coactively and as super-capacity. In contrast, low experience with other-race faces reflects limited capacity and independent processing of facial identity and emotional expression.

Chapter VII (Experiment 8) demonstrated that the interaction between identity and emotional expression in faces was preserved across the lifespan. Further, the results indicated that older adults can benefit more than younger adults from the combination of target information and this benefit was not due to general slowing associated with age. The results of the Miller test (1982) clearly discovered that redundant targets emerged by integrating the two types of information and that integration was used more with increased age. The enhanced performance in responding for the redundant target in the elderly may reflect the fact that older people experience declines in ignoring irrelevant information or more efficient combining of information as a compensation for the age-related declines.

7.2 What cognitive mechanisms are underlied integrative processing of identity and emotion in faces?

From a cognitive perspective, face processing consists of many underlying sub-processes operating on many different representations. The influential Bruce and Young’s (1986) model does not assume any interaction between processes of identity and emotional expression. Data obtained in the present study contradict this assumption: responses to faces that contained both target identity and target emotional expression were reliably faster than responses to either single target. A very conservative mathematical test compared the probability for the response times obtained on redundant targets trials relative to sum of probabilities for responses being made to either single target trial showed that RT for redundant targets were too fast to be explained by statistical facilitation. This result is consistent across six experiments (including sub-experiments) that employed over 150 participants in total.

The data obtained in the current research suggest that only co-active processing of both dimensions may explain the results. According to the co-activation view (Figure 1.5) the information supporting a response 'target present' response is pooled across the features defining the targets prior to response execution (Miller, 1982). When, in this case, both target identity and target emotional expression contribute activation toward the same decision threshold, the response has to be activated more rapidly relative to when only one attribute contributes activation. It has to be noted that the strongest test for interaction (Miller, 1982) requires that RTs distribution for the single targets will be as close as possible in order to obtain maximal redundancy gain. In all the experiments in the current research, the stimuli were selected to satisfy this condition. This provides even stronger support for the co-activation account.

Importantly, Experiment 4 demonstrated that 'target present' responses were not influenced by inter channel crosstalk (when identification of target signal is influenced by irrelevant signal, e.g., in faces when an identity target was accompanied by irrelevant emotional expression) and non-target-driven decision bias (the possible effects that the non-target attributes may have on "target present" decisions). In all the sub-experiments (4a, 4b, 4c) were the overlap of facial features was manipulated, the magnitude of the redundant targets effect was similar to those found in Experiment 1 and 2. This finding evidences against previously suggested asymmetric dependencies between identity and emotion in faces such as expression judgements was more affected than identity and gender judgements by variations in the other dimension (Atkinson et al., 2005; Baudouin et al., 2002; Schweinberger et al., 1999; Schweinberger & Soukup, 1998).

It is likely that the co-activation (or integration) between identity and emotional expression occurs after initial analysis of physical properties in faces but prior to the later motor stage. Indeed, the redundancy effect in Experiments 1 and 2, using a task with two responses, was not different from that in Experiment 4, which required only a single response. This suggests that the interaction is unlikely to occur at late motor stage. Data in Experiment 7 also evidences against both the early (sensory specific) and the later (motor) stage.

I speculate here that the most likely mechanism of the enhanced response for the redundant target information in faces may link to match-to-template mechanism similar to the template-matching selection mechanism (Duncan & Humphreys, 1992) or the Houghton-Tipper model (1994). When participants learn the target identity and emotional expression, the cognitive system creates templates containing facial features (or their combination) that specify the object of the target for action. When viewed faces are matched against the templates, faces containing both targets has as twice more chance for response ‘target present’ compared to faces containing either single target. However, the greater probability of matching to the template cannot explain faster responding for the redundant target faces. The crucial assumption here is that information from both the target identity template and the target emotional expression template may be combined to produce a qualitatively new template containing integrated information about targets. Containing a distinguish information compared to either single template the new template may enhance processing of redundant faces at the perceptual level (presumably, by top-down modulation). Although the mechanism of the facilitation effect described above is hypothetical and need further investigation, it seems to be plausible to explain the coactivation in processing of identity and emotional expression in faces.

7.3 What conditions modulate the co-active mechanism?

At least two conditions can affect the co-activation mechanism.

1. Co-activation occurs for combinations of identity and emotional expressions, but not a neutral expression sad. The results of Experiment 3 suggest that viewing a distinct emotional expression (e.g. sad or angry) paired with target identity benefits recognition, perhaps, because these emotions are conveyed by distinct visual features. In contrast, unfamiliar faces bearing a neutral expression do not carry expression-contingent features and a neutral expression may be defined by the absence of a universal emotional expression, making it more idiosyncratic to the particular face. For these reasons, there may be no co-activation due to absence of triggered response (i.e. response 'target present' is based mainly on the identity target cues). This also suggests that neutral expression is not processed in the same way as the other size basic facial expressions.

2. Co-activation in the processing of identity and emotional expression is dependent on individual experience with faces. Experiment 6, where experience with a set of faces was manipulated through the ethnicity (race) of the observer and the faces, demonstrated that co-activation increased with increasing individual experience with particular race faces. Here redundancy gains in the processing of own-race faces were found for all three groups of participants, whilst the redundancy gain was reduced for other race faces that individuals did not have great experience of. These findings

provide a new account for the own-face advantage (Ackerman et al., 2006; Bukach, Bub, et al., 2006; Bukach et al., 2012; Bukach, Gauthier, et al., 2006).

7.4 What neural network supports the co-active processing of identity and emotion in faces?

MVPA showed differential neural connectivity pattern of regions in the frontal lobe for the redundant targets as compared to both single targets: The Orbitofrontal Cortex in both hemispheres and the right Inferior Frontal Cortex. Post Hoc seed-to-voxels analysis revealed that this difference links to functional connectivity between the right OFC and the medial and inferior regions in The Occipital Cortex for the redundant face. This result supports previous findings that demonstrated synchronized activity between occipital visual regions and the OFC (J. Li et al., 2010). In particular, it was shown that the OFC regulates the activities in the Occipital Face Area, and the Occipital Face Area in turn efficiently detects facial features of faces even from noise images and then sends the information to the higher areas for further analysis (J. Li et al., 2010). The new finding here is that this functional coupling between the right OFC and infOccC/mOccC supported the redundant target facilitation effects observed in faces. This finding indirectly supports the assumption that the enhanced response for the redundant target faces may link to top-down modulation that facilitate recognition of the redundant information at perceptual level.

Previous studies that examined the neural basis of redundancy effect using simple stimuli (e.g., flashing lights presented bilateraly or unilateraly or small checkerboards) linked this effect to motor cortex (the precentral and the postcentral sulcus) (Iacoboni & Zaidel, 2000) or early visual areas in the brain (Miniussi, Girelli, & Marzi, 1998). Reinholz and Pollmann (2007) argued that a behaviourally observed redundancy effect for category detection task was associated with activation increase in the object-selective visual areas (Reinholz & Pollmann, 2007). The authors using a delayed matching-to-sample task with more complex stimuli (pictures of faces and buildings presented in a mixed order at both visual fields) reported activation in the left and right hippocampus and the right FFA for bilateral presentation of faces as compared to buildings. Although it is difficult to compare the results of the present study with the previous findings, fMRI result here suggests that the redundancy effect in processing of facial identity and emotional expression does not correspond to a single area in the brain, but rather reflects functional connectivity between areas in the brain. It has to be noted that the very few studies examining the neural basis of the redundancy effect looked at the neuroanatomical locus of this effect assuming neural summation as a main mechanism that support faster responding for the redundant targets. In contrast, the present study focused on the neural network supporting the interactive processing of facial identity and emotional expression and showed that the main mechanism for the redundancy effect reflect functional connectivity between brain regions involved in face processing.

Although the MVPA does not support inferences about causal relationship between the OFA and OcC, it is plausible to assume that the orbitofrontal cortex plays a crucial role in the top-down processing of faces by regulating the activities of the occipital face area as it was suggested previously (J. Li et al., 2010). I speculate here that the OFC receives structural representation of faces from the OcC and then uses it to generate predictions regarding the identification of either target. Due to greater match to target information for redundant compared to either single target, top-down predictions will match better target information in redundant face. Alternative explanation may reflect value-based computations in the OFC, if correct recognition of a target is associated with a reward (Kringelbach, 2005). Here the OFC may facilitate processing of the redundant targets as being associated with higher reward compared to the single targets. Also, the OFC was shown to be involved in error monitoring (Summerfield et al., 2006) that may account for faster processing of the redundant target as having ‘no error’. However, the precise mechanism of the regulation is a topic for the further studies.

The multivariate pattern analysis used here to explore differences in connectivity between faces containing targets is sensitive to even subtle differences between conditions. This is because principle components are extracted to represent the most differentiating property of the obtained correlations maps between each voxel and the rest of the brain across participants and conditions. Assuming that facial identity and emotional expression are encoded by separate modules (Bruce & Young, 1986), and, therefore, processed by distinct neural networks, such a sensitive method of analysis employed here should detect some differences in connectivity patterns between single targets (the faces of different identities and different emotional expressions). However, there was no reliable difference in connectivity in these conditions. Moreover, the difference in connectivity between redundant targets and both single targets was found at the OFC. Similar result was obtained when the redundant targets face was contrasted with the target identity face alone. However, contrasting redundant targets with the target emotional expression localized a difference in connectivity at SMG. These results together suggesting largely overlapping neural representations for processing identity and emotional expression in faces, consistent with facial identity and emotional expression being coded by a single multidimensional system (Calder &

Young, 2005). It has to be noted that the idea about the single multidimensional system for coding both identity and emotional expression does not necessarily mean that there is integrative processing of these facial dimensions. However, based on the behavioural and the neural data in the present thesis it is plausible to assume that the multidimensional system is controlled by a high level mechanism that regulates all intermediate steps in processing of both identity and emotional expression in faces. One candidate for such high level mechanism may be predictive coding implemented through hierarchical top-down and bottom-up processes (Feldman & Friston, 2010; Hesselmann, Sadaghiani, Friston, & Kleinschmidt, 2010; Summerfield et al., 2006).

7.5 Is the interaction in processing identity and emotional expression in faces preserved across lifespan?

The results of Experiment 8 indicate that the redundant target effect in processing of identity and emotion in faces is not unique for young adults group but preserved across the lifespan. Moreover, this effect was more pronounced in elderly as compared to young adults. This finding is in a line with previous studies reporting enhanced performance for double relative to single target in the older population (Diederich et al., 2008; Groth & Allen, 2000; Laurienti et al., 2006). However, this is a new finding in respect to processing of facial information with age, thought that age-related declines in identity and emotional expression recognition are well studies (Bartlett & Fulton, 1991; Bartlett et al., 1991; Fulton & Bartlett, 1991; Lamont, Stewart-Williams, & Podd, 2005).

Importantly, as it was demonstrated in section 6.3, the enhanced performance for redundant targets in the elderly did not occur at expense of response accuracy and unlikely to reflect to general age-related slowing in cognitive processing. One possible explanation of the enhanced performance in responding to the redundant target in the elderly is that older people experience declines in ignoring irrelevant information (Allen, Weber, & Madden, 1994a) such that the redundant targets in the present study is containing no internal noise as compared to the identity target (containing the "noise" emotional expression) and the emotional expression target (containing the "noise' identity information), and this noise under single target conditions may be detrimental to older participants. Another possibility reflects to enhanced integrative processing in the as a compensation for declines in perceptual processing as it was suggested in previous study by Bucur, Madden, et al. (2005).

An interesting question may arise regarding results of the Experiments 6 and 8. What neural mechanisms support the enhanced performance in the elderly? Although the answer for the question may be obtained by a future study, results of previous neuroimaging studies indicate that the neural mechanism for the redundancy effect may be changed with age. For example, a number of studies reported a vulnerability of the OFC to age-related decline in this brain structure, and here needs to be differential recruitment of alternative brain regions for successful task completion. For example, Lamar et al. (2004) implemented a delayed match and non-match to sample task paradigm and demonstrated that older adults showed prefrontal activation during the match relative to the non-match task and posterior temporal and limbic involvement during the non-match relative to the match task. In contrast, the younger group in the study revealed activation for medial OFC regions during the match task compared to the non-match task and lateral OFC activation during the non-match task compared to the match task. This result indicates that changing the function of OFC with age reflects to involvement of different brain regions. Exploring neural mechanism of the enhanced performance for the redundant targets in older participants may have social and clinical implications.

7.6 How does the present research contribute to the field?

1. The present results make a theoretical contribution to the field by contravening a strictly modular account of processing facial identities and emotions, as suggested by both psychological (Bruce & Young, 1986) and neural-level models(Haxby et al., 2000). According to the functional model of face recognition proposed by Bruce and Young (1986), the recognition of facial expressions and of identity are assumed to be independent. Data in the present research refute this, since they show that an independent processing model cannot account for the magnitude of the redundancy gain we observe at the very fastest responses that are produced on a trial. The data show that, at some point along the processing stream, facial identity and expression interact. This presents a strong constraint on models of face processing.

This finding might become particularly important for a rehabilitation of patients with impaired recognition of facial emotional expression or identity: the possibility to integrate information from both sources may enhance the impaired processing. Additionally, investigations into the functional networks of face processing will enhance not only our understanding of normal development, but may provide insight into developmental disorders such as autism and developmental prosopagnosia.

2. The present study adds new findings in mechanism of processing of identity and emotional expression in faces by exploring the neural basis of the redundancy effect in faces. Specifically, in was shown that faster responding to the redundant information in faces reflects functional coupling between OFC and OcC. This finding adds to the model of distributed neural system for face recognition proposed by Haxby

and Gobbini (2000, 2011) by demonstrating functional connectivity between the core and the extended neural networks.

3. Research on processing of other-race faces has been important area of examining neural mechanisms of the own-race advantage. The present thesis contributes onto this research field by demonstrating that the own-race bias is linked to integration of identity and emotional expression information in faces. Moreover, it was shown that ability to integrate facial information in other-race faces is modulated by number of contacts with other-race people. As a society becomes more multicultural, these findings may have an important implication in every day life.

4. Previously, facilitation effect of redundant information on RT performance in older people was shown for simple displays, but not for complex stimuli such human faces. One of the main findings here is that older adults process redundant information in faces more efficiently compared to young individuals: the workload capacity gradually increases wit age. The theoretical implication of this finding reflect possible mechanism of integration information in normal aging. In a practical way, the developing methods to take a greater use of redundant information may improve a quality of live in older population.

7.7 Main limitations of the present research

First, although the current study overcomes some limitations of previous studies employing the Garner task (e.g. matching the efficiency of discriminating identity and emotion targets), there remains an issue about a small number of stimuli being used. Modification of the task is needed to minimise effects of repetition against the large number of trials required to test the Race Model.

Second, further work needs to be done to establish what information in faces is perceived as redundant. This will help us understand the stages of processing where the coding of the structural identity of a face interacts with or bifurcates from the coding of emotional expression. For example, it would be interesting to see whether an intensity of expressed emotions in faces affects the size of redundancy gains and capacity of the processing. Also, manipulation in identity information such as degree of similarity between redundant target faces and either single target may affect the interaction and capacity of the processing.

Third, the current study has only examined a limited number of emotions (angry, sad and neutral). The evidence points to there being interactive processing of identity and the universal emotions of sadness and anger, but there was no evidence for interactive involving a possibly more idiosyncratic ‘neutral’ expression. Whether the universality of the expression is critical requires further studies exploring a wider range of facial expressions.

Fourth, in the present thesis, capacity analysis has been employed to evaluate the relationship between conditions in terms of work done at each time bin. This analysis has a great potential for psychological application. However, some methodological issue limit interpretation and use this method. For example, capacity analysis is commonly used at individual level, but there is little development of using it at the group level. Here I followed Hugenschmidt et al. (2010) for creating the capacity coefficient curve at group level. However, a difference in computing group’s CDF and cumulative hazard function (e.g., capacity curve does not have numerical values before responses begin, but CDF has value of 0 before response starts) makes difficult to directly compare average race curve and average capacity coefficient curve.

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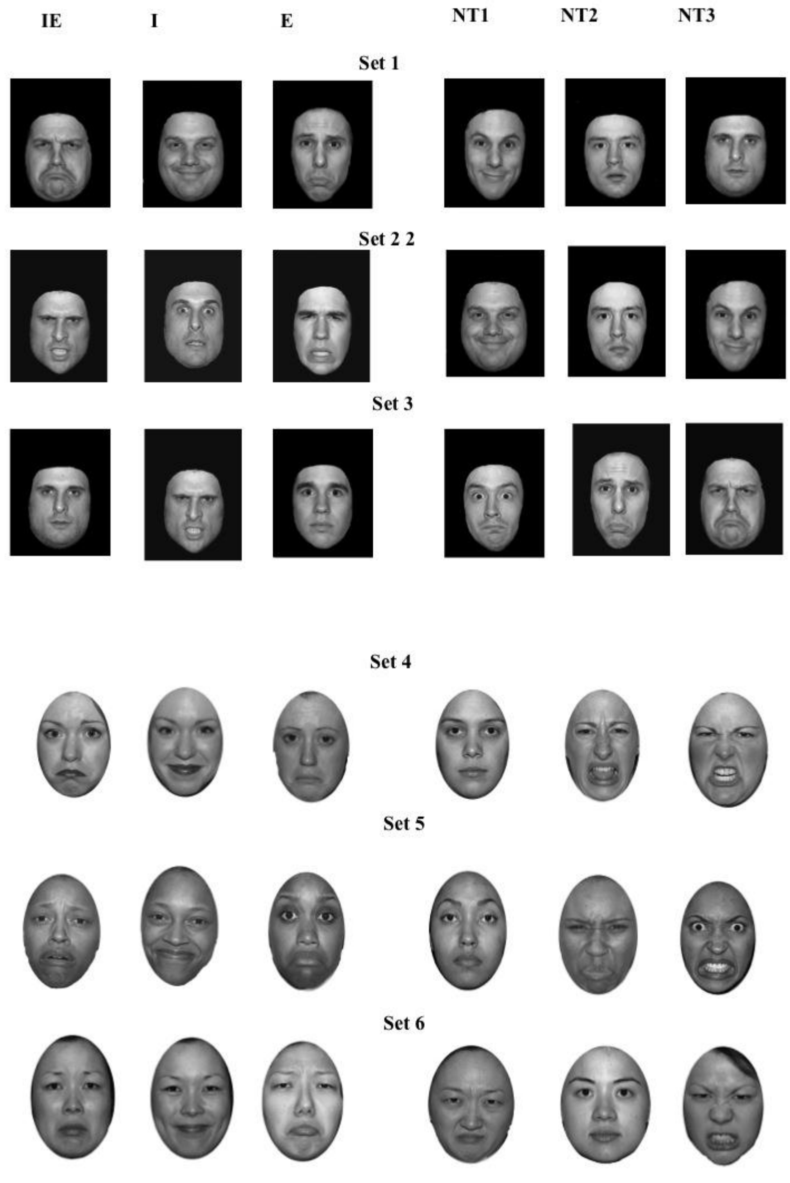
Appendix A

Stimuli sets



Appendix B

Matlab codes for computing CDF and plotting results

(modified for Mac OX Lion)

```
RaceModel
X=xlsread('fMRI_behavioural.csv','A1:A50');
Y=xlsread('fMRI_behavioural.csv','B1:B50');
Z=xlsread('fMRI_behavioural.csv','C1:C50');
P=xlsread('fMRI_behavioural.csv','D1:D19');
%X,Y,Z are arrays with RTs for conditions Cx, Cy, Cz, respectively.
%P is an array which contains the probabilities for computing
% percentiles.
%If Plot==true, a plot of the result is generated.
%%% Step 1: Determine Gx, Gy, and Gz %%%
%Check for ties
[Ux Rx Cx]=ties(X);
[Uy Ry Cy]=ties(Y);
[Uz Rz Cz]=ties(Z);
%Get maximum t value
%tmax=ceil(max([X,Y,Z])); %this line is original, but does not work
tmax=[(max(X)),(max(Y)),(max(Z))]; %This line is written by
%A Yankouskaya on 30/04/2011. Works well with different length of columns
T=1:1:tmax;
%Get function values of G
[Gx]=CDF(Ux,Rx,Cx,tmax);
[Gy]=CDF(Uy,Ry,Cy,tmax);
[Gz]=CDF(Uz,Rz,Cz,tmax);

%%% Step 2: Compute B = Gx plus Gy %%%
for t=1:tmax;
B(t)=Gx(t)+Gy(t);
end
% Check whether requested percentiles can be computed
OKx = check(Ux(1),P(1),Gx);
if OKx == false
disp('Not enough X values to compute requested percentiles')
Xp=NaN;Yp=NaN;Zp=NaN;Bp=NaN;
return
end
OKy = check(Uy(1),P(1),Gy);
if OKy == false
disp('Not enough Y values to compute requested percentiles')
Xp=NaN;Yp=NaN;Zp=NaN;Bp=NaN;
return
end
```

```
OKz = check(Uz(1),P(1),Gz);
if OKz == false
disp('Not enough Z values to compute requested percentiles')
Xp=NaN;Yp=NaN;Zp=NaN;Bp=NaN;
return
end
% %%% Step 3: Determine percentiles %%%
[Xp] = GetPercentile(P,Gx,tmax);
[Yp] = GetPercentile(P,Gy,tmax);
[Zp] = GetPercentile(P,Gz,tmax);
[Bp] = GetPercentile(P,B,tmax);
Plot=true;
%Generate a plot if requested
if Plot == true
plot(Xp,P,'o-',Yp,P,'o-',Zp,P,'o-',Bp,P,'o-')

grid on
title('Test of the Race Model Inequality','FontSize',16)
xlabel('Time t (ms)','FontSize',14)
ylabel('Probability','FontSize',14)
legend('G_x(t)','G_y(t)','G_z(t)','G_x(t)+G_y(t)',4)
end

% return to calling routine.

function [U R C]=ties(W)
% Count number k of unique values
% and store these values in U.
W=sort(W);
n=length(W);
k=1;
U(1)=W(1);
for i=2:n
if W(i)~=W(i-1)
k=k+1;
U(k)=W(i);
end
end
% Determine number of replications R
R=zeros(1,k);
for i=1:k
for j=1:n
if U(i)==W(j)
R(i)=R(i)+1;
end
end
end
%Determine the cumulative frequency
C=zeros(1,k);
```

```
C(1)=R(1);
for i=2:k
C(i)=C(i-1)+R(i);
end
end
%END of Ties

function [Tp] = GetPercentile(P,G,tmax)
%Determine minimum of |G(Tp(i))-P(i)|
np=length(P);
for i=1:np;
cc=100;
for t=1:tmax
if abs(G(t)-P(i)) < cc
c=t;
cc=abs(G(t)-P(i));
end
end
if P(i) > G(c)
Tp(i)=c+(P(i)-G(c))/(G(c+1)-G(c));
else
Tp(i)=c+(P(i)-G(c))/(G(c)-G(c-1));
end
end
end
% End of GetPercentile

function OK=check(U1,P1,G)
OK=true;
for t=(U1-2):(U1+2);
if (G(t)>P1) && (G(t-1)==0)
OK=false;
return
end
end
end


function [G]=CDF(U,R,C,maximum)
G=zeros(1,maximum);
k=length(U); n=C(k);
for i=1:k;
U(i)=round(U(i));
end
for t=1:U(1);
G(t)=0;
end;
for t=U(1):U(2);
G(t)=(R(1)/2+(R(1)+R(2))/2*(t-U(1))/(U(2)-U(1)))/n;
```

```
end;
for i=2:(k-1);
for t=U(i):U(i+1);
G(t)=(C(i-1)+R(i)/2+(R(i)+R(i+1))/2*(t-U(i))/(U(i+1)-U(i)))/n;
end
end
for t=U(k):maximum;
G(t)=1;
end
end
```

Appendix C

Self-report questionnaires

The quantity of social-contact

How many Black people do you know very well?

(Up to 2, Up to 5, Up to 8, Up to 12 and More than 12)

How many European people do you know very well?

(Up to 2, Up to 5, Up to 8, Up to 12 and More than 12)

How many Asian people do you know very well?

(Up to 2, Up to 5, Up to 8, Up to 12 and More than 12)

I often talk to other-race people in college (university)

strongly agree, sort of agree, not sure, sort of disagree, strongly disagree

I often see other race people outside of college (university)

strongly agree, sort of agree, not sure, sort of disagree, strongly disagree

'I often hang out with other-race people (University)

strongly agree, sort of agree, not sure, sort of disagree, strongly disagree

'I often see other-race people at social events I attend

strongly agree, sort of agree, not sure, sort of disagree, strongly disagree

summary_________________

Experience in individuating different race groups

'How often do you spend time with other-race friends/friend at their place?'

Never, rarely, once in a while, sometimes, frequently

'How often do you have other-race friends round to your place?'

Never, rarely, once in a while, sometimes, frequently

'How often have you helped someone other-race with a problem they had in class?'

Never, rarely, once in a while, sometimes, frequently

'How often have you asked for/received help from someone other-race when you had a problem in class?'

Never, rarely, once in a while, sometimes, frequently

'How often have you given other-race person advice on a personal problem?'

Never, rarely, once in a while, sometimes, frequently

'How often have you received advice from a others-race person when you are having a personal problem?'

Never, rarely, once in a while, sometimes, frequently

'How often have you comforted other-race person when they were upset/sad?'

Never, rarely, once in a while, sometimes, frequently

'How often have you been comforted by other-race person when you were upset/sad?'

Never, rarely, once in a while, sometimes, frequently

'How often have you worked with other-race classmates on projects?'

Never, rarely, once in a while, sometimes, frequently

'How often have you had others-race person on your team during sports or your group during other activities?'

Never, rarely, once in a while, sometimes, frequently

Summary________________

Appendix D

Examining accuracy/RT trade off in Experiment 8

The overall correlation between RT and accuracy in the three groups of participants is displayed in Table A.

Table A

The overall correlation between RT and number of errors for the redundant targets (IE), the identity target (I), and the emotional expression target (E) in groups of young, middle-aged and older participants

Groups of participants	Stimuli IE	Stimuli I	Stimuli E
Young	0.31 (p > .05)	-0.42 (p > .05)	-0.16 p > .05)
Middle-aged	0.38 (p > .05)	0.1 (p > .05)	-0.17 (p > .05)
Older	*	0.64 (p < .05)	0.08 (p > .05)

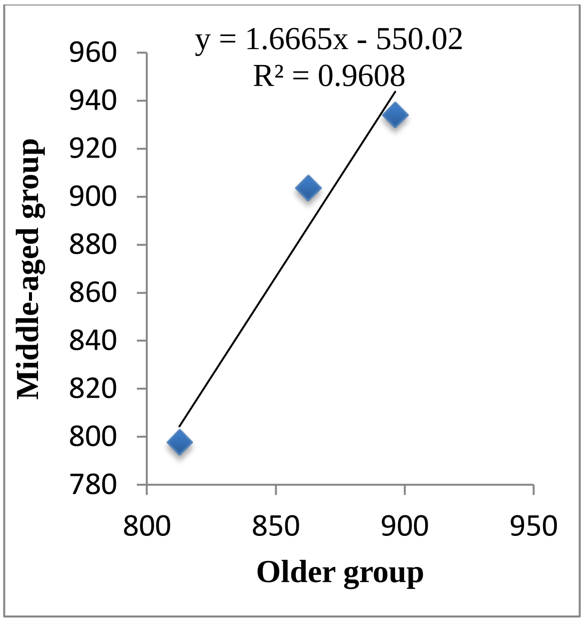
- the value was not computed because of 100 % accuracy

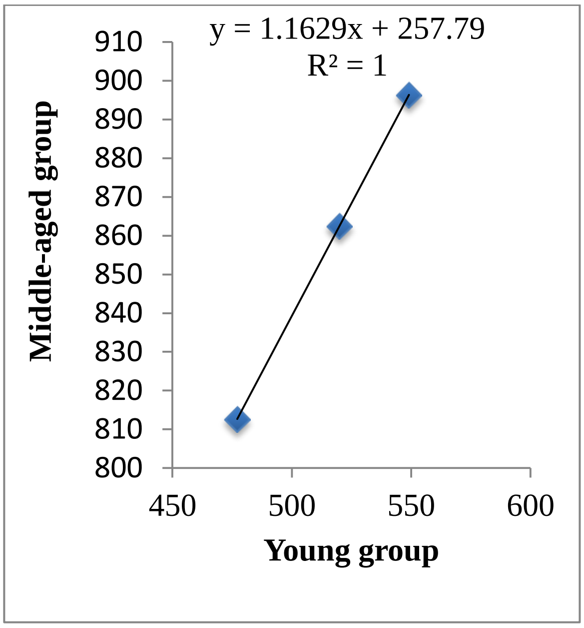
Correlation between response latencies for each stimulus on “go” trials and number of errors was small and not reliable, excluding correlation for the target identity in the older group. The elderly shows significant positive correlation between RT and errors for the stimulus containing target identity. Given that a difference in RT between the identity and emotion targets was not significant and the positive character of the correlation does imply for speed-accuracy tradeoff, the accuracy performance can be ignored in redundancy gain analyses for the older group.

Appendix E

Examining a proportional relation in RT performance for each condition containing targets across young, middle-aged and older groups

To assess whether the age differences in speed variables are attributable to the operation of a single slowing factor or reflect specific (or at least non-general) effect, systematic relation between stimuli were defined using Brinley plot. Brinley plot is a graphical representation of the proportional relation in RTs for a task conditions across groups (i.e., if older adults are slower than younger adults by an amount proportional to the RTs of younger subjects, then Brinley plot will represent linear relation between performance in the older and young groups). Figure A demonstrates such relation between groups of participants.





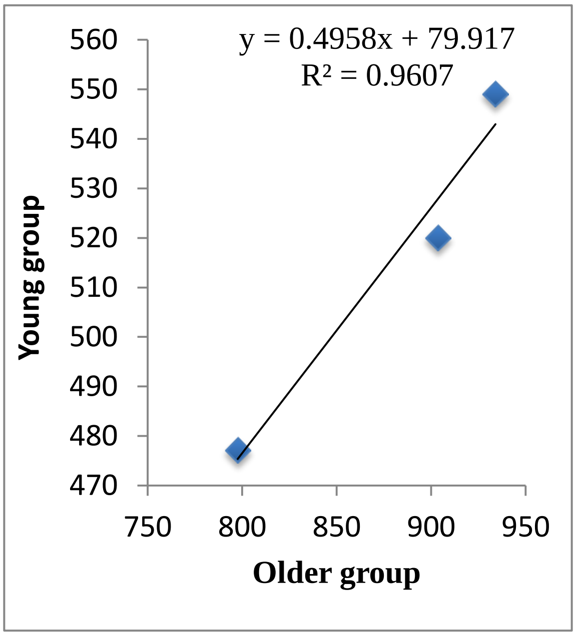


Figure A. Systematic relation between RTs for the redundant target, the identity target and the emotion target (three blue dots) for groups of young, middle-aged and older participants. Each point in each scatterplot corresponds to mean RT for a particular target, with the abscissa representing RTs (ms) for one group, and the ordinate representing RTs (ms) for the other group. The solid line is the regression line relating the values for the two particular groups in each scatterplot.

Figure A illustrates relations when the mean response times of older versus young, young versus middle-aged and middle-aged versus older subjects are plotted for each condition containing targets. The slops and intercepts displayed in Figure A are in a line with previous studies reported a slope greater 1 and intercepts varied between +214 ms and - 693 ms (Cerella, 1991; Faust, 1999). Interestingly in each case the slope and intercept are different. In the present experiment participants' performed target detection task on 6 conditions, three of them required response 'target present'. If the difference between groups in responding for stimuli containing targets was caused by age-related slowing then we should expect similar parameters for the Brinley plots across all groups. One explanation of this result may be that relative placements of the means and standard deviations of RT distributions for each group different (Ratcliff, Spieler & McKoon, 2000). For example, Ratcliff et al. (2000) using the relative standard deviations of older versus young subjects' response times showed that the linear relation arose from a larger spread in the distribution of mean response times for older subjects than for young subjects. For instance, the negative intercept of the Brinley plot was linked to larger older subjects' means than younger subjects' means, but not by too much, relative to their standard deviations. Further, Ratcliff at al. (2000) demonstrated that difference in the patterns of RT distributions in older and young groups might be due by different response criteria, different quality of information that older subjects.