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School of Psychology

Spatial and Temporal Factors in the Development of Second Order Relational Processing

by

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ABSTRACT

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This thesis examines whether the improvements in the efficiency of second-order relational processing that are seen across development are underpinned by changes in the spatial extent, the time course and the orientation range over which second-order relations are computed. The results showed that the spatial scale across which second-order relations are computed does not change with development, neither does the time course across which second-order relations are computed. The results did, however, demonstrate that there are developmental differences in the stopping rule used when participants are asked to detect differences between two faces. In addition, the results highlighted that younger participants adopted a more conservative response criterion compared with adults when asked to select an 'odd' face from a pair of faces. Finally, the results showed that the range of orientations across which faces can be processed using second-order relational processing increases with development.

Contents

List of Tables

List of Figures

Publications

The Journal of Experimental Psychology: General has invited a resubmission of the experiments that form Chapter 5 of this thesis. They were also presented at the Edinburgh meeting of the Experimental Psychological Society and the Psychonomic Society in June 2007. In addition, the results of Experiments 1-4 were presented at the Configural Processing Consortium in Houston in November 2006 and also at the Annual Conference for the Cognitive Section of the British Psychological Society in Lancaster in September 2006. The results of the experiment reported in Chapter 6 have been accepted for presentation at the Annual Conference of the Vision Sciences Society in Naples, Florida in May 2008.

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Chapter 1

Face processing begins with the structural encoding of facial stimuli; it is the development of this stage of processing that is explored in this thesis. It is generally assumed that, by adulthood, faces are processed using featural (i.e. the shapes of the individual features; Mondloch, LeGrand & Maurer, 2002) and configural information (i.e. the spatial distances between features; Maurer, LeGrand & Mondloch, 2002). Until recently, the general consensus has been that children below the age of ten-years process faces as a collection of features, but children above the age of ten-years process faces configurally (Carey & Diamond, 1977). More recently, research has suggested that there is a gradual (i.e. continuous) improvement in the efficiency (i.e. the relative rate and accuracy) of configural processing across childhood, adolescence and into adulthood (e.g. Mondloch et al., 2002; Donnelly & Hadwin, 2003; Hay & Cox, 2000). This thesis examines whether the improvements in the efficiency of configural processing that are seen across development are underpinned by changes in the spatial extent, the time course and the orientation range over which configural relations are computed.

In order to explore the development of face processing it is first necessary to have a clear understanding of the end point of development, i.e. the adult face processing system. Having a clear understanding of the way in which adults process faces means that we can accurately examine the age at which face processing becomes adult-like. In addition, it means that we can investigate whether development is associated with qualitative or quantitative changes. For example, if children use the same strategy as adults to process faces but use it less efficiently (i.e. less accurately and more slowly), then we would be able to conclude that development is associated with quantitative changes. Alternatively, if children use a different strategy to process faces compared with adults, then we would be able to conclude that development is associated with qualitative changes.

The adult face processing system

Adults encode upright faces using configural processing (e.g. Bartlett & Searcy, 1993; Tanaka & Farah, 1993). The term 'configural processing' refers to "any phenomenon that involves perceiving the relations among features" (Maurer et al., 2002, p.255). Although a great deal of research has supported the idea that faces are encoded using configural processing, the term 'configural' has been poorly specified.

Indeed, the term 'configural' has been described as being "bereft of precision" (Wenger & Townsend, 2001, p.229) and "un-quantified and ill-defined" (Uttal, 1988, p.22). To complicate matters further, a number of terms such as 'configural', 'second-order relational' and 'holistic' have been used interchangeably in the literature.

To address the inconsistent use of terms in the literature several authors have proposed definitions. First, Maurer et al. (2002) proposed three forms of configural processing: first-order relational processing (for example, the eyes are above the nose, which is above the mouth), second-order relational processing (for example, the distance between the eyes and the nose) and holistic processing (gluing features together into a gestalt).

Subsequently, Boutsen and Humphreys (2003) proposed two alternative forms of second-order relational processing differing in the spatial scale across which second-order relations are computed. They defined local-configural processing as being the encoding of second-order relations locally around each feature (for example, the distance between the eyes) and global-configural processing as being the processing of second-order relations more globally across the face (for example, the distance between the eyes and the mouth). More specifically, local-configural processing involves the encoding of face-parts (features) and their spatial relations independently of the face context and other face-parts, whereas global-configural processing involves the encoding of face-parts and their spatial relations within the face context (i.e. spatial relations between the face-parts or the spatial relations between the face-parts and the outline of the face).

The spatial scale of second-order relational processing in adults

Research that has been conducted to examine the spatial scale (i.e. local or global-configural processing) over which adults process second-order relations has not always provided consistent results. The face inversion effect (faster and more accurate performance with upright than inverted faces) is often cited as a marker for second-order relational processing (e.g. Bartlett & Searcy, 1993; Searcy & Bartlett, 1996) and so Boutsen and Humphreys (2003) investigated whether inversion impairs the ability to process global or local-configural relations. The authors employed a two alternative forced choice (2AFC) task with the Thatcher illusion (Thompson, 1980). In the Thatcher illusion, the eyes and the mouth are inverted and then returned to the context of the face. When the face is upright it appears grotesque, however, when the face is inverted perceived grotesqueness disappears (e.g. Bartlett & Searcy, 1993, see Figure 1). The Thatcher illusion arises because participants are able to process the configural features when the face is upright, but are unable to process the configural features when the face is inverted (Young Hellawell & Hay, 1987; Bartlett & Searcy, 1993; Rhodes, Brake & Atkinson, 1993; Lewis & Johnston, 1997; Searcy & Bartlett, 1996).

Figure 1. An example of the Thatcher illusion. The manipulations are more apparent when the face is upright (right panel) compared with when the face is inverted (left panel).

In their study, Boutsen and Humphreys (2003) presented participants with pairs of different identity faces (Experiments 2 and 4). Different identity faces were used so that participants could not base their decisions on low-level featural information. In 'same' trials, both faces were either 'Thatcherised' or 'normal', and in 'different' trials one face was 'normal' and one was 'Thatcherised'. Participants were asked to decide whether the two faces were of the 'same' or 'different' type. In Experiment 2, participants were presented with part faces, where the background colour was used to mask all areas of the face other than a small area surrounding the eyes and the mouth. In Experiment 4, whole faces were used. The authors argued that if upright faces are processed using global-configural processing, then the magnitude of the inversion effect should be greater in the whole-face experiment compared with the part-face experiment. The results highlighted a significant effect of inversion in both experiments, indicating that participants were employing second-order relational processing to discriminate between 'normal' and 'Thatcherised' faces. However, there was no difference in the magnitude of the inversion effect between the part-face experiment (Experiment 2) and the whole-face experiment (Experiment 4), suggesting that the face context (which was present in the whole-face experiment, but not the part-face experiment) did not facilitate performance when faces were upright. The authors argued that participants were using local-configural processing rather than global-configural processing in both the part-face experiment and the whole-face experiment, suggesting that inversion disrupts local-configural processing.

Boutsen and Humphreys' (2003) study does, however, have some limitations. The authors masked their faces to create face-parts rather than presenting the parts of the faces separately. Consequently, the eyes and the mouth remained in a naturalistic position relative to one another hence participants may have been able to use amodal completion (Kanizsa, 1979) and compute second-order relations across the illusory face. If this was the case, the absence of a difference in the magnitude of the inversion effect between the part-face experiment and the whole-face experiment may have resulted from participants using global-configural processing in both experiments, rather than participants using local-configural processing in both experiments as Boutsen and Humphreys suggested. Consequently, inversion may disrupt global-configural processing rather than local-configural processing as Boutsen and Humphreys (2003) concluded.

The finding that the effect of inversion is underpinned by disruption to local-configural processes suggests that participants may rely only on local-configural processing when processing upright faces rather than global-configural processing. Despite the potential limitation associated with Boutsen and Humphreys' (2003) experiment, other researchers have found results that are consistent with the idea that faces are processed using local-configural processing. For example, Leder, Candrian, Huber and Bruce (2001) used a paradigm that was similar to the one later employed by Boutsen and Humphreys (2003) to investigate the spatial scale of second-order relational processing. Their experiment was similar because, like Boutsen and Humphreys (2003), they manipulated the amount of the face that was visible to participants. In their experiment, participants were presented with two successive faces; one was an original face and the other had the distance between the eyes either increased or decreased. In condition one, faces were masked so that only the eye region was visible. In condition two, participants were presented with the eyes, nose and cheek area. Finally, in condition three, participants were presented with the eyes, nose, mouth, chin and cheek area. Participants were asked to decide which of the two faces had the largest inter-ocular distance. The results showed no effect of condition, suggesting that participants judged inter-ocular distance irrespective of the other areas of the face that were visible (Experiment 2). These results suggest that the additional information that was provided by the nose, mouth, chin and cheeks did not facilitate performance, indicating that inter-ocular distance was processed independently of other features, supporting the idea that participants were processing second-order relations relatively locally.

Leder and Bruce (2000, Experiment 4) also found evidence consistent with a locally based form of second-order relational processing. They asked participants to learn names associated with eight faces. Participants were then shown a critical feature in isolation but with relational information preserved (for example, a pair of eyes shown with the correct distance between them) or the critical feature in a face context (for example, the eyes only within the face context) and were asked to name the face that the feature belonged to. Leder and Bruce (2000) argued that if participants computed second-order relations relatively globally during the task, then the additional information that was provided when the features were presented within the face-context should aid performance. However, the results showed that presenting features within the face context did not facilitate performance relative to the isolated-part condition, suggesting that participants were computing second-order relations locally rather than globally.

The experiments conducted by Boutsen and Humphreys (2003), Leder et al. (2001) and Leder and Bruce (2000) are not the only experiments suggesting that faces are processed using a locally based form of second-order relational processing (e.g. Macho & Leder, 1998; Leder & Bruce, 2000). A further way that the spatial scale of second-order relational processing has been investigated was achieved by examining whether features have independent representations. If second-order relations are processed globally (i.e. across multiple features), then features would be "tightly bound" (Wenger & Ingvalson, 2002, p.873), so that they do not have independent representations. Accordingly, participants should not be able to base their responses on single features, rather responses will be influenced by other facial features (Donnelly & Davidoff, 1999; Tanaka & Farah, 1993; Farah, Wilson, Drain & Tanaka, 1998). Alternatively, if second-order relations are processed relatively locally, then features would not be "tightly bound" (Wenger & Ingvalson, 2002, p.873) and so features would have independent representations. Consequently, participants' responses would not be influenced by other features.

Macho and Leder (1998) found evidence suggesting that features were processed independently of other features, which is also consistent with the idea that second-order relations are processed relatively locally. A single face was modified; the distance between the eyes, the size of the mouth and the width of the nose were modified by two values. The original face was labelled '222'. In face '111' all features were smaller than the original face, and in face '333' all features were larger than the original face. All combinations of features were presented, such that face '123' had a small distance between the eyes, the original nose and a large mouth. Participants were simultaneously presented with faces '111' and '333'; these two faces were then replaced by a target face. Participants were asked to decide whether the target face was more similar to face '111' or '333'. The results were analysed by examining whether the data fitted Massaro's (1998) Fuzzy Logical Model of Perception (FLMP). According to the FLMP, participants evaluate each feature independently to determine how similar it is to the corresponding feature in face '111' or '333'. Each feature is assigned a score depending on how similar it is to either target. The total score for the target face is equal to the sum of the score for the eye, nose and the mouth. If the total score exceeds a threshold, then the response face '111' can be generated. Alternatively, if the score exceeds the threshold for face '333', then the opposite response can be generated. Importantly, the evaluation of each feature occurs independently of the other features. The results showed that the FLMP fitted the data, suggesting that whole faces were represented as a sum of the score for the eyes, nose and mouth. The authors, therefore, argued that each feature was processed independently of the other features and so features were not "tightly bound" (Wenger & Ingvalson, 2002) suggesting that second-order relations were processed locally rather than globally.

Not all experiments support the idea that faces are processed using local-configural processing. Instead, some claim to show evidence that would be consistent with global-configural processing. Sergent (1984) asked participants to perform dissimilarity judgements between two simultaneously presented faces that varied along 3 dimensions (eyes, internal space and the contour of the face) with 2 levels on each dimension (small or large). The results were subjected to multidimensional space (MDS) analysis. Multidimensional space analysis is based on work conducted by Ramsay (1978). It aims to represent the dissimilarity between stimuli in terms of distance between points positioned in a multidimensional space. Sergent (1984) reasoned that if each feature contributed independently and equally to the dissimilarity judgement, then MDS analysis should have revealed a shape with equal length sides and 90 degree angles between each side. Alternatively, if each feature contributed independently but unequally (i.e. participants assigned more importance to one feature over another) then MDS analysis should reveal a rectangle-parallelepiped form. Finally, if features did not contribute independently to the dissimilarity judgement, then MDS analysis should reveal a form with unequal sides and non-orthogonal dimensions. The results of the MDS analysis revealed a non-orthogonal form with unequal dimensions, suggesting that features were not processed independently, which is consistent with global-configural processing. However, Macho and Leder (1998) highlighted the fact that Sergent (1984) did not conduct a statistical test to verify her conclusions, raising the possibility that the results may not have been statistically significant.

Another experiment that claims to show evidence that would be consistent with global-configural processing is the part/whole experiment that has been used by Davidoff and Donnelly (1990; and also Tanaka & Farah, 1993; Donnelly & Davidoff, 1999 among others). The part/whole task examines the effect of increasing the amount of the face that is visible on participants' ability to identify features. Davidoff and Donnelly (1990) asked participants to learn names associated with faces. In the part-face condition, participants were presented with two features and were asked to select a particular person's feature (e.g. which is Bob's nose?). In the whole-face condition, participants were presented with whole faces which were identical except for the critical feature (i.e. one face was Bob's face and the other was Bob's face but with Tom's nose). Participants were asked to select a particular person's face (e.g. which is Bob?). Davidoff and Donnelly (1990) showed that participants were more accurate in the whole-face condition than in the part-face condition. They argued that superior performance in the whole-face condition arose because participants computed second-order relations between features and then relied on these relations when they were asked to recognise the face. These relations were not available in the part-face condition (because only single features were present) and so they could not facilitate performance. These results suggest that participants were computing second-order relations between features and so the results are consistent with global-configural processing. These results are, therefore, inconsistent with the research presented above.

The part/whole task is very similar to a task that has been used by Farah et al. (1998). Farah et al. (1998) investigated whether participants' responses were influenced by features that were irrelevant to the task they completed. This task is similar to the part/whole experiment because both experiments are examining the effect of features that are irrelevant to the task on performance. In Farah et al.'s experiment, participants were presented with a target face. They were then presented with a test face and were asked to make 'same'/'different' decisions about an individual pre-designated feature. In compatible trials, if the target features were the 'same', then the irrelevant features were also the 'same' (alternatively, if the target features were 'different', then the irrelevant features were also 'different'). In incompatible trials, if the target features were the 'same', then the irrelevant features were 'different' (alternatively, if the target features were 'different', then the irrelevant features were the 'same'). Farah et al. (1998) showed that reaction times (RTs) to make 'same' decisions were faster when irrelevant features were compatible, compared with when irrelevant features were incompatible, suggesting that RTs were influenced by task irrelevant features. The authors argued that irrelevant features could only influence performance if they were "tightly bound" (Wenger & Ingvalson, 2002, p. 873) to the relevant features, hence the results are consistent with global-configural processing.

More recently, Wenger and Ingvalson (2002; also see Ingvalson & Wenger, 2005) highlighted that Farah et al. (1998) reported the accuracy of both 'same' and 'different' responses to both compatible and incompatible trials and so it was possible to re-analyse their results using the signal detection measure of *d'* and *c*. Signal Detection Theory (SDT) concerns the participants' ability to discriminate between signal and noise. In the case of Farah et al.'s (1998) task, a 'different' feature constitutes the signal and a 'same' feature constitutes the noise. If the participant perceives the 'same' features and the 'different' features as being perceptually very similar, then the two distributions (one distribution relating to the signal and one to the noise) will overlap. In this case, the participant will find the discrimination difficult. Alternatively, if the participant perceives the 'same' features and the 'different' features are being perceptually very different, then the distributions relating to the signal and the noise will not overlap. In this case, the participant will find the discrimination relatively easy. The ability of the participant to discriminate between signal and noise is measured in terms of *d'*. Analysing the results in terms of *d'* is more powerful than analysing the results using accuracy (as Farah et al. did) because it considers hit rates and false alarm rates simultaneously and secondly, because it is independent of the participants' response criterion. The response criterion is used to determine which response to generate. It is measured using the *c* statistic. If the level of activation from the stimulus exceeds the response criterion, then the participant will generate a 'different' response. Alternatively, if the level of activation from the stimulus does not exceed the response criterion then the participant will generate a 'same' response. If the response criterion is set too liberally, then the participant will respond 'different' on a high proportion of trials. In this case, they will correctly identify a large number of 'different' trials as being 'different', but will also misidentify a large number of 'same' trials as 'different'. In other words, participants will make lots of hits (responding 'different' to 'different' trials), but also lots of false alarms (responding 'different' to 'same' trials). Contrastingly, if the response criterion is set too conservatively, then the participant will respond 'same' on a large proportion of 'different' trials, but will not misidentify 'same' trials as 'different'. In other words, participants will make fewer hits, but also fewer misses. D prime is a measure of sensitivity that is independent of bias and so any differences between conditions can be localised to differences in perceptual processing rather than to differences in decisional processes.

If Farah et al.'s conclusions are to hold, then Wenger and Ingvalson's results should show greater values of *d'* in the compatible condition compared with the incompatible condition. However, Wenger and Ingvalson (2002) showed that when Farah's data was reanalysed the results showed no difference between conditions in terms of *d'*, but did show differences between conditions in terms of *c*. Specifically, participants set their response criterion more conservatively in the incompatible condition compared with the compatible condition. This means that although participants reduced their hit rates they also reduced their miss rates. The results of this reanalysis, therefore, demonstrate that the reduction in hit rate that Farah et al. reported was caused by participants responding more conservatively in the incompatible condition compared with the compatible condition and not because participants experienced interference from task irrelevant features. Wenger and Ingvalson's (2002) reanalysis, therefore, suggests that Farah et al.'s task is not suitable for investigating the spatial scale of second-order relational processing and consequently the results should be treated cautiously. Given the similarity between Farah et al.'s task and the part/whole task, it may be that the difference between the part-condition and the whole-condition are underpinned by differences in response criterion. This possibility requires empirical investigation, which is beyond the scope of this thesis.

Since Wenger and Ingvalson (2002) conducted their study, another study has been conducted to examine whether the composite face effect (e.g. Young et al., 1987; Hole, 1994) is underpinned by differences in response criterion or differences in sensitivity. Composite faces are constructed by combining the top half of one face with the bottom half of another face. Face-halves are presented either aligned or non-aligned. Young et al. (1987) showed that responses were slower and less accurate when face-halves were aligned relative to when they were non-aligned when faces were upright, but there was no difference between conditions when faces were inverted (Young et al., 1987; Hole, 1994). Young et al. (1987) reasoned that the composite face effect arose because participants computed second-order relations between the top and bottom half of the face in the aligned condition, which interfered with the recognition of either face-half. The composite face effect could, therefore, be used as evidence to support a global-configural account of face processing as second-order relations were argued to be processed between multiple features. However, Richler, Gauthier, Wenger and Palmeri (2006) have recently shown that differences between the aligned and non-aligned conditions are underpinned by differences in response criterion, indicating that the composite face paradigm, like Farah et al.'s (1998) task is not be a good test of the spatial scale of second-order relational processing.

The research reviewed above suggests that performance on a number of tasks that have been used to explore the spatial scale of second-order relational processing is influenced by differences in response criterion. Any research that has used these tasks should, therefore, be treated cautiously. It is worth briefly considering the consequences of Wenger and Ingvalson's (2002) and Richler et al.'s (2006) research for previous research that has used these tasks. The composite face task has been applied to examine a range of different facets of face processing. For example, it has been used to show that children, like adults, are more accurate at identifying face halves when they are non-aligned compared with when they are aligned (e.g.

Mondloch, Pathman, Le Grand & De Schonen, 2007). This result has been taken as evidence to suggest that young children are capable of processing second-order relations (e.g. Mondloch et al., 2007; Hay & Cox, 2000). However, given the possibility that performance on this task is underpinned by differences in response criterion, these results might also be interpreted as showing that children change their response criterion between conditions in a similar way to adults, rather than demonstrating that children are equally sensitive to second-order relations as adults.

The composite face task has also been used to investigate whether there are deficits in face processing between typically developing children and children with autism. For example, Teunisse and de Gelder (2003) showed that children with autism show no differences between the aligned and non-aligned conditions. The authors interpreted these results as suggesting that children with autism do not process faces using second-order relational processing. However, given that performance on this task is likely to be underpinned by differences in response criterion, these results might also be interpreted as showing that children with autism adopt the same response criterion across conditions whilst typically developing children change their response criterion between conditions. Indeed, setting and adapting a response criterion is an ability that is controlled by the prefrontal cortex (Bogte, Flamma, van der Meere & van Engeland, 2007) and deficits in the prefrontal cortex have long been associated with the aetiology of autism (e.g. Ohnishi et al., 2007). It, therefore, seems possible that children with autism might not be able to adjust their response criterion in accordance with task demands. In fact, evidence of an inability to adjust response criterion in children with autism has previously been provided by Bogte et al. (2007). They showed that children with autism fail to show evidence of post-error slowing (slowing down RTs after making an error), an ability that is often cited as evidence of participants adjusting their response criterion (Rabbitt, 1966).

In summary, although there are a number of studies which claim to show evidence of global-configural processing, further examination reveals that their results can be explained in alternative ways. Sergent's (1984) data may be non-significant and any study demonstrating results consistent with global-configural processing using either Farah et al.'s (1998) paradigm or the composite face task is likely to reveal differences in response criterion between conditions rather than evidence consistent with global-configural processing. Instead, more recent research, that has not used paradigms that are susceptible to differences in response criterion, has shown that faces are processed using local-configural processing. There are, however, limitations associated with this research and so further research is required in order to clarify the spatial scale that adults process second-order relations over.

The time course over which adults process second-order relations

Research suggesting that second-order relations may be encoded relatively locally around features raises the question as to whether differences between faces are detected simultaneously (i.e. in parallel) or sequentially (i.e. in serial) and whether responses are made when the first difference between a pair of faces is detected (i.e. using a self-terminating stopping rule) or when all features have been compared (i.e an exhaustive stopping rule). Only three previous studies (Bradshaw & Wallace, 1971; Smith & Nielsen, 1970; Walker-Smith, 1978) have been conducted to directly examine whether differences between faces are processed in serial or parallel and using a self-terminating or exhaustive stopping rule. The lack of research examining this issue may be accounted for by the apparent support for holistic processing (e.g. Tanaka & Farah, 1993). Holistic processing posits that all features are processed interdependently, in parallel and under an exhaustive stopping rule (see Farah et al., 1998). Given the apparent support for holistic processing in the literature, researchers had no reason to directly investigate the architecture and stopping rule used to compare faces. However, recent support for the idea that features are processed using local-configural processing, coupled with current research suggesting limitations with research claiming to show evidence of global-configural processing (e.g. Wenger & Ingvalson, 2002; Ingvalson & Wenger, 2005; Richler at al., 2006) indicates that there is no reason to assume that differences between faces are processed in a parallel using an exhaustive stopping rule.

The architecture (whether differences between faces are detected in parallel or serially) of the face processing system has previously been investigated by Bradshaw and Wallace (1971, also see Walker-Smith, 1978). They presented participants with a list of face pairs. Participants decided whether each face-pair was the 'same' or 'different' and RT was measured for the time each participant took to complete the list of face-pairs. Bradshaw and Wallace (1971) argued that if differences between faces were detected in parallel, then RT would remain relatively constant as the number of differences between faces increased from 2 to 4 to 7. Alternatively, if participants detected differences between faces in serial, then RT would decrease as the number of differences between faces increased, as a difference would be encountered after searching fewer features. Indeed, the results did show evidence of a decrease in RT as the number of differences between faces increased, supporting a serial model.

There are, however, a number of limitations associated with Bradshaw and Wallace's (1971) study. First, a parallel model can only predict a flat search function (i.e. no change in RT as the number of differences between faces increases) when the time to process each feature is constant (Townsend, 1972). If the time taken to process each feature is not constant (as shown by Sergent, 1984), then creating an additional difference between the faces may have meant that the processing of a new feature was completed before the old features. If participants were using a self-terminating stopping rule (i.e. they responded as soon as any of the features were identified as being 'different'), then participants could respond as soon as the new feature had finished being processed, which would result in faster RTs. Both parallel and serial models can, therefore, predict a decrease in RT when the number of differences between faces is increased, suggesting that Bradshaw and Wallace's (1971) conclusions should be treated with care. Second, it is possible that Bradshaw and Wallace's (1971) use of identikit faces rather than veridical faces promoted an un-natural comparison process between faces indicating that participants may detect differences between faces in parallel when more naturalistic faces are being processed.

Smith and Nielsen (1970) used a set of schematic faces which varied at the ears, eyebrows, eyes, nose and mouth, to investigate whether participants compared faces in parallel or serial and whether they used a self-terminating or exhaustive stopping rule. Participants were asked to complete a 2AFC 'same'/'different' task with pairs of successive faces. In one condition, all features varied between trials and so participants had to search a maximum of 5 features in order to decide whether the faces were the 'same' or 'different'. In the second condition, the size of the ears was kept constant to make them irrelevant to the task. Hence, participants only had to search a maximum of 4 features in order to decide whether the faces were the 'same' or 'different'. In the final condition, the size of the ears and the eyebrows was kept constant so that participants only had to search a maximum of 3 features in order to decide whether the faces were the 'same' or 'different'. The results showed that when the faces were the 'same', there was no effect on RT of the number of features that faces could differ by (5, 4 or 3). In contrast, when faces were 'different', there was an effect on RT of the number of features by which faces could differ. Specifically, participants were slower when the number of features that faces could differ on increased. Smith and Nielsen (1970) used these results to argue that participants compared faces in parallel using an exhaustive stopping rule when the faces were the 'same', but compared faces in serial using a self-terminating search when faces were 'different'. Unfortunately, Smith and Nielsen's (1970) argument is somewhat circular. Participants would not know whether the faces were the 'same' or 'different' until after they had finished processing them. They would not then be able to choose the mode in which to compare the faces, because processing would already have been completed. Smith and Nielsen's (1970) conclusions are, therefore, difficult to reconcile within any reasonable processing model.

In sum, only a limited amount of previous research has explored the architecture and stopping rule used to compare pairs of faces. There are a number of limitations associated with this research and so further research is required in order to establish whether adults compare differences between pairs of faces in serial or parallel and whether they use a self-terminating or exhaustive stopping rule.

The range of stimuli that adults process configurally

Research has shown that adults are not able to process all faces using second-order relational processing. Rather, adults rely more on second-order relational processing for the types of faces that they experience frequently in the environment. For example, adults process faces from their own race using second-order relational processing, but do not process faces from other races using second-order relational processing (for reviews see Bothwell, Brigham & Malpass, 1989; Brigham & Malpass, 1985; also see Tanaka, Kiefer & Bukach, 2003). Michel, Rossion, Han, Chung and Caldera (2006) used the composite face task to test whether Caucasian and Asian participants processed Caucasian and Asian faces using second-order relational processing (the composite face task is described above, see p.24). The results showed that the magnitude of the composite face effect was greater for own race faces than for other race faces (i.e. the difference between the aligned and non-aligned conditions was greater for own race than other race faces). The authors argued that these results arose because participants processed second-order relations for own race faces but not for other race faces. However, as discussed above (see p.24), the possibility that differences between the aligned and non-aligned conditions in the composite face task are underpinned by differences in response criterion rather than by differences in processing between conditions suggests that this task may not be an appropriate to examine whether second-order relational processing is in fact being employed.

Despite the potential confound of Michel et al.'s (2003) research, equivalent conclusions have been reached using the Thatcher illusion (see Figure 1). Importantly, sensitivity to the Thatcher illusion has been shown to exist independently of differences in response criterion. This has been demonstrated by Collishaw and Hole (2002) who showed that participants were more sensitive at discriminating between 'Thatcherised' and 'normal' faces when faces were upright compared with inverted even when differences in response criterion were controlled by using *d'*. D prime is a measure that is independent of response criterion and so any differences between conditions can be localised to differences in processing strategy rather than differences in response criterion. Using the Thatcher illusion, Stevenage, Cornes, Cropp & Clarke (submitted) showed that the magnitude of the inversion effect was greater for own race faces than for other race faces, suggesting that participants relied on second-order relational processing more when processing faces of their own race compared with other race faces.

Not only do individuals experience more own race faces compared with other race faces in the environment, they also experience more faces that are oriented close to upright compared with inverted. Research investigating the effect of orientation on face processing has shown that adults do not process faces at all orientations using second-order relational processing (e.g. Sjoberg & Windes, 1992; Lewis & Johnston, 1997; Lewis, 2001). For example, Lewis (2001) presented adult participants with a series of 'Thatcherised' (see Figure 1) and 'normal' faces between 0 and 180 degrees and asked participants to decide whether each face was 'odd' or 'normal'. The results showed that adults were sensitive to the Thatcher illusion to approximately 90 degrees. Given that sensitivity to the Thatcher illusion is an accepted diagnostic test of whether second-order relational processing is being employed (e.g. Bartlett & Searcy, 1993), these results suggest that adults were able to process second-order relations when faces were oriented between 0 and 90 degrees, but not when faces were oriented between 90 and 180 degrees. Presumably, adults experience many more faces at orientations close to upright and so have developed second-order relational processing only for these orientations.

Stürzel and Spillmann (2000) also used the Thatcher illusion to investigate the angular range across which participants are sensitive to second-order relations. They examined the orientation at which 'Thatcherised' faces were no longer seen as 'odd'. Participants were asked to rotate an inverted version of the Thatcher illusion until it appeared 'odd'. They showed that 'Thatcherised' faces switched from appearing 'normal' or 'odd' at around 95 degrees.

Using a different paradigm, Murray, Young and Rhodes (2000) showed that when participants were asked to make grotesqueness ratings for faces made to look grotesque by moving the features closer together or further apart, ratings remained constant from 0 to approximately 90 degrees followed by a sharp decrease to 180 degrees. These results suggest that participants were highly sensitive to the manipulations between 0 and 90 degrees, but were less sensitive between 90 and 180 degrees, suggesting that participants were only processing second-order relations between 0 and 90 degrees. In sum, research suggests that not all faces can be processed using second-order relational processing. Instead, individuals appear to reserve second-order relational processing for the types of faces that they experience frequently in the environment.

Summary of adult face processing

In summary, there are limitations with experiments claiming to show that second-order relations are computed relatively locally. Similarly, there are also limitations associated with experiments claiming to show that second-order relations are computed globally. Further research is, therefore, required in order to determine the spatial scale of second-order relational processing in adults. There are only a handful of experiments which have examined the time course of second-order relational processing. More recent research has shown that the results of these experiments can be interpreted in alternative ways and so further research is required to determine the time course of second-order relational processing in adult participants. Finally, research has demonstrated that adults cannot process faces of all orientations using second-order relational processing; rather adults are only able to process faces using second-order relational processing when they are oriented within approximately 90 degrees of upright.

The development of face processing

The primary theoretical account of the development of face processing has been provided by Carey and Diamond (1977). They suggested a qualitative switch in processing style between children and adults. More specifically, they argued that children below the age of 10-years process solely featural information, whereas children above the age of 10-years process configural information (the authors do not distinguish between second-order and holistic processing). Carey and Diamond (1977) used the results of two experiments to support their theory. In the first experiment, adults and children aged 6, 8 and 10-years were presented with a set of faces and a set of houses. Within each set, stimuli were presented in pairs, with one face/house upright and the other face/house inverted. After each set, participants were given an old/new recognition test, in which they were asked to identify the old face/house from a pair. The results were analysed in terms of participants' ability to correctly identify the old item. The difference in accuracy between upright and inverted faces was compared with the difference in accuracy between upright and inverted houses. For 6 and 8-year-olds the magnitude of the inversion effect was the same across stimulus types. In contrast, the magnitude of the inversion effect was significantly greater for faces than for houses for 10-year-olds and adults. Importantly, this effect was driven by enhanced performance with upright faces. Carey and Diamond (1977) argued that the improvement in the ability to represent upright faces was underpinned by the use of configural processing, suggesting that second-order relations are only processed by children over 10-years.

Carey and Diamond (1977) conducted a second experiment to verify their findings. They proposed that if children below the age of 10-years could not encode configural information, they would instead rely on isolated features, such as paraphernalia and expression when processing a face. In Experiment two, participants were given a set of faces to inspect. In the test phase, they were presented with two faces, one of which was the original face and the other a new face, and were asked to identify the original face. To make the task more difficult, in some conditions paraphernalia (e.g. a hat) and/or expression varied between the inspection phase and the recognition phase. In conditions one and two the paraphernalia changed between the inspection phase and the recognition phase, but in condition four it remained the same. Likewise, in condition one the expression changed between the inspection phase and the recognition phase, but remained the same in conditions three and four. Carey and Diamond (1977) suggested that reliance on either paraphernalia or expression would produce a characteristic pattern of errors. Specifically, error rates would be high in conditions one and two, where both expression and paraphernalia changed between the inspection and recognition phases. The results showed that 6 and 8-year-olds made more errors than other age groups in conditions one and two, suggesting that they were susceptible to confounding paraphernalia and expression. These results are consistent with the idea that children below 10-years were unable to encode second-order relations and so they relied on paraphernalia and expression which resulted in high error rates.

There are a number of problems associated with Carey and Diamond's (1977) account of the development of face processing. First, Carey and Diamond's experiments are open to challenge. Subsequent research has shown that the failure to find evidence of a face-specific inversion effect (shown in their first experiment) was caused by floor effects (i.e. performance was not significantly different from chance). A reanalysis of Carey and Diamond's data showed that percentage correct, averaged across all 6-year-olds was 64% for inverted faces, suggesting that some children may have been performing at chance level for inverted stimuli (Young & Bion, 1980). If this was the case, the magnitude of the inversion effect would have been artificially decreased, which may explain why there was no difference found between stimulus types. Young and Bion (1980) showed that if the task was simplified, by using a smaller set of faces, a face-specific inversion effect could be found in children below the age of 10-years. Indeed, more recent research has shown that a face-specific inversion effect can be found in children as young as 5-months (Hayden, Bhatt, Reed, Corbly & Joseph, 2007; also see Cohen & Cashon, 2001).

Carey and Diamond's paraphernalia study (Experiment 2) can be challenged because of the high perceptual similarity between faces. West and Odom (1979) showed that young participants often ignored relevant information if it was of lower salience than other information. Given that the faces used by Carey and Diamond were high in perceptual similarity (Flin, 1985); children may have ignored second-order relational information in favour of the more salient paraphernalia and expression. Carey and Diamond's task may not, therefore, be a reliable and sensitive measure of whether second-order relational information was being processed by children. To investigate the effect of perceptual similarity further, Flin (1985) replicated Carey and Diamond's (1977) method but used two different sets of faces:

a set high in perceptual similarity and a set low in perceptual similarity. Similarity was determined prior to the experiment using a 10-point rating scale. Pairs of faces rated high in similarity were used in the high-perceptual similarity condition and pairs of faces rated low in perceptual similarity were used in the low-perceptual similarity condition. All other details of Flin's experiment remained the same as in Carey and Diamond's (1977) original experiment. Importantly, the results of the high-perceptual similarity condition were identical to those found by Carey and Diamond (1977). However, the low-perceptual similarity condition showed no differences between age groups, suggesting that young children were capable of encoding second-order relations when they were more salient than confounding paraphernalia and expression.

The second problem associated with Carey and Diamond's theory is that recent studies have shown evidence of second-order relational processing in children under 10-years (e.g. de Herring, Houthuys & Rossion, 2007; Hay & Cox, 2000; Pellicano, Rhodes & Peters, 2006; Tanaka, Kay, Grinnell, Stansfield & Szechter, 1998; Bertin & Bahtt, 2004; McKone & Boyer, 2006; Pellicano & Rhodes, 2003). For example, Gilchrist and McKone (2003) used Leder and Bruce's (1998) paradigm to investigate whether faces made more distinctive by altering featural information (e.g. by making the eyebrows bushier) or configural (second-order relational) information (e.g. by moving the eyes further apart or closer together) could facilitate memory performance for children aged seven-years. Previous research (Leder & Bruce, 1998) showed that when faces were upright, memory was enhanced for faces made more distinctive by featural and configural manipulations compared with the original versions. However, when faces were inverted, memory was only enhanced for the faces made more distinctive by featural manipulations. Gilchrist and McKone (2003) presented participants with either 30 faces (for adults) or seven or eight faces (for children, depending on their age) and asked participants to study them for 5 seconds and remember them. One third of the faces were original faces, one third of the faces were made more distinctive by featural manipulations and the final third were made more distinctive by configural manipulations. During the test phase, participants saw the same faces presented during the study phase, but each face was paired with a previously unseen face. Participants were asked to point to the previously seen face. Results showed that both 7-year-olds and adults showed a memory advantage for both featural and configural versions compared with original faces. These results suggest that distinctive second-order relational information facilitated memory performance in all age groups, suggesting that all age groups were encoding second-order relational information.

The third problem associated with Carey and Diamond's theory is that the face processing mechanism has been shown to develop continuously over a protracted time course, and is not fully developed until late adolescence. For example, Donnelly and Hadwin (Experiment 2, 2003) presented children aged 6, 8, 10, 12-years and adults with pairs of monochrome faces. Monochrome faces are constructed from only black and white. In their experiment, one face was always a 'normal' face and the other face was a 'Thatcherised' version (see Figure 1) of the same face. Donnelly and Hadwin (2003) asked participants to decide which of the two faces was 'odd'. When faces were upright, accuracy to detect the 'Thatcherised' face rose from approximately 53% for 6-year-olds to approximately 95% for adults. Interestingly, even 12-year-olds were not as sensitive at detecting 'Thatcherised' faces as adults (adults achieved approximately 95% correct whereas 12-year-olds achieved approximately 87% correct). The explanation offered for this result was that the identification of 'Thatcherised' faces required participants to detect the disruptions in the second-order relational information made by 'Thatcherisation'. With development, participants were better able to detect these disruptions because second-order relational information was encoded more efficiently.

There are a number of other studies which have shown that the ability to encode second-order relations is not mature by 10-years. Mondloch et al. (2002) asked participants to perform a 'same'/'different' task using three sets of faces: a featural set, in which the shape of the features was manipulated, a spacing set, in which the distance between the eyes and the mouth was manipulated, and an external contour set, in which the external contour of the face was manipulated. Participants were presented with a single face for 200 ms. After the face disappeared, a test face was shown for 300 ms. The first face was always an original face and the second face was either the 'same', or was a face from the featural, spacing or external contour set. Face type was separated by block so that all participants completed three blocks. Participants signalled their choice of 'same' or 'different' using a joy-stick. Children aged 6 and 8-years were significantly less accurate than adults when responding to featural manipulations, but there was no difference between children aged 10-years and adults. In contrast, children of all ages performed significantly less accurately than adults when responding to spacing manipulations. The authors argued that although featural processing was mature by 10-years, second-order relational processing developed over a more protracted time course and was not fully developed until sometime after 10-years.

Electrophysiological experiments have also highlighted that the face processing mechanism develops continuously over a protracted time course. FMRI experiments have highlighted that development differences in fusiform (an area associated with face processing, McCarthy, Puce, Gore & Allison, 1997) activity exist between children over 10-years and adults (Passarotti et al., 2003; Aylward et al., 2005). For example, Passarotti et al. (2003) asked participants to perform a face matching task. Participants were presented with a target face for 500 ms, 250 ms later two distractors were presented and participants were asked to decide which of the distractors matched the target. Results showed that although the overall amount of right fusiform activity did not differ between adults and children, but adults exhibited more extended medial than lateral fusiform activation, whereas children exhibited equal medial and lateral activation. The finding, that children display more distributed activation for face processing tasks at age 10 to 12-years compared with adults suggests that face processing is still undergoing development beyond this age.

ERP experiments have also shown that the development of face processing is not mature by 10-years (e.g. Taylor, McCarthy, Saliba & Degiovanni, 1999; Itier & Taylor, 2004). For example, Itier and Taylor (2004) presented participants aged 8 to 9, 10 to 11, 12 to 13 and 14 to 16-years with blocks of upright, inverted and contrast-reversed faces (contrast-reversed faces have luminance values reversed so black appears white and white appears black). Participants were instructed to respond as soon as they saw the 'same' face presented in succession. Interestingly, the results showed that latency (the time from the onset of the stimulus to the neuronal response) of the N170 (a component thought to be associated with configural processing, Itier & Taylor, 2004) decreased sharply between 8-9-years and 10-11-years but it continued to decrease steadily until 14-16-years. Similarly, the amplitude (the level of neuronal activation) of the N170 increased until at least 14-16-years. These results indicate that differences in face processing can be found between adults and 14-16-year-olds, suggesting that face processing continues to develop well beyond 10-years.

Although research suggests a general improvement in the efficiency of second-order relational processing between young childhood and late adolescence, some research suggests that there may be a dip or a plateau in the increase in efficiency around 10-12-years (e.g. Carey, Diamond & Woods, 1980; Flin, 1980; Flin, 1985). For example, Flin (1985) presented participants aged 7, 10, 11, 12, 13 and 16-years with a set of 10 faces. Each face was presented for 8 seconds. After participants had been shown all 10 faces they were asked to perform an 'old'/'new' recognition test. The results showed that sensitivity to discriminate between 'old' and 'new' faces increased with age, except for a dip in sensitivity between 10 and 12-years. Carey (1981) noted that many children move from relatively small primary schools to larger secondary schools around 10 and 12-years and that the dip in the efficiency of face processing may be caused because children need to encode many new faces. This requirement means that children develop a compensatory strategy of using superficial properties to encode faces, resulting in poorer performance in face processing tasks.

In sum, research does not support the idea of a qualitative switch between featural and configural (second-order relational) processing at 10-years. Instead, except for a possible dip in late childhood, research suggests that the ability to process a face using second-order relational processing increases in efficiency across childhood and into late adolescence.

The spatial and temporal development of second-order relational processing

To date, there has been no investigation into whether children process second-order relations globally or locally. It may be that the spatial scale over which second-order relations are computed decreases with development. Decreasing the spatial scale of second-order relational processing may allow relations to be computed more accurately.

There has been no investigation into whether children compare differences between faces in serial or parallel and using a self-terminating or exhaustive stopping rule. Research suggesting that children are less efficient (i.e. slower and less accurate) at second-order relational processing may indicate that they have less capacity to process second-order relations, which may mean that they have to process second-order relations serially. Reduced efficiency may also mean that children use a more conservative rule to determine the time point at which to terminate their search (i.e. they may use an exhaustive rather than self-terminating stopping rule). In other words, children may choose to accrue the maximum amount of information possible before they generate their response. If children do adopt a more conservative criterion to determine the time point at which to terminate their search they may also adopt a more conservative response criterion to determine the response that they generate. In particular, given that children are less efficient than adults at processing second-order relations, they may have a greater degree of uncertainty about whether activation entering the face processing system represents an actual characteristic of the stimulus, or whether it simply represents noise in the system. Younger participants may react to this uncertainty by setting a more conservative response criterion in order to minimise the likelihood of generating a false alarm. To date, there has been no previous research of this hypothesis and so empirical investigation is necessary.

Facial stimuli that children process using second-order relational processing

Previous research has shown that infants (children under the age of 1-year) are capable of responding to a wide range of facial stimuli, and that the range of stimuli which can be processed using second-order relational information decreases with development (e.g. Kelly, Quinn, Slater, Lee, Ge & Pascalis, 2007; Kelly et al., 2005; Quinn, Yahr, Kuhn, Slater & Pascalis, 2002; Nelson, 2001). For example, Pascalis de Hann & Nelson (2002) showed that 6-month-olds were able to discriminate between human and monkey faces with equal sensitivity. In contrast, 9-month-olds were able to discriminate between different human faces, but were unable to discriminate between different monkey faces. Pascalis et al. (2002) argue that the neural mechanisms that are responsible for processing faces become more specialised at processing the types of faces that individuals experience in the environment. Increasing specialisation means that individuals are able to process faces that are experienced frequently in the environment with high efficiency, but lose the ability to use second-order relational processing to process faces that are not experienced very frequently.

Much of the research investigating the range of facial stimuli that can be processed using second-order relational processing has been conducted with infants. It may be that the face processing mechanism continues to narrow (i.e. the range of facial stimuli that can be processed using second-order relational processing becomes smaller) with development. Only two studies have examined whether the face processing mechanism continues to narrow in later childhood and adolescence. Both of these studies have investigated the range of orientations across which faces can be processed using second-order relational processing. Given that individuals experience many more faces that are oriented close to upright compared with faces oriented close to inverted it seems sensible to suggest that the face processing system would narrow to focus on upright faces. In the first of these studies, Lewis (2003) presented participants aged between 6 and 75-years with an inverted 'Thatcherised' face (see Figure 1) and asked them to rotate the face until they noticed that the face was 'odd'. The results were analysed in terms of the orientation that participants reported the switch occurring from 'normal' to 'odd'. The results showed no evidence of a developmental difference in the orientation at which the face appeared 'odd'. A 95% confidence interval for the angle at which the switch from 'normal' to 'odd' occurred was 65.1 to 80.2 degrees for children under 10-years and was 63.3 to 79.5 degrees for participants over 10-years suggesting that there is no developmental differences in the range of stimuli that can be processed using second-order relational processing. Failure to find evidence of developmental differences may however have been caused by Lewis's use of a famous face. The use of a famous face (Gareth Gates, a popular singer) may have proved problematic given that the face may have been differentially familiar for adults and children. Specifically, Gareth Gates may have been more familiar to younger participants than older participants. Although young children may not be as efficient at processing second-order relations as adults when faces are unfamiliar, they may be equally as efficient as adults at processing second-order relations when faces are familiar (Carey & Diamond, 1977). The use of a familiar face may, therefore, account for why Lewis (2003) failed to find any effect of development. Secondly, although a broad range of ages were recruited, there were only 12 participants aged between 10 and 20-years, which may have limited the power of the experiment.

The second experiment to examine developmental differences in the effect of orientation on face processing was conducted by Donnelly, Hadwin, Cave & Stevenage (2003). They presented participants aged 6-10-years and adults with a series of pairs of overlapping faces. One face was always anchored upright whilst the other was oriented 45, 90, 135, and 180 degrees. Participants were asked to select the face that dominated the composite image. In adult participants, the selection of the oriented face declined between 45 and 135 degrees. The authors argued that the decline occurred because the oriented face was being signalled less and less strongly than the upright face as it was not being processed configurally (i.e. using second-order relational processing). In contrast, children experienced a decline in the selection of the oriented face between 45 and 90 degrees but not between 90 and 135 degrees, suggesting that there is some developmental change in the range of orientations across which the oriented face could be processed configurally. However, given that a limited number of orientations (only 4 orientations were used) were used in this experiment further research is required. It may be that the range of orientations that can be processed using second-order relational processing continues to decrease across development so that resources can be 're-tuned' towards processing upright faces. This 're-tuning' towards upright faces may facilitate the decrease in the spatial scale and time course of second-order relational processing.

Thesis aims and objectives

It is currently unclear as to whether changes in the spatial scale, time course and orientation range of second-order relational processing underpin the increase in the efficiency of second-order relational processing that is seen across development. In adult participants, there is a lack of clarity regarding the strength of evidence used to support both local-configural and global-configural accounts of face processing. Similarly, there is also a lack of clarity regarding the time course across which adults detect differences between pairs of faces. Given this, it is necessary to conduct further investigation to establish the spatial scale and time course across which adults process second-order relations before considering developmental differences. Chapters 2 and 3 of this thesis will investigate the spatial scale and time course of second-order relational processing in adults and Chapter 4 will investigate whether there is evidence of developmental differences. Finally, research has suggested that adults are not able to process faces at all orientations using second-order relational processing. Rather, they process faces within 90 degrees of upright using second-order relational processing. Little is known about whether the range of orientations that can be processed using second-order relational processing increases or decreases with development and so Chapter 5 will investigate whether there are developmental differences in the range of orientations that can be processed using second-order relational processing.

Many experiments that have previously investigated the spatial scale and time course of second-order relational processing have cited either the phenomenology of a task (e.g. the Thatcher illusion) or differences between conditions (e.g. composite face task). Although this approach can yield interesting results, it is not always possible to be certain that the results reflect the encoding strategy used by the participant. For example, differences between conditions in the composite face task may be subject to differences in response criterion rather than differences in encoding strategy (e.g. Wenger & Ingvalson, 2002, reviewed above). To avoid this potential confound, this thesis will use formal tests to help define the spatial scale across and time course across which second-order relations are processed in adults and in children.

The use of formal tests means that results can be considered on an individual basis as well as at the group level. Examining individual differences is particularly important when considering development. In particular, evidence of individual differences may be useful in helping to understand pervasive developmental disorders such as autism and Asperger Syndrome Disorder (this will be explored in more detail in the General Discussion).

By considering participants on an individual basis it is possible to compare performance across multiple tasks. Where possible, participants recruited for research completed multiple experiments. This allowed performance to be compared across tasks and so facilitated an investigation into whether all abilities develop independently or non-independently. For example, it may be that the sensitivity to second-order relations increases alongside changes in response criterion. Similarly, it might be that the range of stimuli that can be processed using second-order relational processing decreases alongside an increase in sensitivity to second-order relations. In this thesis it will be argued that, where possible, development might be understood as a point moving through a multi-dimensional space, with the dimensions of 1) sensitivity to second-order relations 2) response criterion and 3) the range of orientation over which second-order relations can be processed. It is the confirmation of the validity of the multi-dimensional space as a descriptive framework for locating mechanisms responsible for encoding faces, and the tracking of the developmental shift through the space, that form one of the key objectives for the thesis.

Chapter 2

Boutsen and Humphreys (2003) have proposed two alternative forms of second-order relational processing, which differ in the spatial extent over which second-order relations are processed. They defined local-configural processing as being the encoding of second-order relations locally around each feature (for example, the distance between the eyes) and global-configural processing as being the processing of second-order relations more globally across the face (for example, the distance between the eyes and the mouth). More specifically, local-configural processing involves the encoding of face-parts and their spatial relations independently of the face context and other features, whereas global-configural processing involves encoding the face-parts and their spatial relations either within the face context or with respect to other features.

Boutsen and Humphreys (2003) conducted a series of experiments using the Thatcher illusion to explore whether the face inversion effect, a marker for second-order relational processing, is driven by impairment in the processing of global or local-configural relations. In the Thatcher illusion, the eyes and the mouth are inverted and then returned to the context of the face. When the face is upright it appears grotesque, however, when the face is inverted perceived grotesqueness disappears (Bartlett & Searcy, 1993, see Figure 1). The Thatcher illusion arises because the manipulations that are made alter second-order relations. These manipulations are apparent when the face is upright because participants process second-order relations. However, participants do not process second-order relations when the face is inverted and so the manipulations are less apparent (Young et al., 1987; Bartlett & Searcy, 1993; Rhodes et.al., 1993). In their study, Boutsen and Humphreys (2003) showed that the face inversion effect was underpinned by an inability to process local-configural relations when faces were inverted (see p.17 for a full description of the study). However, as noted on p.18, Boutsen and Humphreys' (2003) study is open to challenge. In particular, the authors masked their faces to create face parts rather than presenting parts of the faces separately. Consequently, the eyes and the mouth remained in a naturalistic position relative to one another and so participants may have been able to use amodal completion (Kanizsa, 1979) and compute second-order relations across the illusory face. Using masked faces may, therefore, have meant that participants could use global-configural processing in both experiments rather than local-configural processing as Boutsen and Humphreys (2003) concluded.

Despite this potential limitation, other researchers have reported results that are consistent with the idea that faces are processed using local-configural processing (Macho & Leder, 1998; Leder & Bruce, 2000; Leder at al., 2001). For example, Leder and Bruce (2000, Experiment 4) asked participants to learn names associated with eight schematic faces. Participants were then shown a critical feature in isolation, but with relational information preserved (for example, a pair of eyes were presented in isolation but with the correct distance between them), or the critical feature in a face context (for example, only the eyes were presented within the face context) and were asked to name the face that the feature belonged to. Leder and Bruce (2000) argued that if participants computed second-order relations globally during the task, then the additional information provided when the features were presented in the face-context should facilitate performance. However, the results showed no difference between the isolated-part condition and the whole-face condition, suggesting that the face context was not aiding performance, in turn indicating that participants were identifying features by means of a locally based form of second-order relational processing.

There are, however, several limitations of the paradigm adopted by Leder and Bruce (2000). First, the authors used schematic faces rather than veridical faces. It is possible that participants adopted an atypical encoding strategy (i.e. local-configural processing) because the faces were not sufficiently face-like to activate face-specific mechanisms (Tong, Nakayama, Moscovitch, Weinrib & Kanwisher, 2006; Halgren, Raij, Marinkovic, Jousmaki & Hari, 2000). Second, Leder and Bruce (2000) required participants to make judgements based on individual features. This task may have encouraged local-configural processing. If this was the case, then we cannot be certain that participants adopt local-configural processing rather than global-configural processing in more naturalistic face processing tasks.

Aims and objectives

The research reviewed above, coupled with the research reviewed in Chapter 1, suggests that participants use local-configural processing when processing faces. However, there are a number of limitations associated with these experiments. Similarly, as noted in Chapter 1, there are also limitations associated with a number of experiments which have claimed to demonstrate evidence of global-configural processing (specifically, experiments which have employed Farah's et.al.'s (1998) task and the composite face task, see p.24). In sum, there is a lack of clarity regarding the strength of evidence used to support both local-configural and global-configural accounts of face processing. Given this, it is necessary to conduct further investigation to establish the spatial scale across which adults process second-order relations.

The aim of Experiments 1-4 was to investigate whether any evidence of global-configural processing can be found using a different methodology to those that have previously been used to examine the spatial scale across which second-order relations are computed. Experiments 1-4 employed the Thatcher illusion (Thompson, 1980; see p.17) to investigate the spatial scale of second-order relational processing. The Thatcher illusion was exploited because the phenomenology of the illusion is recognised as being one of the most convincing demonstrations of the orientation specificity of second-order relational processing (M.J. Wenger, personal communication, October 4, 2007). Secondly, the Thatcher illusion exists independently of response criterion (Collishaw & Hole, 2002) and so we can be certain that participants are employing second-order relational processing. By using the Thatcher illusion the likelihood of finding evidence of global-configural processing was maximised. Experiments 1-4 used a formal test of second-order relational processing. Using a formal test means working from a theoretical definition of global-configural processing to the associated behavioural regularities, rather than working from behaviour to theory.

In these experiments, participants were presented with 'normal' and 'Thatcherised' faces that were manipulated either at the eyes, the mouth or both the eyes and the mouth. The spatial scale of second-order relational processing was examined using an approach developed by Wenger and Townsend (2001). According to their approach, if features are processed independently (i.e. using local-configural processing) then RTs in the condition in which both eyes and mouths are manipulated should be as fast, but not faster, than the fastest RTs in the conditions in which either the eyes or the mouth is manipulated. Alternatively, if features are not processed independently, then RTs in the condition in which the eyes and mouths are manipulated should be faster than the fastest RTs in the condition in which either the eyes or the mouth is manipulated.

Wenger and Townsend's (2001) approach supposes that participants hold an internal representation of a face, against which perceptual inputs are matched and classified. When evidence begins to accumulate indicating that a facial feature matches (part of) an internal representation, activation builds in the processing channel specific to that that particular feature. When two features match (part of) an internal representation, activation builds in two processing channels. Consequently, when the face contains two features that match (part of) the representation, the amount of work that might be conducted by the system is greater than when the face only contains one feature that matches (part of) the representation. Wenger and Townsend's (2001) approach to investigating perceptual independence between features, therefore, examines the effect on RT of increasing the workload (the number of features that match part of the representation) that the system has to accomplish.

In Experiments 1-4, workload was manipulated by presenting faces with either one 'Thatcherised' feature (single feature change conditions) or two 'Thatcherised' features (two feature change condition). Following Wenger and Townsend's (2001) approach, it is assumed that in order to categorise a face as a 'Thatcherised' face, the participant must first define an internal representation of a 'Thatcherised' face which contains representations of inverted eyes and inverted mouths. When the eyes match the representation, activation builds in the eye channel. Similarly, when the mouth matches the representation, activation builds in the mouth channel. When both the eyes and mouth match the representation activation builds in both channels.

Increasing the number of 'Thatcherised' features from one to two can result in three possible outcomes. First, a seemingly perverse effect of increasing the number of 'Thatcherised' features is that RTs might actually increase. This would occur if the capacity to process features is 'limited' (Wenger & Townsend, 2001) and evidence begins to accumulate that resources should be split across both eyes and mouths. Furthermore, that processing speed for both features is a function of the resource allocated and that decisions are made on the basis of the evidence in either channel reaching a response threshold.

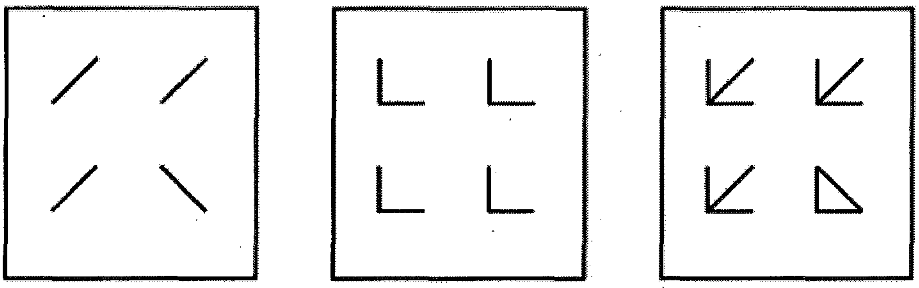
The second possible outcome of increasing the number of 'Thatcherised' features is that RTs might stay the same or decrease so that the fastest RTs in the two feature change condition are equal to the fastest RTs in either single feature change condition. This would occur if capacity is 'unlimited' (Wenger & Townsend, 2001) and decisions are made on the basis of the evidence in either channel reaching a response threshold. An example of this type of processing is the independent channels race model (Raab, 1962). According to a race model, when two features are processed independently, activation builds in both channels until a response threshold or criterion on either channel is reached. The response is driven by the target that causes activation levels to build the fastest. The time to detect the target is not constant across trials and should be considered as a normally distributed random variable. As a result, the time to detect the target will, on average, be shorter when two targets are present compared with when either target is presented by itself.

The third possible outcome of increasing the number of 'Thatcherised' features is that RTs might decrease so that the fastest RTs in the two feature change condition are faster than the fastest RTs in the single feature change conditions. In this case, the system is characterised as exhibiting 'supercapacity' (Wenger & Townsend, 2001). There are at least two alternative forms of processing that can account for RTs in the two feature change condition that are faster than the fastest RTs in either single feature change condition. These are coactive processing (Wenger & Townsend, 2001) and global-configural processing (Cornes, Menneer & Donnelly, 2006).

Coactive processing occurs when activation from two channels is pooled into a common output channel (Wenger & Townsend, 2001). The response is generated when the level of activation in the common output channel reaches a criterion. When activation enters the output channel from two processing channels (eyes and mouths), the level of activation builds faster than if activation entered the output channel from only one processing channel (eyes or mouths). An increase in the speed at which activation builds results in the response criterion being reached faster and so responses are generated earlier.

Global-configural processing occurs when the configuration, or emergent features, between two features are encoded faster than either single feature. In this case, the relationship between the eyes and the mouth is encoded faster than the eyes and mouths themselves. Evidence that configurations are encoded faster than features has previously been demonstrated using the configural superiority effect (Pomerantz, Sager & Stoever, 1977). Pomerantz et al. (1977) showed that the time to identify the location of a negatively sloped target (shown in Figure 2a) was faster when a redundant context (shown in Figure 2b) was added to the display (shown in

Figure 2c). It was argued that the addition of a redundant context created an emergent property, or configuration, in this case closure, which participants encoded faster than the original features.



A B C

Figure 2. Example of the stimuli used by Pomerantz et al. (1977) to show evidence of configural superiority. The location of the 'odd' element is identified faster in panel C than in panel A.

Global-configural processing assumes that there are three activation channels, an eye channel, a mouth channel and a configuration channel. Activation levels build faster in the configuration channel than in either the eye or mouth channel. Consequently, when both eyes and mouths are 'Thatcherised', the level of activation in the configuration channel reaches threshold before the eye or mouth channel and so responses are generated earlier. Global-configural processing is the only form of processing that posits that the configuration between the eyes and the mouth is encoded.

Before it is possible to distinguish between local-configural processing and global or co-active processing it is necessary to confirm the presence of a significant inversion effect. The inversion effect has frequently been cited as evidence for second-order relational processing of faces (see Valentine, 1988 for a review). Researchers claim that the presence of an inversion effect suggests that participants switch between using second-order relational processing for upright faces to using featural processing for inverted faces (e.g. Yin, 1969; Farah, Wilson, Drain & Tanaka, 1998). Second-order relational processing is a more efficient form of processing compared with featural processing and so participants are faster and more accurate at processing upright faces compared with inverted faces. However, by demonstrating inversion effects for faces alone it is difficult to determine whether the inversion effect is caused by a change in processing style or whether the inversion effect is caused by participants mentally rotating a stimulus before processing it in its canonical orientation. One way that researchers have distinguished between these two explanations is by comparing performance on upright and inverted faces to performance on upright and inverted objects (e.g. Yin, 1969). If the inversion effect was caused because participants were mentally rotating the face and not because they were switching processing style then this research should demonstrate a similar cost of inversion for faces and objects. In contrast, research has demonstrated that inversion is more detrimental for face processing compared with object processing. Specifically, there was a cross over interaction between faces and objects suggesting that the face inversion effect is caused by a switch in processing style. In Experiment 1 only faces were employed. However, in Experiment 5 the same face stimuli were employed along with church stimuli and a significant cross over interaction was confirmed. It is, therefore, safe to assume that these stimuli do induce second-order relational processing.

The most important distinction for the current thesis is whether detection of the Thatcher illusion can be accounted for by an independent channels race model. If such a model were to be falsified (i.e. if RTs in the two feature change condition were faster than the fastest RTs in the single feature change conditions) there would be formal evidence to support the view that faces were processed by either a coactive system or one that generated global-configurations across eyes and mouths. If an independent channels race model cannot be falsified, then there would be no evidence of coactive or global-configural processing. If there is no evidence of co-active or global-configural processing then, assuming that participants do demonstrate an inversion effect with the Thatcher illusion, we would have to conclude that the configurations were generated by relatively local processes.

Using formal tests of second-order relational processing to explore the Thatcher illusion

Wenger and Townsend (2001, and also Miller, 1982; Grice, Nullmeyer & Spiker, 1977) have developed formal tests to examine whether the fastest RTs in the two feature change condition are equal to the fastest RTs in the single feature change conditions. These formal tests involve the computation of the capacity coefficient, the Miller inequality and the Grice inequality.

The capacity coefficient (Wenger & Townsend, 2000; also see Cox, 1972)

The capacity coefficient (see Formula 1) is based on the survivor functions for the single feature change conditions and the two feature change condition. The survivor function originates from medical research, where researchers were interested in calculating the probability that the patient would survive longer than a particular time. Imagine a researcher recruited 100 patients with a particular chronic disease at the beginning of an investigation (t(0)). At one month intervals the researcher recorded the number of patients still surviving. Data collection continued until all patients had passed away. To calculate the survivor function, the researcher divided the number of patients still alive each month by 100 (the number of patients at t(0)). For example, if at three months only 35 patients were still alive, then the value of the survivor function at t(3) would be 35/100=0.35. The investigation would continue until all patients had passed away and so the value of the survivor function was 0/100=0. The survivor function monotonically decreases from 1 to 0, with a steep curve representing short survival times and a shallower curve representing longer survival times. The curve represents the probability that the patient would still be alive at a particular time.

Survivor functions can be calculated for RT data by considering the participant's response as being equivalent to the patient's death. By presenting participants with multiple trials it becomes possible to generate a survivor function for each participant, rather than across a group (as is the case when considering patients). The survivor function is calculated from the time at which the stimulus is displayed until the longest RT recorded for each particular participant. For the purposes of RT data, the survivor function represents the probability that a response has not been made by a particular time.

The Hazard function (also known as the conditional probability function or intensity function) can be computed from the survivor function. The hazard function represents the probability of responding in the next instant of time given that the response has not yet been made. It is computed by dividing the probability density function (f(t), the inverse of s(t)), which represents the probability that the response has already been made, by the survivor function (s(t)).

Once the hazard function for each condition has been computed, they are integrated up to the longest RT. Wenger and Townsend (2000) describe the integrated hazard function as a measure of the total amount of work the system has to accomplished up to some point in time. The integrated hazard functions (*H*) are used to compute the capacity coefficient. Specifically, the integrated hazard function for the two feature change condition (also know as the redundant condition (RC) because one additional piece of information is present that is not necessary to complete the task) is divided by the by the sum of the integrated hazard functions for the first single feature change condition (S1) and the second single feature change condition (S2).

$$C(t) = \frac{H_{RC}(t)}{H_{S1}(t) + H_{S2}(t)} \qquad (1)$$

Where $H_{RC}(t)$ is the integrated hazard function for the two feature change condition,
$H_{S1}(t)$ is the integrated hazard function for the first single feature change condition,
$H_{S2}(t)$ is the integrated hazard function for the second single feature change condition.

If H_{RC} (t) is equal to H_{S1} (t) + H_{S2} (t) then the value of the capacity coefficient will equal 1 and the system can be classified as having unlimited capacity. In this case, the system has as much capacity for processing two co-occurring 'Thatcherised' features as it does for processing single 'Thatcherised' features. Alternatively, if H_{RC} (t) is less than H_{S1} (t) + H_{S2} (t) then the capacity coefficient will be less than 1 and the system can be classified as having limited capacity. In this case, the system does not have sufficient resources to be able to allocate as much capacity to each 'Thatcherised' feature when they co-occur, compared with when single features are 'Thatcherised'. Finally, if H_{RC} (t) is greater than H_{S1} (t) + H_{S2} (t) the value of the capacity coefficient will be greater than 1, and the system can be classified as having supercapacity. In this case, presenting two 'Thatcherised' features simultaneously reduces RT so that the fastest RTs in the two feature change condition are faster than the fastest RTs in either single feature change condition.

The Miller inequality (Miller, 1982)

The Miller inequality (see Formula 2) is computed by subtracting the survivor functions for both single feature change conditions from the survivor function for the two feature change condition and adding 1.

$$S_{RC}(t) - S_{S1}(t) - S_{S2}(t) + 1 \qquad (2)$$

Where $S_{RC}(t)$ is the survivor function for the two feature change condition,
$S_{S1}(t)$ is the survivor function for the first single feature change condition,
$S_{S2}(t)$ is the survivor function for the second single feature change condition.

If the system has as much capacity for processing two 'Thatcherised' features as it does for processing one 'Thatcherised' feature, the values of the survivor function for all three conditions would be equal. In this case, the value of the Miller inequality would be greater than 0. If, however, the system has more capacity for processing two 'Thatcherised' features compared to one 'Thatcherised' feature then the value of the survivor function for the two feature change condition would be less than the values of the survivor functions for the single feature change trials. In this case, the value of the Miller inequality would be less than 0. A violation of the Miller inequality (indicated by a value less than 0), therefore, suggests that the system has more capacity to process two co-occurring features compared with when they occur separately. The Miller inequality is cumulative over time (i.e. the values of the Miller inequality increase across time) and so it tends towards 1. Therefore, violations of the Miller inequality will only occur at the start of the processing distribution.

The Miller inequality is consistent with the capacity coefficient; if there is a violation of the Miller inequality then the capacity coefficient will be greater than 1. However, unlike the capacity coefficient, the Miller inequality allows detection of very fast responses in the two feature change condition. The capacity coefficient can only be computed when $H_{S1}(t) + H_{S2}(t)$ is not equal to 0. If $H_{S1}(t) + H_{S2}(t)$ did equal 0 the equation would produce a divide by 0 error. The capacity coefficient can, therefore, only be computed once the participant has made responses in one of the two single feature change trials which means that it might be insensitive to very fast responses in the two feature change condition.

The Grice inequality (Grice et al., 1977)

The Grice inequality (see Formula 3) is computed by subtracting the survivor function for the two feature change condition from either the survivor function of the first single feature change condition or the second single feature change condition, depending on which value is the lowest. It is violated by a value of less than 0.

$$\text{Min}\ [S_{S1}\ (t),\ S_{S2}\ (t)] - S_{RC}\ (t) \qquad (3)$$

Where $S_{RC}(t)$ is the survivor function for the two feature change condition,
$S_{S1}(t)$ is the survivor function for the first single feature change condition,
$S_{S2}(t)$ is the survivor function for the second single feature change condition.

If the survivor function for either of the single feature change trials is lower than the survivor function for the two feature change condition (i.e RTs are faster in either single feature change condition compared with the two feature change condition) then the Grice inequality would be violated. The Grice inequality is, therefore, violated by a value of less than 0. The Grice inequality, therefore, highlights evidence of limited capacity.

The Grice inequality is a more stringent test of limited capacity than the capacity coefficient and so is a useful addition to it. It examines the survivor function of the two feature change condition relative to the survivor function of the fastest single feature change condition. In contrast, the capacity coefficient examines the survivor function of the two feature change condition relative to the sum of the survivor functions for the two single feature change conditions. The Grice inequality is not, therefore, subject to averaging artefacts (which might occur using the capacity coefficient if one single feature change condition was relatively fast and the other relatively slow).

Importantly, the capacity coefficient, Miller inequality and Grice inequality are computed across the whole processing distribution, i.e. from the fastest RT to the slowest RT. The capacity coefficient may, therefore, be above 1 at all time points or only at some time points. Equally, there may be evidence of a violation of the Grice inequality at all time points or only at some time points. Given that the Miller inequality is cumulative over time, it is likely that there will only ever be evidence of a violation of the Miller inequality at early time points.

Summary and inferences

The capacity coefficient and Miller and Grice inequalities test how much faster performance is in the two feature change condition compared with the single feature change conditions. If the capacity coefficient is above 1 and/or the value of the Miller inequality is less than 0, then there is evidence of supercapacity. Supercapacity indicates that RTs in the two feature change condition are faster than the fastest RTs in the single feature change conditions. Evidence of supercapacity would, therefore, provide support for either coactive (Townsend & Nozawa, 1995) or global-configural processing (Cornes et al., 2006). Further research would be required in order to differentiate between these models in order to reach conclusions regarding whether perception of the Thatcher illusion was facilitated by local or global-configural processing. Alternatively, if the capacity coefficient is below 1 and there is no violation of the Miller inequality then there is evidence of unlimited capacity. Unlimited capacity means that RTs in the two feature change condition were only as fast as the fastest RTs in the single feature change conditions. Finally, if the value of the Grice inequality is less than 0 then there is evidence of limited capacity processing. Limited capacity indicates that RTs in the two feature change condition were slower than the fastest RTs in the single feature change conditions. In this case, the independent channels model could not be falsified. So far as participants are faster and more accurate with upright than inverted faces then evidence of unlimited or limited capacity would be consistent with local-configural processing.

Experiment 1

The aim of Experiment 1 was to measure the value of the capacity coefficient, Miller and Grice inequalities when participants performed a sequential 'same'/'different' task with 'normal' and 'Thatcherised' faces. Participants were presented with two successive faces and were asked to decide whether they were the 'same' or 'different'.

When participants inspect faces freely they typically make eye movements across the face (Althoff & Cohen, 1999; Henderson, Williams & Falk, 2005). Participants make these eye movements so that detailed information from all parts of the face can be encoded with high acuity (Henderson et al. 2005). However, if participants were required to make eye movements to accrue information about the face in Experiment 1, information about the eyes and mouth would enter the face processing system at different times. If faces are typically processed using global-configural processing, then processing may be impaired if the experiment alters the time at which information enters the system relative to naturalistic processing. Three highly conservative measures were employed in Experiment 1 to minimise differences in the temporal acquisition of information. First, stimuli were presented at a visual angle of less than 2 degrees to allow participants to perceive the whole image with high acuity within one fixation. Second, stimuli were presented at 150 ms to minimise the likelihood of participants making eye movements. Finally, eye movements were monitored throughout the experiment. All trials in which participants made eye movements were later excluded from data analysis.

Method

Participants

Fifteen postgraduates and undergraduate students from the School of Psychology at the University of Southampton participated in Experiment 1. Undergraduates participated in return for course credits. Three participants were excluded as overall error rates across the whole experiment were greater than 25% (Townsend & Wenger, 2004, reported that simulations showed the capacity coefficient to be reliable until the participant exceeded a threshold of 25% errors). The mean age of the 12 remaining participants was 26.2 years (SD=6.6 years). Eight participants were male, all were right handed and all had normal or corrected to normal vision.

Apparatus and Stimuli

Stimuli were displayed and responses (eye movements, 'same'/'different' choice and RT) were recorded using a SR Research EyeLink 1000 eye tracker and associated software. Viewing was binocular, although only recordings of the movements of the right eye were taken. The position of the eye was recorded every millisecond. Stimuli were presented on a 24 inch screen with a refresh rate of 60 hertz and a resolution of 1280 by 1024 pixels. Participants sat 57 cm from the screen and were asked to lean on a chin and forehead rest during the experiment to minimise head movements. Responses were made using a button box.

Sixteen grey scale female faces were obtained from the Stirling Picture Database. These 16 faces were used to create four sets of stimuli: a 'normal' set; a set which had the eyes manipulated; a set which had the mouth manipulated and a set which had both the eyes and mouth manipulated, creating a total of 64 images. Adobe Photoshop was used to cut out the eyes and the mouths of the faces. These were then inverted and pasted back into the face (see Figure 3). Stimuli were 20 mm in height by 15 mm wide corresponding to a visual angle of 2 by 1.5 degrees. The blur tool was used to remove high contrast edges, caused by manipulating the image, which could act as local featural cues. Finally the whole image was blurred using a one pixel Gaussian blur.

Figure 3. An example of the four different types of face stimuli used. From left to right, a face with the eyes manipulated, a face with the mouth manipulated, a face with the eyes and the mouth manipulated and a 'normal' face.

Control Tasks

A control task was conducted with the same participants who completed Experiment 1 to ensure that these 'Thatcherised' faces produced the typical face-inversion effect. Evidence of an inversion effect would usually constitute evidence for second-order relational processing (e.g. Bartlett & Searcy, 1993). Evidence of second-order relational processing is necessary before the analysis can be conducted to establish whether second-order relational processing was local or global. Participants (N=12) were simultaneously presented with a 'Thatcherised' face and a 'normal' face and were asked to select the 'Thatcherised' face. The mean RT across 16 trials for the upright faces was 822.2 ms compared with 2427.0 ms for inverted faces and percentage correct was 98.4% for upright faces and 71.9% for inverted faces. Both mean RT and percentage correct comparisons were significant ($t(12)=11.64$, $p<.01$ and $t(12)=6.62$, $p<.01$ respectively), indicating that the stimuli showed typical inversion effects. Importantly, all participants showed an increase in

RT and a decrease in accuracy with inversion, suggesting that all participants were employing second-order relational processing (Bartlett & Searcy, 1993).

A second control task was conducted with the same group of participants to ensure that manipulations made to the eyes and the mouth were equally discriminable. Independent processing could be promoted under conditions when the manipulation made to one feature was more difficult to detect than the manipulation made to the second feature. In the second control task, participants (N=12) were presented with isolated features corresponding to the manipulated and non-manipulated regions of the face (see Figure 4). Each feature was paired either with itself ('same' trial) or with the inverted version of itself ('different' trial). Participants were asked to perform a 2AFC 'same'/'different' task. There was no difference between eyes and mouths in terms of RT or accuracy ($t(11)<1$ and $t(11)=1.3$ respectively), suggesting that eyes and mouths were matched for discriminability.

Figure 4. Examples of the stimuli shown in the second control task. From left to right, an example of 'normal' eyes, 'odd' eyes, 'normal' mouth and an 'odd' mouth.

Design and Procedure

Each of the 32 faces was paired with all other versions of the same face (the 'normal' version of each face was paired with the face with the eyes manipulated, with the face with the mouth manipulated and with the face with the eyes and mouth manipulated) creating a total of 96 pairs of faces. Each pair was presented to participants twice, with each member of the pair appearing once as the first face and once as the second face. The presentation of each face was pseudo-randomised. Half of the trials consisted of 'same' pairs and half of 'different' pairs equating to a total of 384 trials. The order of 'same'/'different' trials was pseudo-randomised, as was the order of eye, mouth and two feature change trials.

Participants sat in front of a screen in a dimly lit quiet room. They were informed of how the faces had been manipulated and were shown an example of the four stimulus types. Participants were instructed to decide whether the two faces were the 'same' or 'different' and to respond using the corresponding button on a control box. Response buttons were counterbalanced between participants. Participants were asked to minimise errors whilst responding as quickly as possible. They were given a practice session of 15 trials, the data from which were not included in the analysis.

The eye tracker was calibrated whilst participants were asked to look at nine fixation points displayed across the full screen. The calibration was checked for accuracy. If mean error rate was less than 0.30 degrees then the practice trials were displayed. If mean error rate was greater than 0.30 degrees then the calibration was repeated. Following each trial the calibration was checked for accuracy and calibration was repeated when required.

After calibration, participants were presented with a fixation cross in the centre of the screen. The experimenter manually initiated each trial when the participant was looking at the fixation cross. After the fixation cross disappeared the first face was presented for 500 ms. The face was then replaced with a black screen for 300 ms. The second face was presented for 150 ms. After the second face disappeared four question marks were displayed, these were present until the response was made. Participants completed a practice session of 16 trials. The second face in the practice sessions was presented for 250 ms to allow participants to become accustomed to the task.

Results

Before analyses were conducted at the level of the survivor function, it was necessary to investigate whether there was evidence of a redundancy gain (faster performance at the level of the mean in the two feature change condition than in either the eye or mouth condition). All three forms of processing (independent, co-active and global-configural) can account for a redundancy gain; however, the absence of a redundancy gain would immediately rule out coactive and global-configural processing as both forms of processing can predict faster RTs in the two feature change condition relative to the single feature change condition.

Redundancy gain at the level of the mean

RTs were computed for correct responses using the harmonic mean ($1/\mu_h = \sum I$ ($1/t_i$)) to minimise the influence of outliers (Ratcliff, 1993). The error data were transformed according to the formula DV= LOG(X/(100-X)), where DV= dependant variable and X= percentage error. This transformation was required for two reasons. First, the data was right skewed and second, percentage error is bounded between 0 and 100. As ceiling scores would generate a division by zero error, all scores of 0 were replaced with 0.1.

RTs and error rates were compared separately in a repeated measures ANOVA. The data is shown in Figure 5. The main effect of condition was significant for RTs ($F(2, 22)=3.75, p<.05$) and error rates ($F(2, 22)=15.50, p<.01$). For RTs, participants were significantly faster in the two feature change condition compared with the mouth condition ($t(11)=2.30, p<.05$). The difference between the two feature change condition and the eye condition approached significance ($t(11)=2.16, p=.07$). There was no difference between the eye and mouth conditions ($t(11)=1.18$). For error rates, participants were significantly more accurate in the two feature change condition compared with the eye or mouth conditions ($t(11)=4.23, p<.01$ and $t(11)=4.28, p<.01$ respectively). There was no difference between the eye and mouth conditions ($t(11)<1$).

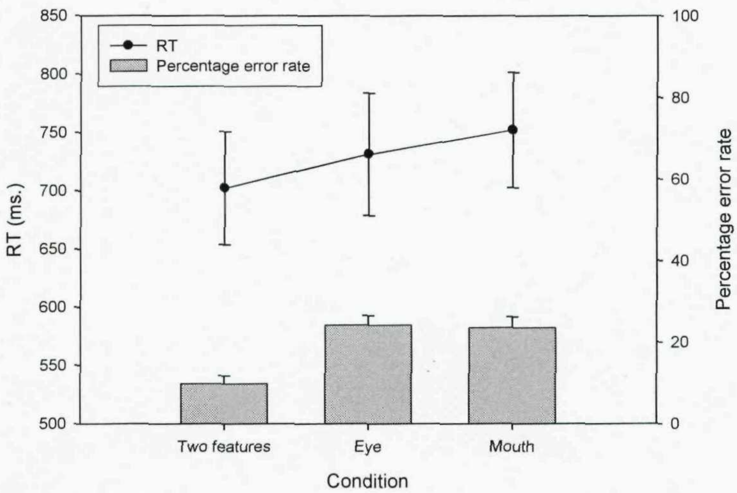


Figure 5. Mean reaction time and percentage error in all conditions with standard errors.

A redundancy gain was found, confirming that it is necessary to conduct analyses at the level of the survivor function to differentiate between independent and coactive/global-configural processing.

Computing survivor (and hazard) functions

Analysis of the values of the capacity coefficient, the values of the Miller inequality and the values of the Grice inequality requires the calculation of survivor functions. The tests, defined by Wenger and Townsend (2001), require that survivor functions are calculated for 'different' trials only. This is because data from 'same' trials do not involve a change in workload (defined as the number of 'Thatcherised' features between stimuli), which is required for these analyses. All 'same' trials were, therefore, excluded from further data analysis. In addition, seven trials across all participants were excluded because the participant fixated more than once on the second face. These were 2 two feature change trials, 3 eye change trials and 2 mouth change trials.

Survivor functions for the eye, mouth and two feature change conditions were computed separately for each participant. This was achieved by plotting RTs in ascending order starting with the fastest RT and finishing with the slowest RT. RTs were plotted against *P* which is the proportion of remaining trials using Formula 4. Survivor functions were then imported into Sigmaplot and a cubic function was fitted. The coefficients for the fits were extracted and used to generate the values of the survivor function. Values of the survivor function were generated in 10 ms intervals starting with the fastest RT and finishing with the longest RT. The survivor functions were also used to calculate integrated Hazard functions H(t) using the formula H(t)=-In(S(t)) for each participant. Regression analyses revealed that across all participants and conditions, the cubic function was a good fit to the data; R^2 values ranged from 0.92 to 0.99.

$$P = \frac{-1}{N} \qquad (4)$$

Where N= the total number of correct responses made.

Capacity Coefficient

The capacity coefficient, C(t) was calculated by dividing the integrated hazard function for the two feature change condition by the sum of the integrated hazard functions for the eye and mouth conditions (see Formula 5).

$$C(t) = \frac{H_{E,M}(t)}{H_E(t) + H_M(t)} \qquad (5)$$

Where $H_{E,M}(t)$ is the integrated hazard function for the two feature change condition,
$H_E(t)$ is the integrated hazard function for the eye condition,
$H_M(t)$ is the integrated hazard function for the mouth condition.

The Miller inequality

The Miller inequality was computed by subtracting the survivor function for the eye condition and the survivor function for the mouth condition from the survivor function of the two feature change condition and adding 1 (see Formula 6).

$$S_{E,M}(t) - S_E(t) - S_M(t) + 1 \qquad (6)$$

Where $S_{E,M}(t)$ is the survivor function for the two feature change condition,
$S_E(t)$ is the survivor function for the eye condition,
$S_M(t)$ is the survivor function for the mouth condition.

The Grice inequality

The Grice inequality was computed by subtracting the survivor function of the two feature change condition from either the survivor function of the eye condition or the survivor function of the mouth condition depending on which value is the lowest (see Formula 7).

$$\text{Min}\,[S_E(t), S_M(t)] - S_{E,M}(t) \qquad (7)$$

Where $S_{E,M}(t)$ is the survivor function for the two feature change condition,
$S_E(t)$ is the survivor function for the eye condition,
$S_M(t)$ is the survivor function for the mouth condition.

Data from Experiment 1

The data from Experiment 1 were processed as detailed above and the results are shown in Figure 6. The graphs show the results for all the measures (the values of the capacity coefficient, the Grice inequality and the Miller inequality), for each participant and at all time points. As noted on p.51 the key indicators that define performance are whether the capacity coefficient is above or below 1, and, whether both the Miller and the Grice inequalities are above or below 0. These indicators should be considered for each participant and at all time points.

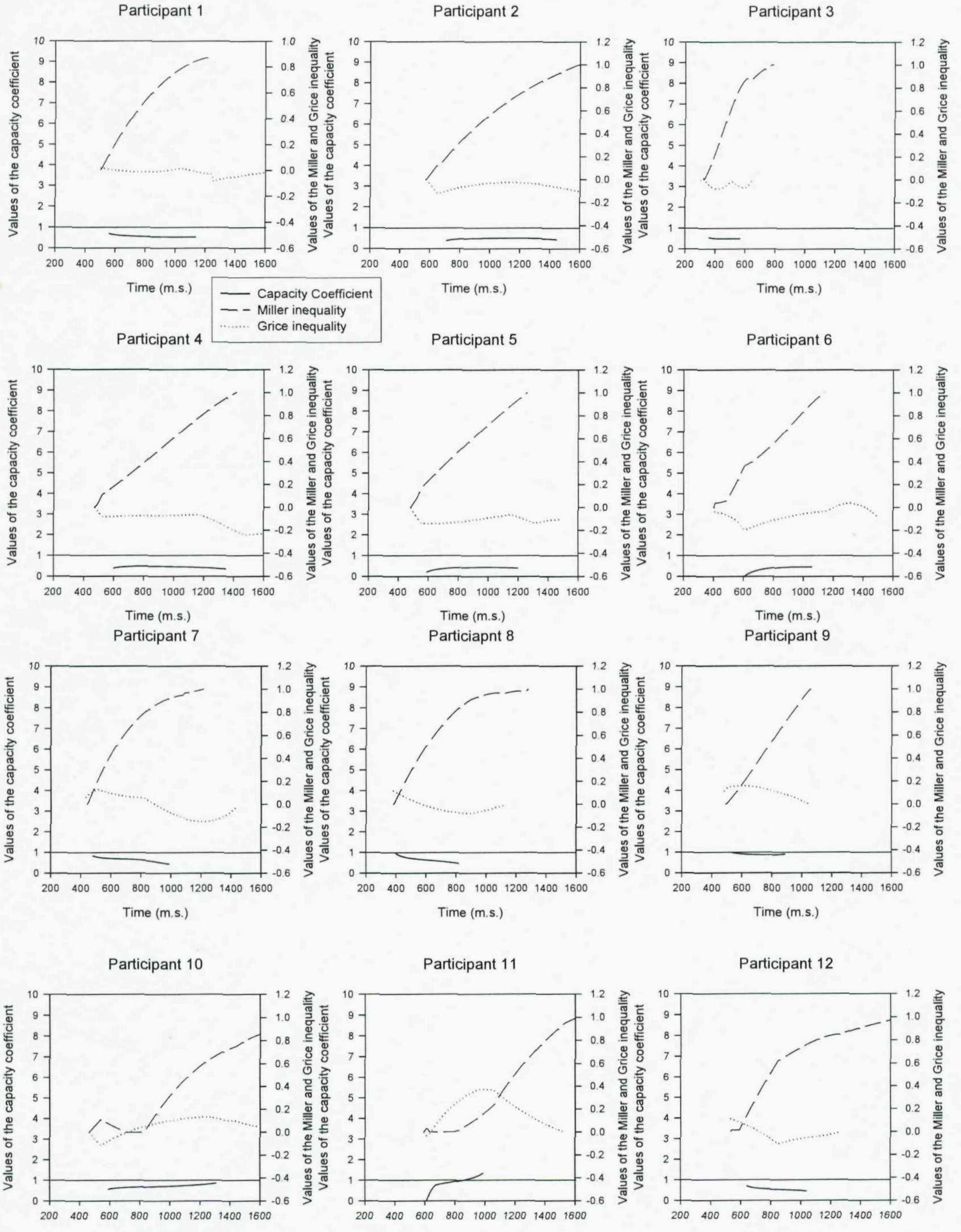


Figure 6. Values of the capacity coefficient, Miller inequality and Grice inequality for all participants. Excursions above the solid reference line for the capacity coefficient is consistent with coactive/global-configural processing. Excursions

below 0 for the Miller inequality is also consistent with coactive/global-configural processing.

Figure 6 demonstrates no violation of the Miller inequality for any participant at any time point. It also highlights evidence of a violation of the Grice inequality at some time points for all participants except participants 9 and 11. In addition, the capacity coefficient was below one for all participants at all time point except for participant 11 where there was evidence that it was above 1 at some time points.

Discussion

Analysis of harmonic mean RTs showed that RTs were faster in the two feature change condition than the single feature change conditions confirming that the participants did produce a redundancy gain in Experiment 1. The analyses of the survivor functions, that were calculated from the same data that showed evidence of a redundancy gain, showed that for 11/12 participants, the redundancy gain could be entirely accounted for by an independent channels, unlimited capacity system (i.e. a race model). This result held at all time points. For one participant, there was some evidence that the capacity coefficient moved above one at some time points, suggesting that for this participant alone there was evidence of either coactive or global-configural processing. For 10/12 participants there was evidence of a violation of the Grice inequality at some time points, indicating that processing capacity was limited at some times. Given that presence of a significant inversion effect with these stimuli (shown in the control experiment) the data for 11/12 participants is consistent with a local-configural account of the Thatcher illusion, at least as represented in Experiment 1.

The fact that one participant did produce some limited evidence of coactive or global-configural processing is interesting. It implies some level of individual difference in how the Thatcher illusion is processed. This issue of individual differences will be returned to in the General Discussion. Before considering the results further it is necessary to investigate whether any aspect of the design of Experiment 1 prevented participants using global-configural processing or promoted the use of local-configural processing. Likely candidates might be the very short exposure duration that was used or the large number of trials that were used to generate the data. In Experiments 2-4 various aspects of the experimental design will be changed to examine whether evidence of global-configural processing can be found.

Experiment 2

Experiment 2 examined the values of the capacity coefficient, Miller inequality and Grice inequality when participants were presented with stimuli for a longer duration. Longer stimulus durations allowed participants to make eye movements and so a less stringent control measure had to be implemented. However, presenting stimuli until a response is made is a more naturalistic task (in everyday life individuals can usually examine a face for as long as they like) and so evidence of global-configural processing may be found.

In Experiment 1 participants were required to judge whether two successive faces were the 'same' or 'different'. In Experiment 2, the use of unlimited exposure durations allowed a simple 'odd' or 'normal' decision to be made in response to single faces.

Method

Participants

Twelve undergraduate students from the School of Psychology at the University of Southampton participated in Experiment 2 in return for course credits. Participants had a mean age of 20.5 years (SD=3.6 years), 2 were male, 10 were right handed, all had normal or corrected to normal vision. None of the participants had participated in Experiment 1.

Apparatus and Stimuli

Stimuli were presented on a Viglen Genuine Intel Contender P3800 computer with a screen size of 15 inches and a refresh rate of 60 hertz. The screen was set to a resolution of 1280 by 1024 pixels. The stimuli were presented and responses (RTs and errors rates) recorded using e-prime software (Psychology Software Tools Inc). Responses were made using the right and left mouse keys. Stimuli were the same as those used in Experiment 1.

Design and Procedure

All details were the same as in Experiment 1 with the following exceptions. Stimuli were presented until a response was made. Participants were asked to decide whether each face was 'odd' or 'normal'. The experiment was divided into 4 blocks. The order of the blocks was counterbalanced between participants. In each block, participants were presented with 32 two feature change trials, 32 eye trials, 32 mouth trials and 96 'normal' trials, equating to 128 two feature change trials, 128 eye trials, 128 mouth trials and 384 'normal' trials across the whole experiment. Each of the 16 faces was presented 12 times in each block, twice each for two feature, eye and mouth trials and 6 times in 'normal' trials.

Participants were given a short self-timed break between each block. Each block contained an equal number of 'odd' and 'normal' trials. The order of 'odd' and 'normal' trials was randomised within each block. Face and manipulation type was also randomised within each block.

Results

In Experiment 1, analyses of mean RTs were presented to show evidence of a redundancy gain. In the remaining experiments in this Chapter these analyses are presented in the appendices. Redundancy gain calculations are done as a precursor to the analyses based on survivor functions and do not form the major focus of this thesis. For note, in this and all subsequent experiments in this Chapter a significant redundancy gain was found (see Appendices A-C).

The capacity coefficient, Miller and Grice inequality were calculated in the same way as in Experiment 1. Figure 7 demonstrates that there was no evidence of a violation of the Miller inequality at any time point for any participant. It also highlights some evidence of a violation of the Grice inequality at some time points in participants 1, 2, 4 and 6. The capacity coefficient was below 1 at all time points for all participants except participants 5 and 12. Participant 12 produced a capacity coefficient that was greater than 1 at some time points. Participant 5 produced a capacity coefficient that was above one across all time points. The data are shown in Figure 7.

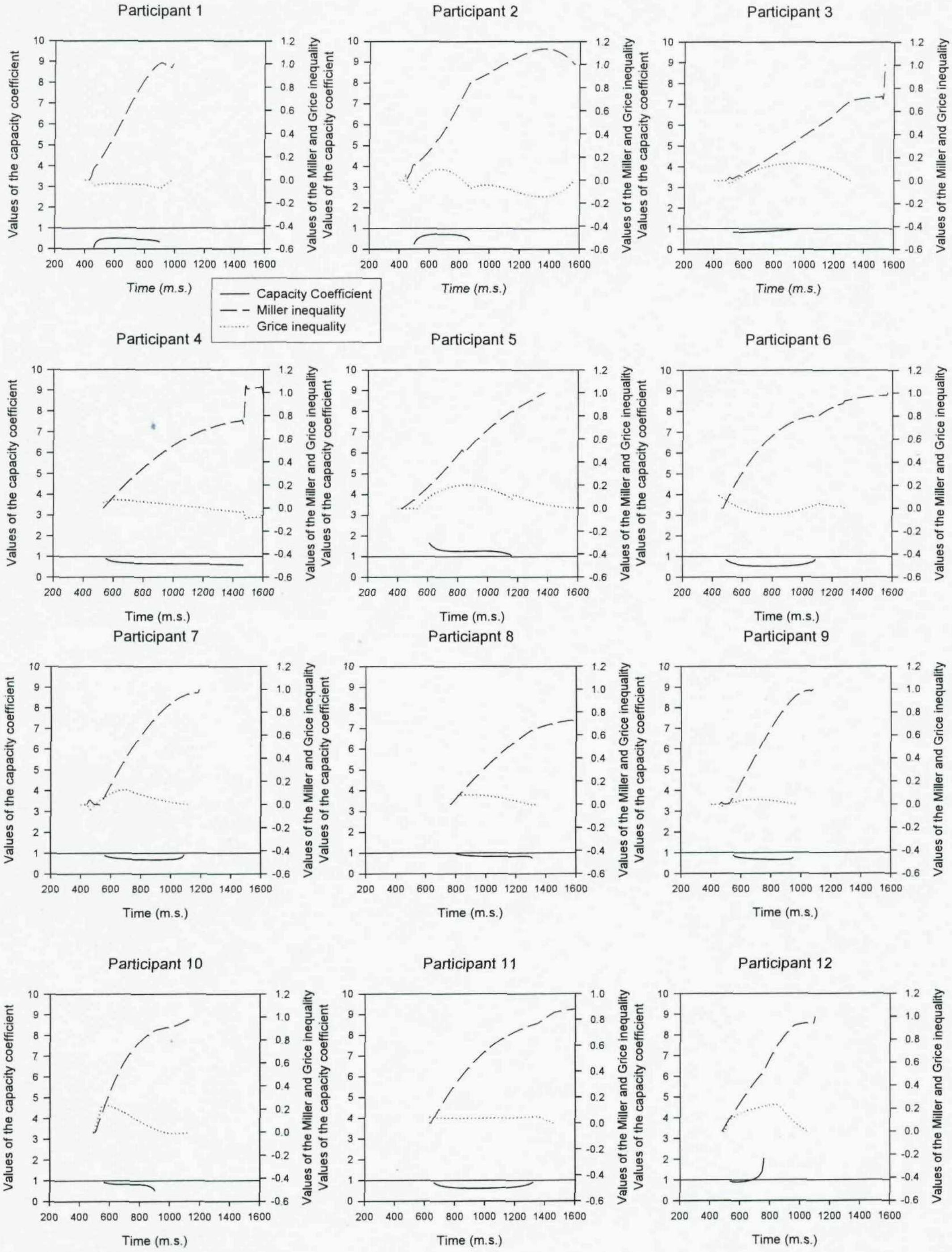


Figure 7. Values of the capacity coefficient, Miller inequality and Grice inequality for all participants. Excursions above the solid reference line for the capacity coefficient is consistent with coactive/global-configural processing. Excursions below 0 for the Miller inequality is also consistent with coactive/global-configural processing.

Discussion

The results of Experiment 2 were consistent with the results of Experiment 1 at the level of the mean and the survivor function. The analyses of the survivor functions, that were calculated from the same data that showed evidence of a redundancy gain, showed that for 10/12 participants, the redundancy gain could be entirely accounted for by an independent channels, unlimited capacity system (i.e. a race model). This result holds at all time points. For two participants, there was some evidence that the capacity coefficient moved above one at some or all time points, suggesting that for these participants alone there was evidence of either coactive or global-configural processing. For 4/12 participants there was evidence of a violation of the Grice inequality at some time points, indicating that processing capacity was limited at some times. Given that presence of a significant inversion effect with these stimuli (shown in the control experiment for Experiment 1) the data for 10/12 participants is consistent with a local-configural account of the Thatcher illusion, indicating that local-configural processing is employed under more naturalistic conditions where participants are allowed to inspect the stimuli freely. However, the results also confirm the presence of individual difference in processing with respect to the Thatcher illusion. This issue will be returned to in the General Discussion.

In Experiment 3, participants were only presented with a small number of trials. One possibility is that the strategic requirements of Experiments 1 and 2 determine a process. This is especially so because of the large number of repetitious trials used in these Experiments. In Experiment 3, the number of trials participants were required to complete was much reduced in order to reduce strategic influences on performance. It was hypothesised that participants would not have sufficient trials to learn that they could complete the task using a less effortful strategy (i.e. local-configural processing) and so the results would represent naturalistic face processing.

Experiment 3

In order to address the possibility that the large number of trials that participants were required to complete meant that participants adopted a less effortful strategy (i.e. local-configural processing), Experiment 2 was repeated, but the number of trials that participants were required to complete was reduced from 768 to 196.

Given that participants completed many fewer trials the results may be less reliable at the individual level. Therefore, to accommodate this approach, data were combined across participants and analysed, rather than analysed at the individual level. Data were combined by vincentizing (Vincent, 1912; Rouder & Speckman, 2004), described below.

Method

Participants

Twelve undergraduate students from the School of Psychology at the University of Southampton participated in Experiment 3 in return for course credits. Participants had a mean age of 22.28 years (SD=5.29 years), 2 were male, all were right handed and all had normal or corrected to normal vision. None had participated in the previous experiments.

Stimuli, Design and Procedure

All apparatus and stimuli were the same as those used in Experiment 2. All details of Experiment 3 were the same as Experiment 2 except participants were only presented with 32 eye, 32 mouth, 32 two feature trials and 96 'normal' trials, resulting in 196 trials across the whole experiment.

Results

At the level of the mean, evidence of a redundancy gain was found (see Appendix B). Analyses were, therefore, conducted at the level of the survivor function as in Experiment 1 but with one important difference. The reduction in the number of trials that were completed in Experiment 3 relative to Experiments 1 and 2 meant that each individual participant's data was relatively noisy. In Experiment 3, the issue of individual data was set aside and a single dataset was generated for the group of participants by Vincentizing the data (Vincent, 1912). The data was Vincentized by calculating 10^{th} quantiles for each participant (quantiles are similar to percentiles but percentiles range from 0 to 100 whereas quantiles range from 0 to 1). The value of each quantile was then averaged across all participants to produce a single composite distribution containing 10 points. The capacity coefficient, Miller and Grice inequality were computed in the same way as in Experiments 1 and 2 using the composite distribution. Values of the capacity coefficient, Miller and Grice inequality are shown in Figure 8.

The results, shown in Figure 8, demonstrated no evidence of a violation of the Miller inequality at any time point. They also highlighted some violations of the Grice inequality at some time points. In addition, the capacity coefficient was below 1 at all time points.

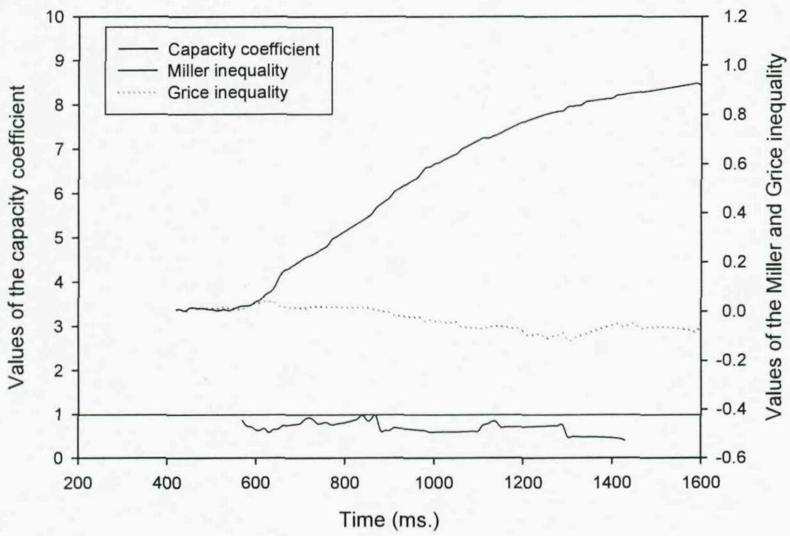


Figure 8. Vincentized values of the capacity coefficient, Miller inequality and Grice inequality for all participants. Excursions above the solid reference line for the capacity coefficient is consistent with coactive/global-configural processing. Excursions below 0 for the Miller inequality is also consistent with coactive/global-configural processing.

Discussion

The results were consistent with the results of Experiments 1 and 2 at both the level of the mean and at the level of the survivor function. The analyses of the survivor functions, that were calculated from the same data that showed evidence of a redundancy gain, showed that the redundancy gain could be entirely accounted for by an independent channels, unlimited capacity system (i.e. a race model). This result holds at all time points. There was evidence of a violation of the Grice inequality at some time points, indicating that processing capacity was limited at some times.

The results of Experiment 3 are consistent with those of Experiments 1 and 2 and suggest that the pattern of results has nothing to do with a strategic response to the task that was driven by the number of trials participants were required to complete. Given that presence of a significant inversion effect with these stimuli (shown in the control experiment) the data are consistent with a local-configural account of the Thatcher illusion.

In Experiment 4 the unlikely possibility that the results of Experiments 1-3 were caused by the need to process single faces was examined.

Experiment 4

In Experiment 4, participants were presented with a simultaneous 2AFC task and were asked to determine whether the 'Thatcherised' face was on the left or the right side of the fixation cross. Exposure duration was unlimited, as in Experiments 2 and 3. Given the failure to find any influence of the number of trials on processing in Experiment 3, Experiment 4 used the same number of trials as in Experiment 1 so that the issue of individual differences could be returned to.

Method

Participants

Twelve postgraduates and undergraduate students from the School of Psychology at the University of Southampton participated in Experiment 4. Undergraduates participated in return for course credits. Participants had a mean age of 36.46 years (SD=11.83 years), five were male, all were right handed and all had normal or corrected to normal vision. No participant had taken part in the previous experiments.

Design and Procedure

All details of Experiment 4 were the same as Experiment 2 with the following exceptions. Participants were simultaneously presented with two faces and were asked to select which of the two faces had been manipulated. The manipulated face was presented equally often on the right and left side of fixation. Each face was presented 24 times, 12 times as a 'normal face', 4 times with the eyes 'Thatcherised', 4 times with the mouth 'Thatcherised' and 4 times with both the eyes and mouth

'Thatcherised'. For each face the position of the manipulated face was counterbalanced.

Participants were instructed to choose which of the two faces had been manipulated and respond using the corresponding mouse button. If the manipulated face was presented on the left side of the fixation cross the participant was asked to press the left mouse button, and if the manipulated face was presented on the right side of the fixation cross the participant was asked to press the right mouse button.

Results

At the level of the mean, evidence of a redundancy gain was found (see Appendix C). Analyses were, therefore, conducted at the level of the survivor function as in Experiments 1-3. Values of the capacity coefficient, Miller and Grice inequality are shown in Figure 9.

Figure 9 demonstrates that there was no evidence of a violation of the Miller inequality at any time point for any participant. It also highlights some evidence of a violation of the Grice inequality at some time points for all participants except participants 5 and 9. The capacity coefficient was below 1 at all time points for all participants except participants 3, 10 and 11. Participant 11 produced a capacity coefficient that was greater than 1 at some time points. Participants 3 and 10 produced a capacity coefficient that was above one across the majority of time points.

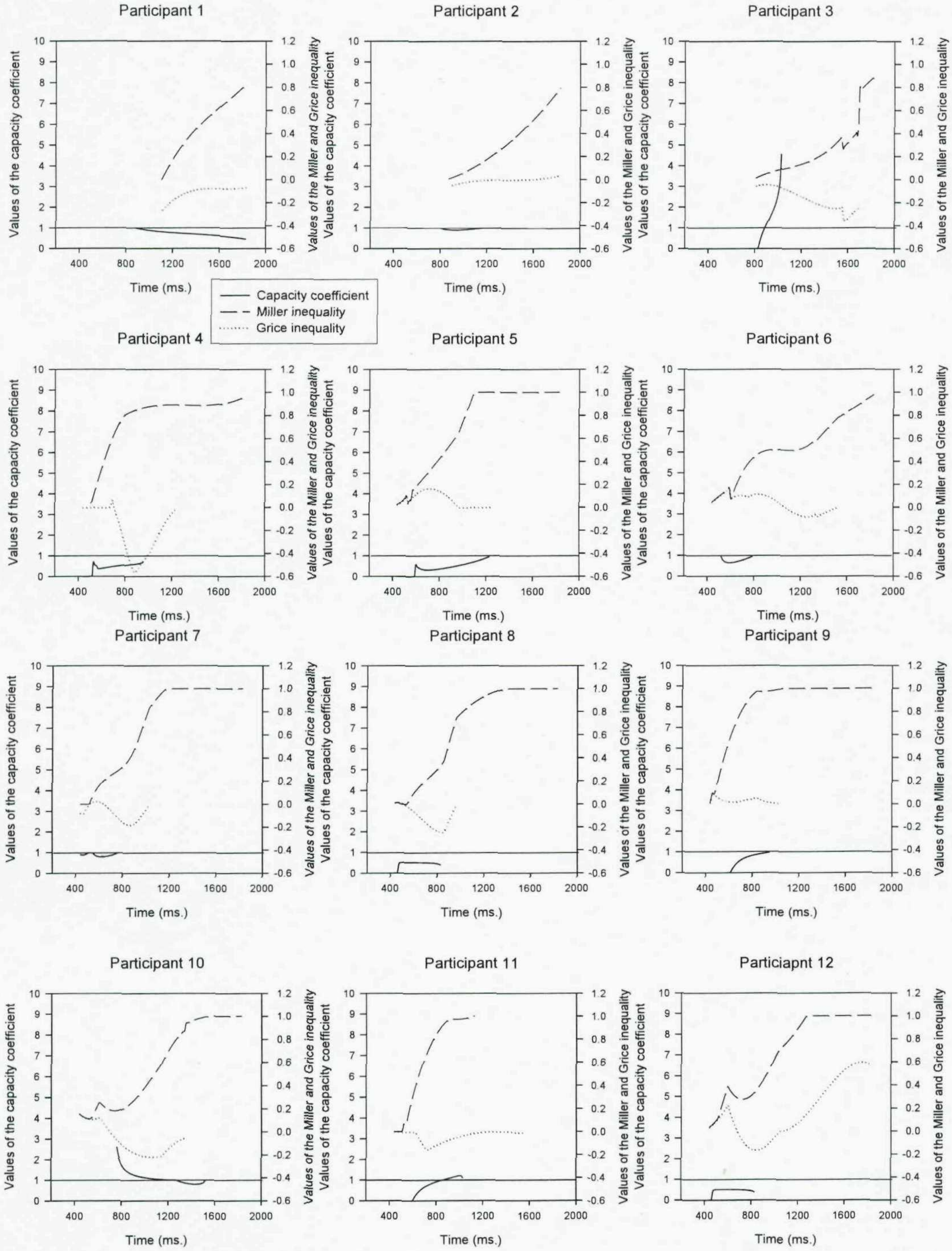


Figure 9. Values of the capacity coefficient, Miller inequality and Grice inequality for all participants. Excursions above the solid reference line for the capacity coefficient is consistent with coactive/global-configural processing. Excursions below 0 for the Miller inequality is also consistent with coactive/global-configural processing.

Discussion

The results have are consistent with the results of Experiments 1-3 at both the level of the mean and at the level of the survivor function. The analyses based on the survivor functions showed that the redundancy gain that Experiment 4 produced could be entirely accounted for by an independent channels, unlimited capacity system (i.e. a race model). There was no evidence found in Experiment 4 to support coactive or global-configural processing and so the results are consistent with local-configural processing. There is no evidence that allowing simultaneous presentation of targets and foils facilitates coactive or global-configural processing.

General Discussion

With a few exceptions, all experiments showed that the capacity coefficient was less than 1 at all time points. In addition, there was no violation of the Miller inequality and some evidence of a violation of the Grice inequality. Importantly, the same results were found when participants were prevented from making eye movements (Experiment 1), when participants were allowed to inspect the stimuli freely (Experiments 2-4), when only a small number of trials were completed (Experiment 3), when participants were asked to decide whether the face was 'odd' or 'normal' (Experiments 1-3) and when participants were asked to select the 'odd' face from a pair of faces (Experiment 4). These results suggest that, for the majority of participants (9-11 at least as measured in Experiments 1 and 2), RTs in the two feature change condition were only as fast, and in some cases slower (given the violations of the Grice inequality in some participants at some time points) as would be predicted based on performance in the single feature change conditions.

The combined results indicate that even when the accepted test of second-order relational processing (i.e. sensitivity to the Thatcher illusion) is passed, there is little evidence to support either coactive or global-configural processing. The only way that these findings can be reconciled is to assume that the majority of participants were processing faces using local-configural processing. The results suggest that the majority of participants compute second-order relations relatively locally around each feature to discriminate between 'odd' and 'normal' faces, and that the processing of these relations is impaired when the face is inverted. This result is consistent with research conducted by Boutsen and Humphreys (2003) and Leder and Bruce (2000).

Before further conclusions can be made it is necessary to consider whether Experiments 1-4 promoted local-configural processing. It may be that using un-natural faces (i.e. 'Thatcherised' faces) disrupted normal processing mechanisms. Boutsen and Humphreys (2003) showed that although performance was better for 'normal' upright faces than 'normal' inverted faces, there was no evidence of an inversion effect (i.e. faster and more accurate performance for upright compared with inverted faces) for 'Thatcherised' faces, suggesting that 'Thatcherised' faces were encoded in a qualitatively different way to 'normal' faces. Boutsen and Humphreys (2003) suggested that 'Thatcherisation' disrupted canonical face processing so that face-specific mechanisms were not employed. Their argument assumes that 'Thatcherisation' alters the face sufficiently so that it becomes so atypical that face detection mechanisms do not activate face-specific processes.

If 'Thatcherised' faces were processed in a qualitatively different way to 'normal' faces because of their atypicality, then one would expect that highly atypical faces would also fail to activate face-specific processes. This might provide a trivial explanation as to why Experiments 1-4 failed to find evidence of co-active or global-configural processing. However, recent research has shown that the magnitude of the inversion effect is the same for typical and atypical faces, suggesting that both typical and atypical faces are processed using second-order relational processing (Stevenage et al., submitted). In addition, it could be hypothesised that if 'Thatcherised' faces were not processed using second-order relational processing then there would be a failure to find evidence of fusiform gyrus activity (the area responsible for face-specific processing, McCarthy et al., 1997) or activation of the neural components known to be involved in face processing (such as the N170, Itier & Taylor, 2004). However, FMRI research has shown that there is no difference in fusiform gyrus activity between 'normal' and 'Thatcherised' faces (Rotshtein, Malach, Hadar, Graif & Hendler, 2001). In contrast, ERP studies that have investigated differences between 'normal' and 'Thatcherised' faces have shown that there are differences in the N170, P1 and P250 components between 'normal' and 'Thatcherised' faces when the faces are upright (Milivojevic, Clapp, Johnson & Corballis, 2003; Carbon, Schweinberger, Kaufmann & Leder, 2005). However, the authors showed that these differences were caused because 'Thatcherised' faces captured attention better than 'normal' faces because of their perceived grotesqueness. Electrophysiological results, therefore, fail to support the idea that

'Thatcherised' faces are processed in a qualitatively different way to 'normal' faces, suggesting that the failure to find evidence of global-configural processing in Experiments 1-4 is unlikely to have been caused because face-specific processes were not being employed. This possibility will, however, be examined further in Chapter 3.

Experiments 1, 2 and 4 showed some evidence of individual differences. One participant in Experiment 1, two participants in Experiment 2 and three participants in Experiment 4 recorded a capacity coefficient that was above 1, suggesting that they were processing faces using either co-active or global-configural processing. These experiments are not the first to show evidence of individual differences in face processing. For example, Schwarzer (2000) asked adults to classify faces that could be classified based on either on their analytic or their featural properties. The results showed that 56% of adults classified faces based on their holistic properties, 29% based on their analytic properties and the final 15 on features, but the feature they based their decisions on was not consistent across the experiment. These results are consistent with the idea that there are individual differences in the way that faces are processed. The results of the present studies suggest that a small minority of people use either co-active or global-configural processing whilst most use local-configural processing.

To summarise, the results of Experiments 1-4 suggest that the majority of participants (in the order of 75% to 83%) consistently use local-configural processing to differentiate between 'normal' and 'Thatcherised' faces. For a relatively few participants, at some time points, there is evidence of either co-active or global-configural processing. The findings exist despite undoubted perception of the Thatcher illusion in this context which is highlighted by the stimuli producing a reliable and significant inversion effect across all participants.

Chapter 3

The experiments reported in Chapter 2 provided no evidence to suggest that participants used co-active or global-configural processing when discriminating between 'normal' and 'Thatcherised' faces. At least as far as the Thatcher illusion is concerned, these data suggest second-order relations are processed locally around the eyes and the mouths and not globally across whole faces. The experiments presented in Chapter 2 do not, however, provide any data that pertain to the question of whether locally-computed second-order relations are processed at the same time or sequentially. This issue can be stated in terms of whether eyes and mouths in 'Thatcherised' faces are processed in serial or parallel. This research question was addressed in the experiments (Experiments 5 and 6) presented in Chapter 3. Experiments 5-6 investigated the time course across which participants detect differences between faces. Additionally, Experiment 6 examined whether participants generate their response as soon as a single difference is detected (i.e. using a self-terminating stopping rule) or whether participants generate their response only after all features have been compared (i.e. using an exhaustive stopping rule).

There has only been a limited amount of previous research which has examined the architecture (serial versus parallel) and stopping rule (self-terminating versus exhaustive) used to compare differences between faces (Bradshaw & Wallace, 1971; Smith & Nielson, 1970; Walker-Smith, 1978). As discussed in Chapter 1, the lack of research on this topic can be accounted for by the support for holistic processing in the literature (e.g. Tanaka & Farah, 1993). Holistic processing necessitates that faces are processed as 'templates' and so all features are processed interdependently, in parallel and under an exhaustive stopping rule (see Farah et al., 1998). Given the apparent support for holistic processing in the literature (e.g. Tanaka & Farah, 1993), researchers had no reason to directly investigate the architecture and stopping rule used to compare faces. However, recent support for local-configural processing, coupled with the results of Chapter 2 suggests that the issues of parallelism in face processing and the stopping rule in face discrimination should be revisited.

The aim of Chapter 3 was to investigate whether differences between faces are processed in parallel or serial and using a self-terminating or exhaustive stopping rule. Experiment 5 explored architecture using a cueing paradigm and Experiment 6 explored both architecture and stopping rule using a formal test. In both experiments, control stimuli were employed to investigate whether there are differences between faces and objects.

Experiment 5

The architecture used to detect differences between pairs of faces was explored in Experiment 5 by examining the effect of manipulating an uncued feature on RT and error rates. Participants were simultaneously presented with pairs of 'Thatcherised' and 'normal' faces and were asked to select the 'odd' face. In the control condition, participants were simultaneously presented with a 'Thatcherised' and 'normal' church and were asked to select the 'odd' church. Churches were selected as control stimuli as they are mono-oriented and have two features (the window and the door) that are easy to invert. Ideally, scrambled faces would be used as control stimuli so differences between conditions can be localised to the configuration of the features, rather than the features themselves (e.g. Easterbrook, Kisilevsky, Hains, & Muir, 1999). However, it was not possible to use scrambled faces in Experiment 5 because participants would not be able to make and 'odd'/'normal' response to a scrambled face, as all scrambled faces would appear 'odd'.

A cue was displayed before each trial informing participants of the feature that had been 'Thatcherised'. Faces were 'Thatcherised' at the eyes (cued-eyes), the mouth (cued-mouth) or both the eyes and the mouth (cued-both). Churches were 'Thatcherised' at the window (cued-window), the door (cued-door) or both the window and the door (cued-both). Two additional conditions were also included. In the first, participants were cued to the eyes (or the window), and both the eyes (window) and the mouth (door) were 'Thatcherised'. This condition was labelled cued-eyes-both (cued-window-both), which is abbreviated to CEB (CWB). In the second, participants were cued to the mouth (door), and both the eyes (window) and the mouth (door) were 'Thatcherised'. This condition was labelled cued-mouth-both (cued-door-both), which is abbreviated to CMB (CDB).

Given that the cued feature was always diagnostic of whether the face/church was 'odd' or 'normal', if participants were detecting differences between faces in serial (i.e. they processed one feature at a time) they would attend to the cued feature and then generate their response (assuming a self-terminating stopping rule). They would, therefore, respond solely on the basis of the cued feature. The uncued feature would never influence performance, and so there should be no difference between the condition in which participants are cued to one feature and one feature is changed, and the condition in which participants are cued to one feature and two features are changed.

Alternatively, if participants detect differences between faces in parallel, they would process both the cued and uncued feature and generate their response as soon as a difference between either feature was detected (assuming a self-terminating stopping rule). Given that processing time is a normally distributed random variable, if two features are manipulated and they are processed in parallel, on some trials the uncued feature would finish being processed before the cued feature and on other trials the cued feature would finish being processed before the uncued feature. On average, RTs will be faster when participants are cued to one feature and two features are manipulated compared with the condition in which participants are cued to one feature and one features is manipulated. In short, if differences between faces are detected in parallel there will be no difference between the CEB and the cued-both conditions or between the CMB and the cued-both conditions. If differences between faces are detected in serial, participants will be slower in the CEB condition than in the cued-both condition and slower in the CMB condition than in the cued-both condition (assuming that eyes and mouths and windows and doors produce similar means and processing distributions).

Method

Participants

Twelve undergraduate students from the School of Psychology at the University of Southampton participated in this study in return for course credits. Participants had a mean age of 24.05 years (SD=5.66 years), 3 were male, all were right handed and all had normal or corrected to normal vision, none had participated in the previous experiments.

Stimuli, Design and Procedure

The same face stimuli were used as in Experiments 1-4. A set of church stimuli were created with inverted windows and/or inverted doors (an example of the stimuli can be seen in Figure 10. All details of Experiment 5 were the same as Experiment 4 (in Chapter 2) with the following exceptions. Before each trial participants were given a cue informing them of which feature had been 'Thatcherised', for example, 'Eyes'. The cue was present on the screen for 2 seconds. Two additional conditions were also employed in Experiment 5. Participants were cued to the eyes (window) and both the eyes (window) and the mouth (door) were 'Thatcherised'. Similarly, participants were cued to the mouth (door) and both the eyes (window) and the mouth (door) were 'Thatcherised'.

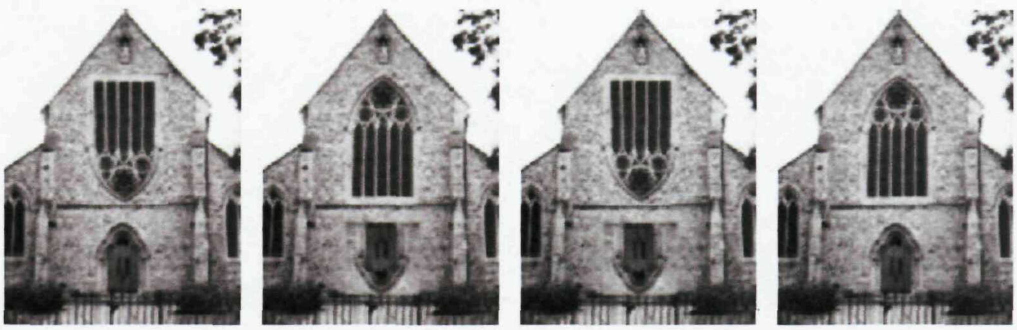


Figure 10. An example of the four different types of church stimuli used. From left to right, a church with the window manipulated, a church with the door manipulated, a church with the window and door manipulated and a 'normal' church.

Control Experiment

Given that a different paradigm was used to Experiment 5 relative to Experiments 1-4 we cannot a priori assume that the basic results of Experiment 1-4 hold for Experiment 5. Specifically, we cannot assume that there will be evidence of an inversion effect when participants are cued to manipulations. If there is not evidence of an inversion effect we would have no confirmation that participants were employing second-order relational processing. The strongest evidence for second-order relational processing for faces would arise in the form of a cross-over interaction between faces and churches. To confirm the presence of an inversion effect a control experiment was conducted with the same participants who participated in Experiment 5. Participants were presented with upright and inverted pairs of faces/ churches and asked to decide which of the two faces/churches were 'odd'. Like Experiment 5, participants were given cues before each trial to inform them as to where the manipulations were made. A mean RT and mean percentage error score was calculated for upright faces, inverted faces, upright churches and inverted churches by combining the results across conditions. For RTs, the results showed that the main effect of stimulus was not significant ($F(1, 11)=1.96$), but the main effect of orientation ($F(1, 11)=106.20$, $p<.01$) and the interaction between stimulus and orientation were significant ($F(1, 11)=16.59$, $p<.01$). The effect of orientation was significant for both faces and churches, but it was larger for faces than churches ($t(11)=8.46$, 2.62, $p<.01$, $<.05$ for faces and churches respectively). For error rates, the main effect of stimulus was significant ($F(1, 11)=29.19$, $p<.01$), participants were more accurate for churches than faces. The main effect of orientation was significant ($F(1, 11)=106.20$, $p<.01$) and the interaction between stimulus and orientation were significant ($F(1, 11)=16.58$, $p<.01$). The effect of orientation was significant for both faces and churches, but it was larger for faces than churches ($t(11)=8.24$, 4.15, both $p<.01$ for faces and churches respectively). Given the significant effect of inversion on RT and error rates for faces and the cross over interaction (see Figure 10) between faces and churches we can be confident that participants were using second-order relational processing in this paradigm.

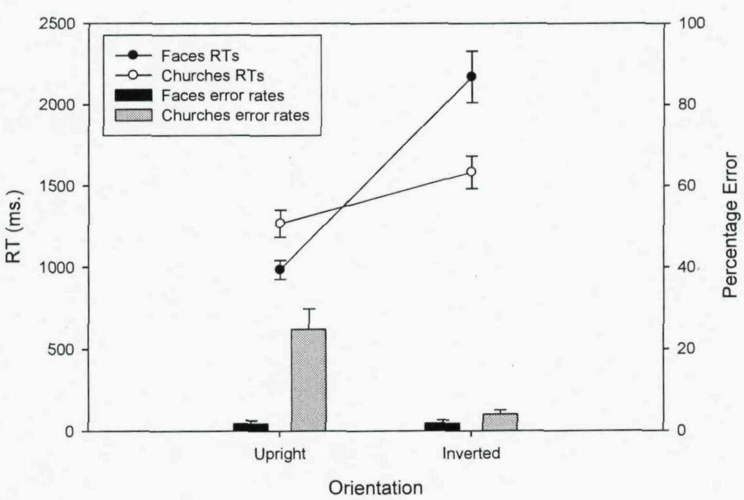


Figure 11. Mean RTs and error rates with standard error in the control experiment.

Results

RT and percentage error data were computed in the same way as in Chapter 2. RTs associated with correct responses and the transformed percentage correct data were compared separately in a 2 (Stimulus: Faces versus Churches) x 5 (Condition: Eye (Window) versus Mouth (Door) versus Two feature changes versus CEB (CWB) versus CMB (CDB)) repeated measures ANOVA. The analyses investigated whether there was a significant interaction between stimulus and condition. The presence of a significant interaction between stimulus and condition would indicate that performance differed between the face and church conditions. If such an interaction did occur then the best way to examine it would be to analyse faces and churches separately. The interaction between stimulus and condition was significant in the RT analysis ($F(4, 44)=10.67, p<.01$) and approached significance in the error analysis ($F(4, 44)=2.55, p=.052$), therefore, faces and churches were analysed separately (see Figure 11).

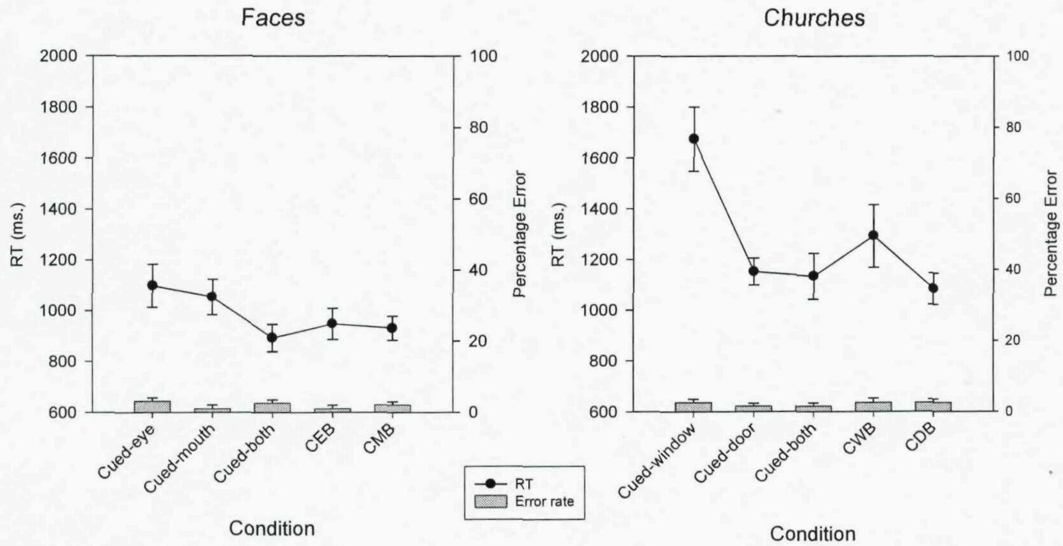


Figure 12. Mean RTs and percentage error rates with standard errors for the face block and the church block.

Faces

RT - The main effects of condition was significant ($F(4, 44)=7.63, p<.01$). Participants were faster to respond in the cued-both condition than in either the cued-eye condition or the cued-mouth condition ($t(11)=4.94$, 4.14, both $p<.01$ for cued-eyes and cued-mouths respectively). There were no significant differences between the cued-eye and cued-mouth conditions ($t(11)<1$). There were no significant differences between the both, CEB and CMB conditions ($t(11)=1.80$, 1.01, <1). Participants were significantly faster in the CMB condition than in the cued-mouth condition ($t(11)=4.03, p<.01$), and were significantly faster in the CEB condition than in the cued-eye condition ($t(11)=2.40, p<.05$).

Accuracy - The main effect of condition was not significant ($F(4, 44)=1.49$).

Churches

RT - The main effect of condition was significant ($F(4, 44)=21.11$, $p<.01$). Participants were faster in the cued-door and cued-both conditions than in the cued-window condition ($t(11)=6.27$, 5.72, both $p<.01$). There was no significant difference between the cued-door condition and the cued-both condition ($t(11)<1$). Participants were faster to respond in the cued-both condition than the CWB condition ($t(11)=-4.44$, $p<.01$). There was no difference between the cued-both and CDB condition ($t(11)=1.10$). Participants were faster to respond in the CDB condition than in the CWB condition ($t(11)=2.93$, $p<.05$). Participants responded significantly faster in the CWB than the cued-window condition ($t(11)=4.18$, $p<.01$). There was no significant difference between the cued-door condition and the CDB condition ($t(11)=2.17$).

Accuracy - The main effect of condition was not significant ($F(1, 11)=2.35$).

Faces versus churches

To explore the interaction between stimulus and condition in more detail the conditions in which participants were cued to one feature and two features were changed was compared across stimulus types in a two (Stimulus: Faces versus Churches) x 2 (Condition: CEB (CWB) versus CMB (CDB) repeated measures ANOVA separately more RTs and accuracy. For RTs, the main effect of stimulus and condition were significant ($F(1,11)=14.89$, 4.33, $p<.01$, $<.05$ respectively) as was the interaction between stimulus and condition ($F(1,11)=13.42$, $p<.01$).For accuracy, neither the main effects of stimulus or condition were significant ($F(1,11)=3.31$, 2.10 respectively) nor the interaction between stimulus and condition ($F(1,11)=1.00$).

Discussion

In both the face and church conditions, RTs were faster when participants were cued to one feature and two features were changed, compared with when they were cued to one feature and one feature was changed. If participants were only processing the cued feature, the uncued feature would not have been processed and so it would not have facilitated performance. Given that manipulating the uncued feature reduced RTs, the results suggest that participants were processing both the cued and uncued features, indicating that participants were detecting differences between both faces and churches in parallel.

Although RTs in both the face and church conditions were faster when participants were cued to one feature and two features were changed, there were, however, important differences between the face and church conditions. In the face condition, there was no cost associated with cueing to one feature and changing two features, relative to cueing to two features and changing two features. Specifically, there were no significant differences between the cued-both, CEB and CMB conditions. However, in the church condition, there was some evidence of a cost associated with cueing to one feature and changing two features relative to cueing to two features and changing two features. This result was highlighted by the significant interaction between faces and churches when only the conditions in which participants were cued to one feature and two features were manipulated. Specifically, there was evidence of a cost of cueing to one feature in the CWB condition relative to the cued-both condition. There was not, however, a cost of cueing to one feature in the CDB condition relative to the cued-both condition. These findings can be readily explained because RTs in the cued-door condition were equal to RTs in the cued-both condition. Any additional change made to windows could not, therefore, influence performance.

One explanation of the difference between the face and church conditions is that there were differences in the distribution of attention across the stimulus. In the face condition, participants may have distributed their attention equally between the eyes and the mouth regardless of which feature they were cued to. This meant that they could process both features at a similar rate, so both features were equally likely to reach threshold and generate the response. In contrast, in the church condition participants may not have distributed their attention equally between the window and door. Rather, participants may have preferentially allocated more attention to the cued-feature compared with the uncued feature. This meant that the cued feature was processed at a faster rate than the uncued feature, resulting in a decreased likelihood of the uncued feature reaching threshold and generating a response. In short, although both windows and doors were processed at the same time, the rate of processing differed between features. This possibility will be explored further in the General Discussion (see p.96).

Two assumptions made in Experiment 5 were that participants used the cues to inform processing, and secondly, that participants used a self-terminating stopping rule. If participants did not pay attention to the cues there would have been no difference between the cued-both, CEB (CWB) and CMB (CDB) conditions. These trials are essentially the same, with a different cue before each trial and so if participants were not attending to cues, then there would be no difference between conditions. Indeed, the results showed no difference between these three conditions in the face session, however, there were significant differences between these conditions in the church session. From these results it is possible to conclude that participants did pay attention to cues in the church session. However, there is no evidence to infer whether participants were paying attention to cues in the face condition. The conclusions drawn from the face condition will, therefore, be treated cautiously at this stage.

The second assumption made in Experiment 5 was that participants employed a self-terminating stopping rule. If participants were using an exhaustive stopping rule, participants would have processed all features regardless of the cues they had been given. If this was the case, then there would be no difference between the cued-both, CEB (CWB) and CMB (CDB) conditions, because the information to be processed was the same across conditions. Given that there were no differences found between these conditions in the face session, the conclusions drawn from Experiment 5 will, again, be considered cautiously at this stage.

To rule out alternative explanations for the results of Experiment 5 (i.e. participants did not pay attention to cues or participants used an exhaustive stopping rule) an additional experiment was conducted to examine the time course across which differences between faces are detected. In addition, Experiment 6 also examined the stopping rule used to detect differences between faces. Experiment 6 used a formal test to examine whether participants encode differences between faces in parallel or serial and using a self-terminating or exhaustive stopping rule.

Experiment 6

Experiment 5 suggested that differences between eyes and mouths, and windows and doors, presented in the context of either a face or a church, were processed in parallel. Experiment 6 aimed to find further support for these conclusions and additionally examined the stopping rule used by participants when performing a 2AFC 'same'/'different' discrimination.

Formal tests of architecture and stopping rule

Experiment 6 was designed to allow a formal test of system architecture and stopping rule to be conducted (Townsend & Nozawa, 1995). The formal test requires interaction contrasts to be computed at the level of the mean and at the level of the survivor function. Interaction contrasts are the same as interactions in ANOVAs, but they are computed separately for each individual and across time (when they are computed at the level of the survivor function). In order to compute an interaction contrast, at least two features are required to be manipulated by at least two levels. This is so that main effects and interactions can be examined.

The interaction contrast at the level of the mean is computed using Equation 8.

$$\overline{IC}_M = \overline{RT}_{BB}(t) - \overline{RT}_{CB}(t) - \overline{RT}_{BC}(t) + \overline{RT}_{CC}(t) \qquad (8)$$

Where BB = two features are manipulated by one level
Where CB = one feature is manipulated by two levels and the other by one level
Where BC = one feature is manipulated by one level and the other by two levels
Where CC = both features are manipulated by two levels

The interaction contrast at the level of the survivor function is computed using equation 9.

$$IC_{SF} = S_{BB}(t) - S_{CB}(t) - S_{BC}(t) + S_{CC}(t) \qquad (9)$$

Where BB = two features are manipulated by one level
Where CB = one feature is manipulated by two levels and the other by one level
Where BC = one feature is manipulated by one level and the other by two levels
Where CC = both features are manipulated by two levels

Townsend and Nozawa (1995) showed that the interaction contrast at the level of the mean and at the level of the survivor function can be used to make inferences regarding the architecture and stopping rule of a system. In particular, if both the IC_M and the IC_{SF} are equal to 0, then one can infer that features were compared in serial using a self-terminating stopping rule. If IC_M is equal to 0 and IC_{SF} moves from negative to positive, then one can infer that features were compared in serial using an exhaustive stopping rule. If both IC_M and the IC_{SF} are greater than 0, then one can infer that features were compared in parallel using a self-terminating stopping rule. Finally, if both IC_M and the IC_{SF} are below 0, then one can infer that features were compared in parallel using an exhaustive stopping rule. The mathematical proofs of these inferences are presented in the appendix of the paper by Townsend and Nozawa (1995).

In Experiment 6 it was not possible to 'Thatcherise' features by two levels, because features can only be upright (un-manipulated, i.e. 'normal') or inverted (manipulated by one level, i.e. 'Thatcherised'). Therefore, a different manipulation was required for Experiment 6. In Experiment 6, the spatial location of features was manipulated. Manipulating the spatial distances between features is an accepted test that has previously been used to examine whether participants are processing second-order relations (e.g. Bartlett & Searcy, 1993). If participants show evidence of an inversion effect (i.e. faster and more accurate performance with upright compared with inverted faces) when asked to detect differences between two faces, one of which has had the spatial distances between features manipulated, there is strong evidence that second-order relational processing is being employed. In Experiment 6, eyes were moved up by 7% or 12% of the distance between the centre of the eyes and hairline. Mouths were moved down by 7% or 12% of the distance between the centre of the mouth and the bottom of the chin (see Table 1 for condition names and descriptions).

Table 1

Descriptions of the Conditions that were Presented in Experiment 6

Face condition			Car condition		
Condition	Eyes	Mouth	Condition	Headlights	Number plate
AA	None	None	DD	None	None
AB	None	7%	DE	None	7%
AC	None	12%	DF	None	12%
BA	7%	None	ED	7%	None
BB	7%	7%	EE	7%	7%
BC	7%	12%	EF	7%	12%
CA	12%	None	FD	12%	None
CB	12%	7%	FE	12%	7%
CC	12%	12%	FF	12%	12%

Features were moved by a proportional amount rather than an absolute amount because the distance between the eyes and the hairline is greater than the distance between the centre of the mouth and the chin. Moving features by the same absolute amount would have meant that the manipulation made to the mouth was more discriminable than the manipulation made to the eyes.

Changing the nature of the manipulations made in Experiment 6 meant that it was also necessary to change the control stimuli that were used. Moving the door down within a church would mean that the door would extend below the outline of the church. Manipulating the images in this way would disrupt to integrity of the image and would encourage participants to compare churches based on an inconsequential low-level feature (i.e. the distance the door protruded below the church outline). To overcome this problem, Experiment 6 employed cars as control stimuli. Cars were selected as the control stimulus as they are mono-oriented, experienced in the environment frequently and have two features (headlights and number plates) that are easy to move. Headlights were moved up by 7% or 12% of the distance between the centre of the headlights and the top of the windscreen. Number plates were moved down 7% or 12% of the distance between the centre of the number plate and the bottom of the bumper.

In Experiment 6, participants were simultaneously presented with two faces (cars) and were asked to decide whether the faces (cars) were the 'same' or 'different'. On 'same' trials, both faces (cars) were the original versions (i.e. the non-manipulated versions) and on 'different' trials one face (car) was the original version and the other had either the eyes (headlights) moved up, or the mouth (number plate) moved down, or both the eyes (headlights) moved up and mouth (number plate) moved down.

The aim of Experiment 6 was to investigate the interaction contrasts at the level of the mean and at the level of the survivor function in order to infer the architecture and stopping rule when detecting changes to eyes and mouths in faces, and headlights and number plates in cars (a control object).

Method

Participants

Twelve undergraduates from the School of Psychology at the University of Southampton participated in Experiment 6 in return for course credits. Participants had a mean age of 20.38 years (SD=2.14 years), 1 was male, 10 were right handed, all had normal or corrected to normal vision and none had participated in the previous experiments.

Stimuli

Faces - Eight greyscale Caucasian female faces were obtained from the Nimstim database (Tottenham, Sorscheid, Ellertsen, Marcus & Nelson, 2002). Faces were photographed in full frontal view and were cropped at the neck. Faces were resized so that the distance between the hairline and the bottom of the chin measured 6.8 cm, corresponding to a visual angle of 5.19 degrees when viewed from a distance of 75 cm. Each of the eight faces was used to create nine variations. Two features, the eyes and the mouth, were manipulated by two values, the eyes were moved up 7% and 12%, and the mouth down by 7% and 12%. These two values were selected so that manipulated versions of the faces would still be naturalistic in appearance (as judged by the author). McKone, Aitkin and Edwards (2005) demonstrated that participants rated manipulated faces as 'normal' when features were moved up or down by a maximum of 9 pixels (7% corresponds to approximately 4 pixels and 12% to approximately 7 pixels). All possible combinations of changes were made.

The eyes were cut out from the face and moved up by 7% or 12% of the distance between the hairline and the centre of the eyes. The area that was previously occupied by the eyes was then filled with the same colour as the cheek to produce a naturalistic appearance (as judged by the author). The blur tool was used to remove high contrast edges. To alter the position of the mouth, the mouth was cut out and moved down by 7% or 12% of the distance between the centre of the mouth and the bottom of the chin. The area that was previously occupied by the mouth was filled with the same colour as the chin to produce a naturalistic appearance (as judged by the author). The blur tool was used to remove high contrast edges. Finally, the whole image was blurred using a one pixel Gaussian blur (see Figure 12 for an example of the stimuli).

Figure 13. Example of the face stimuli used in Experiment 6. From left to right, face AA, BB, CC (see Table 1 for condition names and descriptions).

Cars - Eight Photos of British cars were taken using a Fujifilm FinePix A400 camera. Cars were photographed in full frontal view showing the front headlights and number plate. Cars were all different makes and models and were between 1 and 4-years-old. Cars were converted to greyscale and the lettering on the number plates was covered by a white rectangle. Cars were resized so that the distance between the top of the windscreen and the bottom of the front bumper measured 6.8 cm, corresponding to a visual angle of 5.19 degrees when viewed from a distance of 75 cm. These eight cars were used to create the same nine variations as faces. The headlights were cut out from the car and moved up 7% or 12% of the distance between the top of the windscreen and the centre of the headlights. The area that was previously occupied by the headlights was filled with the same colour as the bumper to produce a naturalistic appearance (as judged by the author). The blur tool was used to remove high contrast edges. To alter the position of the number plate, it was cut out and moved down by 7% or 12% of the distance between the centre of the number plate and the bottom of the bumper. The area that was previously occupied by the number plate was filled using the colour of the bumper to produce a naturalistic appearance (as judged by the author). The blur tool was used to remove high contrast edges. Finally, the whole image was blurred using a one pixel Gaussian blur (see Figure 13 for an example of the stimuli).

Figure 14. Example of the car stimuli used in Experiment 6. From left to right car DD, EE, FF (see Table 1 for condition names and descriptions).

Control studies

The necessity of changing task and stimuli in Experiment 6 relative to Experiment 5 means that it is not possible to assume, a priori, that the basic findings of Experiments 1-4 hold in Experiment 6. That they do so is a precondition to exploring the processing architecture and the stopping rule used in the 2AFC task. Therefore, two control experiments were conducted using the stimuli to be shown in Experiment 6. First, it is necessary to show that the facial stimuli exhibit a significant inversion effect such that we can be sure that these faces are processed using second-order relational processing. The strongest evidence for second-order relational processing for faces would arise in the form of a cross-over interaction between faces and churches. In this control task, the same participants who participated in Experiment 6 (N=12) were simultaneously presented with a non-manipulated face/car and a face/car with eyes (headlights) and mouths (number plates) moved by either 7% or 12%. Participants were asked to decide whether the faces/cars were the 'same' or 'different'. Means and standard errors can be seen in Table 2.

The results were analyzed in a 2 (Stimulus: Faces versus Cars) x 2 (Orientation: Upright versus Inverted) repeated measures ANOVA. For RTs, the interaction between stimulus and orientation was significant when features were manipulated by 7% and 12% ($F(1, 11)=4.70, 6.70$, both $p<.05$ respectively). For error rates, the interaction between stimulus and orientation was significant when features were manipulated by 7% and 12% ($F(1, 11)=20.63, 6.77, p<.01, <.05$). These interactions are shown in Figure 14. The presence of significant interactions for both RTs and error rates in the 7% and 12% change conditions provides evidence consistent with the idea that participants were employing second-order relational processing in the face condition but not in the car condition.

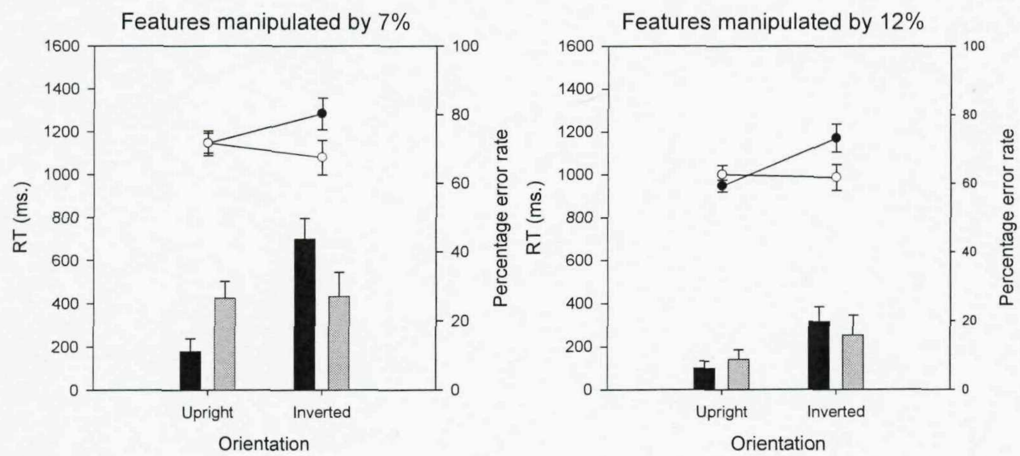


Figure 15. Mean RTs and error rates with standard errors in the control experiment. The left panel shows results for the trials in which both features were manipulated by 7% and the right panel shows results for the trials in which both features were manipulated by 12%.

In a second control task, confirmation was sought that the faces used in Experiment 6 produced similar values of the capacity coefficient, Miller inequality and Grice inequality as those found in Chapter 2. Error rates across the whole experiment exceeded 25% when features were manipulated by 7% and so values of the capacity coefficient, Miller and Grice inequalities could only be computed for trials where features were manipulated by 12% (see Townsend & Wenger, 2004). The results were calculated in the same way as in Chapter 2. All results at the level of the mean and at the level of the survivor function were consistent with those reported in Chapter 2 and so were consistent with local-configural processing (see Appendix D and E). Therefore, the face and car stimuli used in Experiment 6 manifest the same characteristics of processing and capacity characteristics as those stimuli used in all previous experiments.

Design and Procedure

Participants were asked to decide whether two simultaneously presented faces/cars were the 'same' or 'different'. The experiment was divided into two sessions, one for faces and one for cars. The order in which these sessions were completed was counterbalanced between participants. Participants completed both sessions no more than 48 hours apart. Each session was divided into 2 blocks and participants were allowed a short self-timed break between blocks. Each block contained 256 trials. 50% of trials were 'same' trials and 50% were 'different' trials. The order of 'same' and 'different' trials was randomised within each block. For 'same' trials, two non-manipulated faces/cars appeared simultaneously. For 'different' trials, each of the eight manipulated faces/cars were paired with the non-manipulated version of the 'same' face/car. The side that the manipulated face/car appeared was counterbalanced within each block. All of the manipulated faces/cars appeared once on the left hand side of the fixation cross and once on the right hand side of the fixation cross.

Participants were seated 75 cm from the screen in a dimly lit quiet room. Although participants' head movements were not restrained, they were instructed to keep their heads upright. Head position was monitored by the experimenter at all times. Participants were informed of how the faces had been manipulated, and were shown an example of the nine stimulus types. Participants were instructed to decide whether the two faces/cars were the 'same' or 'different' and to respond by pressing the corresponding mouse key. Response keys were counterbalanced between participants. Participants were asked to complete a practice session of 15 trials. The data from the practice trials were not included in data analysis.

Each trial began with a fixation cross that was present on the screen for 100 ms. The fixation cross was then replaced by the two faces/cars. Stimuli were displayed until a response was made. The next fixation cross appeared 100 ms after the response was made. Participants were asked to respond as quickly as possible whilst minimising errors.

Results

Conclusions regarding the architecture and stopping rule are reached by computing both interaction contrasts for mean RTs and survivor functions. With regards to categorising the processing architecture and the stopping rule used, it is essential that the stimulus manipulations that were made influence performance. To be certain that the stimulus manipulations did influence performance the stimuli must show evidence of selective influence. According to the assumption of selective influence, participants must be faster to respond when the eyes (headlights) are manipulated by 12% compared with 7% and when the mouth (number plate) is manipulated by 12% compared with 7%. We cannot interpret interaction contrasts when the differences between conditions are below the threshold for influencing RTs and so we must first show that there truly are two levels to each factor. The assumption of selective influence needs to be confirmed at both the level of the mean and at the level of the survivor function (Ingvalson & Wenger, 2005).

Selective influence at the level of the mean

Selective influence was confirmed by analysing eye (headlight) and mouth (number plate) changes in a 2 (Eye (Headlight) change: 7% versus 12%) x 2 (Mouth (Number plate) change: 7% versus 12%) repeated measures ANOVA. Across all participants there was a significant main effect for the eye (headlight) changes and the mouth (number plate) changes ($F(1, 11)$=12.10, 9.13, both $p<.01$ and $F(1, 11)$=32.85, 8.89, both $p<.01$ respectively). More importantly, each participant showed faster performance in the 12% change conditions compared with the 7% change conditions for both eyes (headlights) and mouths (number plates) (see Appendices F and G).

Selective influence at the level of the survivor function.

For selective influence to hold, the survivor function for the condition in which the eyes (headlights) and mouth (number plates) were changed by 12% should be lower and to the left of the survivor function for the condition in which the eyes (headlights) and mouth (number plates) were changed by 7%. The conditions with one feature changed by 7% and the other by 12% should lie between the BB and CC survivor functions (see Table 1 for condition names and descriptions). For all participants, the survivor function for the condition in which both features were manipulated by 12% was below and to the left of the survivor function for the condition in which both features were manipulated by 7% (see Appendices H and I). The results are, therefore, consistent with the assumption of selective influence at the level of the mean and at the level of the survivor function and so it is possible to analyse interaction contrasts.

Analysis of interaction contrasts

To compute interaction contrasts, mean RTs were computed for correct responses for the BB, CB, BC and CC trials types (see Table 1 for condition names and descriptions). Formula 8 was used to calculate the interaction contrast at the level of the mean (Values can be seen in Appendix J). The interaction contrast at the level of the survivor function was computed by generating survivor functions in the same way as in Chapter 2 for the BB, CB, BC and CC trial types (see Table 1 for condition names and descriptions) and inputting these values into Formula 9 (values can be seen in Appendices K and L). Summaries of the interaction contrasts by participant at the level of both the mean and at the level of the survivor function and the associated inferences are presented in Table 2.

Inspection of Table 2 shows that, for faces, 9/12 participants detected differences between pairs of faces in parallel using a self-terminating stopping rule and 3/12 participants detected differences between pairs of faces in parallel using an exhaustive stopping rule. For cars, 6/12 participants detected differences between pairs of cars in parallel using a self-terminating stopping rule and 6/12 participants detected differences between pairs of cars in parallel using an exhaustive stopping rule.

Table 2

Interaction Contrasts at the Level of the Mean and Survivor Function and the Inferences Supported for Faces and Cars

Participant	Faces				Cars			
	IC_M	IC_{SF}	Architecture	Stopping rule	IC_M	IC_{SF}	Architecture	Stopping rule
1	<0	<0	Parallel	Exhaustive	>0	>0	Parallel	Exhaustive
2	>0	>0	Parallel	Self-Terminating	>0	>0	Parallel	Exhaustive
3	>0	>0	Parallel	Self-Terminating	<0	<0	Parallel	Self-terminating
4	>0	>0	Parallel	Self-Terminating	>0	>0	Parallel	Exhaustive
5	<0	<0	Parallel	Exhaustive	<0	<0	Parallel	Self-terminating
6	>0	>0	Parallel	Self-Terminating	>0	>0	Parallel	Exhaustive
7	>0	>0	Parallel	Self-Terminating	<0	<0	Parallel	Self-terminating
8	>0	>0	Parallel	Self-Terminating	<0	<0	Parallel	Self-terminating
9	>0	>0	Parallel	Self-Terminating	>0	>0	Parallel	Exhaustive
10	<0	<0	Parallel	Exhaustive	>0	>0	Parallel	Exhaustive
11	>0	>0	Parallel	Self-Terminating	<0	<0	Parallel	Self-terminating
12	>0	>0	Parallel	Self-Terminating	<0	<0	Parallel	Self-terminating

Discussion

The results of the control studies demonstrated that, although there was clear evidence of an inversion effect, suggesting that participants were employing second-order relational processing, there was no evidence to suggest that participants were employing co-active or global-configural processing. The results are, therefore, consistent with Chapter 2 in suggesting that participants used local-configural processing to detect differences between faces. Importantly these results suggest that the majority of participants show no evidence of co-active or global-configural processing when veridical (i.e. non 'Thatcherised') faces are used.

The results of the interaction contrasts demonstrated that all participants detected differences between pairs of faces in parallel. This is consistent with the results of Experiment 5, which also highlighted that participants detected differences between faces in parallel. The analysis of interaction contrasts also demonstrated that differences between pairs of cars were detected in parallel. In addition, the interaction contrasts demonstrated that 9/12 participants employed a self-terminating stopping rule for faces whilst the remaining 3 participants employed an exhaustive stopping rule. Interestingly, 6/12 participants employed a self-terminating stopping rule for cars whilst the other 6 participants employed an exhaustive stopping rule.

The tendency for some participants to use an exhaustive search for cars, but not faces, is a theoretically interesting and novel finding and it is worth considering further now. One possibility is that the difference in stopping rule between stimulus types (faces versus cars) results from different levels of expertise at processing faces compared with objects (cars). Expertise at the item level (i.e. for individual faces, rather than for faces as a class of stimuli) has previously been discussed by Tong and Nakayama (1999). They proposed that highly familiar faces (such as the face of your husband/wife) are characterised by 'robust' representations. A 'robust' representation was defined as a representation that has a "more efficient visual code" (Tong & Nakayama, 1999, p.1020). Presumably, the authors mean that the representation is highly detailed and it can be accessed very quickly and accurately. Tong and Nakayama (1999) use the idea of 'robust' representation to characterise faces that participants have received extensive exposure to, i.e. faces that they have become highly expert at processing. Given that participants are described as being expert at processing faces compared with objects (e.g. Le Grand, Mondloch, Maurer & Brent, 2003; Schwaninger, Carbon & Leder, 2003), it may be that representations formed for faces are more 'robust' than the representations formed for objects. If this is the case, participants will have a more detailed representation of one stimulus that they can use to match and compare the subsequent stimuli to in the face condition compared with the object (car) condition. A more 'robust' representation may allow participants to be more certain that any deviation from the representation (in the form of activation building suggesting a difference between the representation and the stimulus) reflects a difference between the two faces and so they are willing to respond before all information has been processed.

General Discussion

Experiments 5 and 6 highlighted that differences between pairs of faces and pairs of objects were detected in parallel. Experiment 6 demonstrated that 9/12 participants detected differences between pairs of faces using a self-terminating stopping rule, whereas 3/12 participants detected differences between pairs of faces using an exhaustive stopping rule. In contrast, 6/12 participants detected differences between pairs of cars using a self-terminating stopping rule and the remaining 6 participants detected differences between pairs of cars using an exhaustive stopping rule. These findings regarding processing architecture and stopping rule must be considered in the light of evidence of locally-based configural processing with faces and locally-based feature processing with cars.

Expertise (which is associated with faces but not with objects) appears to result in both some level of second-order relational processing and a greater tendency to discriminate differences using a self-terminating stopping rule rather than an exhaustive stopping rule. Why might participants be more likely to use self-terminating processing as they become expert at processing a stimulus? It may be that as an individual develops expertise they become more certain that deviation away from the internal representation that is formed of the first face/car that is encoded actually reflects a difference between the two stimuli. Participants may, therefore, be more willing to terminate their search before all information has been processed. If this is the case, participants could be described as adopting a liberal response criterion in terms of the total amount of information that they require before a response is generated.

Adopting a more liberal response criterion may not only apply to the termination of processing, but it may also apply to the response that the participant selects. It may be that with expertise, participants also adopt a more liberal response criterion with respect the response that they generate (see p.23). If this is the case, then participants may be more likely to respond 'different' than 'same'. In other words, they may make more hits and also more false alarms for stimuli with which they are expert at processing compared to stimuli that they are not expert at processing. To date, there has not been any research which has examined this possibility and so it will be examined further in Chapter 5.

An interesting finding that arose from Experiment 5 was that the rate at which information was acquired from features appeared to differ between faces and churches. Participants processed facial features at a similar rate, but processed object (church) features at different rates (i.e. they processed the cued feature at a faster rate than the uncued feature). The difference in the rate at which features were processed may have occurred because participants allocated their attention equally across features in faces, but preferentially allocated more attention to the cued feature over the uncued feature in objects (churches). It is possible to investigate whether there are differences in the allocation of attention between faces and objects using the data from Experiment 6 in the form of survivor functions. Specifically, inferences regarding the allocation of attention across a stimulus are possible by investigating whether there are differences between the gradient or relative positions of the survivor functions. If one survivor function falls more steeply than the other, processing is completed faster in that condition relative to the other condition. If this is the case, one explanation would be that more attention is being given to that particular feature across the whole processing distribution. Alternatively, the survivor functions may differ in terms of their relative position i.e. the survivor functions may decline at the same rate, but one survivor function starts its decline at a later time point than the other. If this is the case, one explanation would be that attention is directed at one feature early on in processing and then divided between features later in time. Assuming that eyes and mouths are equally discriminable (see p.96), if attention is divided equally between features in faces then there should be no difference between either the gradient or the relative position of the eye and mouth survivor function. Assuming that headlights and number plates are equally discriminable, if attention is preferentially allocated to one feature in objects (cars) then there should be a difference in either the relative rate or gradient of the headlight and number plate conditions.

The survivor functions for the eye (headlight) and mouth (number plate) condition are shown in Appendices M and N. Their relative positions and gradients were compared using a log rank test. The log rank test was used to examine the hypothesis that there is a difference between the two conditions in the probability that the response has not yet been made. For each RT, the number of RTs that had already been made were calculated and compared with the number of RTs that would have been expected to have been made under the null hypothesis. Under the null hypothesis there would be no difference between conditions in the number of RTs already made by time t. In contrast, under the alternative hypothesis there would be a difference between the number of RTs already made by time t, and the number of expected RTs made by time t. The observed and expected frequencies were compared using the chi squared statistic. In the face condition, there was a significant difference between eye and mouth survivor function in participants 3, 4, 7 and 12. In the car condition, there was a significant difference between the headlight and number plate survivor function in participants 1, 2, 4, 5, 7, 8, 10 and 11 (see Table 3).

For 8/12 participants, there was no difference in the gradient or relative position of survivor functions between eyes and mouths. In contrast, 8/12 participants did reveal a significant differences in either the gradient or relative position of survivor functions between headlight and number plate conditions. This finding suggests that there is a tendency for participants to distribute their attention equally across faces, but not across cars.

Table 3
Values of the Chi Square Statistic for the Log Rank Test

Participant	Chi-square Eye versus Mouth	Headlight versus Number plate
1	1.40	6.40*
2	<1	4.28*
3	6.54*	<1
4	5.42*	4.18*
5	<1	3.00$^{\#}$
6	<1	<1
7	7.03**	3.40$^{\#}$
8	<1	6.68**
9	1.32	<1
10	<1	5.00*
11	<1	5.35*
12	29.63**	<1

* p<.05; **p<.01; $^{\#}$approaches significance

It is important to note that in the car condition participants did not choose to allocate their attention preferentially to the same feature, some preferring headlights and some preferring number plates. The difference between the two survivor functions was not, therefore, caused because one feature was easier to discriminate than the other; if this was the case, survivor functions would have been ordered in the same way for all participants. These results will be discussed further in Chapter 6 (see p.140).

In sum, the research conducted within this chapter has shown that although there was clear evidence of second-order relational processing (a significant cross over interaction was shown in the control experiment), there was no evidence of co-active or global-configural processing for faces. It must, therefore, be concluded that participants used local-configural processing to discriminate between pairs of faces. The results, however, showed no qualitative differences between the processing of faces and cars in terms of processing architecture or the stopping rule used when discriminating between pairs of faces or cars. Nevertheless, differences between faces tend to be detected in parallel using a self-terminating stopping rule, and differences between objects tend to be detected in parallel using either an exhaustive or self-terminating stopping rule. Participants tend to allocate their attention across faces evenly, but preferentially allocate attention to one feature in objects (churches or cars) such that the processing of one feature dominates over the processing of another.

Chapter 4

The experiments presented in Chapters 2 and 3 demonstrated no evidence of co-active or global-configural processing of faces, suggesting that facial features (i.e. eyes and mouths) were processed using local-configural processing. In addition, Experiments 5-6 highlighted that differences between faces were detected in parallel, and tended to be compared using a self-terminating stopping rule. Object features (i.e. headlights and number plates in cars or windows and doors in churches) demonstrated featural processing. In addition, Experiment 6 highlighted that differences between pairs of objects were detected in parallel, but, participants detected differences using either a self-terminating stopping rule or an exhaustive stopping rule.

Experiment 7 investigated whether there are developmental differences in the spatial scale over which second-order relations are computed and whether there are developmental differences in the time scale across which participants detect differences between pairs of faces. As highlighted in Chapter 1, it may be that younger children process second-order relations over a larger spatial scale than adults and learn to constrain the scale over which they process configural relations so that they can process them more accurately (see p.36). If this is the case, we may see evidence of global-configural processing in young children and adolescents, but not in adult participants. In Chapter 1 it was also suggested that children might require so much capacity to process second-order relations that they have to process second-order relations one at a time (i.e. in serial) rather than in parallel (see p.36). If this is the case, it would be expected that there would be differences in the interaction contrasts between adults, adolescents and younger children.

In Chapter 3 it was suggested that differences in the stopping rule between stimulus types were caused because participants had developed expertise at processing faces but had not developed expertise at processing objects (churches and cars). It was proposed that with expertise, participants are able to form a more 'robust' representation of the first stimulus they process which they can then use to match and classify perceptual inputs against from the second stimulus. A more 'robust' representation allows participants to be more certain that any deviation (in the form of activation building in a response channel to suggest that the two faces are 'different') away from the representation reflects a difference between the two stimuli. Increased certainty means that participants are more willing to generate their response before all information has finished being processed. If the nature of the stopping rule used is dependent on the participants' level of expertise at processing a stimulus, then it would be expected that participants who have not developed expertise at processing faces would tend to use an exhaustive rather than self-terminating stopping rule. This possibility was examined in Experiment 7.

Chapter 3 additionally highlighted that there was a tendency for participants to divide attention equally between features in faces, but participants preferentially allocated attention to one feature in objects (churches or cars). In Experiment 5 this was demonstrated by a cost associated with cueing to one feature and changing two features in the church condition but not in the face condition and in Experiment 6 by differences in the relative position or gradient of the survivor functions for the headlight and number plate conditions but not between the eye and mouth conditions. Differences in the distribution of attention across stimulus types may also arise because participants have developed expertise at processing faces but not objects (e.g. Le Grand et al., 2003; Schwaninger et al., 2003). Specifically, expertise may mean that participants are able to divide their attentional spotlight (see Castiello & Umilta, 1992) or split their attentional spotlight (see LaBerge, 1983) so that resources can be divided equally between features. If the distribution of attention is dependent on the level of expertise that a person has acquired with a particular type of stimuli, then it would be expected that participants who have not developed expertise at processing faces (i.e. children) would tend to allocate attention to one feature when performing a 2AFC 'same'/'different' task. This possibility was examined in Experiment 7.

The aims of Chapter 4 were to examine whether there are developmental differences between young children, adolescents and adults in terms of the stopping rule used to detect differences between pairs of faces and also to investigate whether there are developmental differences in terms of the distribution of attention across faces when participants are asked to perform a 2AFC 'same'/'different' task. Based on the results of Experiments 5 and 6 it was expected that young children would tend to process faces exhaustively and would tend to preferentially allocate their attention to one feature in faces.

In an ideal situation, each individual would complete hundreds of trials so that reliable results could be generated on an individual level. Unfortunately, this approach is not possible when testing young participants. One major issue facing researchers who are interested in development is that children are only able to complete a relatively small number of trials compared with adults. Time constraints are placed on researchers in terms of the amount of time that the child is willing to concentrate for and the amount of time that schools or parents are willing to allow their children to participate in an experiment. Given that children are not able to complete hundreds of trials, an alternative approach is required. The approach taken in Experiment 7 was to set aside the issue of individual differences and combine data across participants. Data was combined using the vincentizing procedure that was described in Chapter 2.

Experiment 7

Experiment 7 investigated whether there are developmental differences in the spatial scale and time course across which second-order relations are computed using the same task that was development in Experiment 6. In addition, the experiment also examined whether there are developmental differences in the stopping rule used when participants are asked to detect differences between faces. Finally, Experiment 7 explored whether there are developmental differences in the distribution of attention across faces when participants are asked to perform a 2AFC 'same'/'different' task.

It may be that young children process second-order relations over a larger spatial scale than adults. If this is the case, then we would expect to see evidence that that the capacity coefficient was above 1, that there was a violation of the Miller inequality and no violation of the Grice inequality. It may also be that children move from detecting differences between faces in serial using an exhaustive stopping rule to detecting differences between faces in parallel using a self-terminating stopping rule. In this case, we would expect to see different values of the interaction contrasts for adults, adolescents and children. Finally, it may be that younger children are unable to distribute their attention equally between eyes and mouths whereas adults are able to distribute their attention equally between features. In this case, we would expect to see differences in gradient or relative decline of the survivor functions for the eyes and mouth conditions for young children and adolescents, but not for adults.

Method

Participants

Four age groups of participants were recruited. Initially, 14 adults, 14 14-15-year-olds, 14 11-12-year-olds and 16 8-9-year olds were recruited. Unfortunately, 3 adults, 6 14-15-year-olds, 2 11-12-year-olds and 8 8-9-year-olds had to be excluded from data analysis either because error rates exceeded 25% across the whole experiment (Townsend & Wenger, 2004) or because they failed to complete all trials. Of the remaining participants, the adult group (N=11) had a mean age of 23.06 years (SD=2.67 years), 2 were male and all were right handed. The 14-15-year-old group (N=8) had a mean age of 14.07 years (SD=0.10 years), 5 were male and 7 were right handed. The 11-12-year-old group (N=10) had a mean age of 11.90 years (SD=0.24 years), 6 were male and all were right handed. Finally, the 8-9-year-old group (N=8) had a mean age of 8.58 years (SD=0.32 years), 3 were male and all were right handed. Adults were recruited through the scheme of research participation at the University of Southampton. Children were recruited through schools. All participants had normal or corrected to normal vision. Neither adults nor children had participated in the previous experiments.

Apparatus and Stimuli

All details of Experiment 7 were the same as in Experiment 6 with the following exceptions. An additional eight male faces were obtained from the Nimstim database (Tottenham et al., 2002). All stimuli were created with the eyes moved up by 9% and 14% of the distance between the centre of the eyes and the hairline; and the mouth was moved down by 9% and 14% of the distance between the centre of the mouth and the bottom of chin. Stimuli were created in the same way in Experiment 7 as they were in Experiment 6. Features were moved by a greater amount in Experiment 7 to make the task easier for children. Importantly, these manipulations were still within the range that participants classified as 'normal' (McKone et al., 2005). Participants were presented with both face and car stimuli as part of Experiment 7. Unfortunately, accuracy rates in the car condition were above 25% for all age groups except adults. Data from the car condition for adult participants was used in a control study (described below) but the data were not analysed further as Wenger & Townsend (2004) have shown that the values of capacity coefficient, Miller and Grice inequalitites become unreliable once participants exceed 25% errors.

Design and Procedure

Participants were asked to decide whether two simultaneously presented faces were the 'same' or 'different'. The experiment was divided into four blocks. Each block contained four faces; two female and two male. Each face was repeated 12 times in each block. In 6 trials the faces were the 'same' and in the remaining 6 trials the faces were 'different'. On 'different' trials, face AA was paired with face AB, AC, BA, BC, BB and CC (see Table 5 for condition names and descriptions). Only combinations necessary to calculate the capacity coefficient, Miller inequality, Grice inequality and interaction contrasts were included in Experiment 7 to reduce the task demands placed on participants.

Table 4
Descriptions of the Conditions that were Presented in Experiment 7

Condition	Eyes	Mouth
AA	No change	No change
AB	No change	9%
AC	No change	14%
BA	9%	No change
BC	9%	14%
BB	9%	9%
CC	14%	14%

Manipulated faces were presented once on the left side of the fixation cross and once on the right side of the fixation cross. The order of each face was counterbalanced within each block as was manipulation type. The order of blocks was also counterbalanced. Participants were asked to respond as quickly as possible, whilst responding as accurately as possible. All other details of Experiment 7 were the same as in Experiment 6.

Control tasks

The necessity of changing stimuli in Experiment 7 relative to Experiment 6 (features were moved by a greater amount in Experiment 7 relative to Experiment 6) means that we cannot, a priori, assume that the basic findings of Experiment 6 hold in Experiment 7. Therefore, two control experiments were conducted using the stimuli to be shown in Experiment 7. The first control task examined whether each age group showed an inversion effect for facial stimuli, such that we can be sure that faces used in Experiment 7 are processed using second-order relational processing. The second control task investigated whether there was evidence of a cross over interaction between faces and cars for adult participants only.

In the first control task, all participants who completed Experiment 7 were shown upright and inverted pairs of faces. Pairs of faces were either the 'same' (i.e. both un-manipulated) or 'different' (i.e. one un-manipulated and one with both features manipulated by 14%). Participants were asked to decide whether the faces were the 'same' or 'different'. Mean RTs and error rates are presented in Table 5.

For RTs, the main effects of orientation and age group were significant ($F(1, 3)=57.44$, $p<.01$ and $F(3, 33)=5.95$, $p<.01$), participants were faster when faces were upright compared with inverted. The effect of orientation was significant for all age groups ($F(1, 10)=44.95$, $p<.01$, $F(1, 7)=13.45$, $p<.01$, $F(1, 9)=18.71$, $p<.01$ and $F(1, 7)=9.31$, $p<.05$ for adults, 14-15, 11-12 and 8-9-year-olds respectively). There was no significant difference between adults and 14-15-year-olds ($t(17)=1.35$), but adults were significantly faster than 11-12 and 8-9-year olds ($t(19)=4.56$, $p<.01$ and $t(17)=3.05$, $p<.01$ respectively). There was no significant difference between the three youngest age groups ($F(2, 23)=2.00$). The interaction between orientation and age group was not significant ($F(3, 33)=1.14$).

For error rates, the main effect of orientation was significant ($F(1, 3)=61.67$, $p<.01$), but the main effect of age group and the interaction between orientation and age group were not significant ($F(3, 33)=2.52$ and $F(3, 33)=1.32$ respectively). The interaction between orientation and age group was also not significant ($F(3, 33)=1.20$). Given that the effect of inversion was significant in the RT analysis we can be confident that participants were using second-order relational processing for upright faces.

Table 5

Mean RTs and Error rates (and standard errors) in the Upright and Inverted Conditions where Two features were Manipulated by 14%

Age	Orientation	RT (standard error)	Error rate (standard error)
Adults	Upright	935.83 (34.77)	3.41 (1.55)
	Inverted	1698.39 (130.32)	20.45 (3.51)
14-15	Upright	1132.81 (123.08)	2.34 (1.45)
	Inverted	2004.32 (358.17)	19.14 (4.24)
11-12	Upright	1419.09 (50.54)	3.75 (1.67)
	Inverted	2631.74 (267.49)	26.25 (3.69)
8-9	Upright	1444.82 (72.66)	6.25 (1.67)
	Inverted	2852.99 (483.23)	37.11 (10.13)

The strongest evidence for second-order relational processing for faces would arise in the form of a cross-over interaction between faces and cars. To investigate whether there is evidence of a cross over interaction adult participants were simultaneously presented with two non-manipulated faces/cars or with a non-manipulated face/car and a face/car with both features moved by 14%. Participants were asked to decide whether the faces/cars were the 'same' or 'different'. Results were analyzed in a 2 (Stimulus: Faces versus Cars) x 2 (Orientation: Upright versus Inverted) repeated measures ANOVA. The interaction between stimulus and orientation was significant in both the RT and error analysis ($F(1, 10)=68.65$, 17.78, both $p<.01$ respectively). These interactions are shown in Figure 15. The presence of significant interactions for both RTs and error rates provides clear evidence that participants were employing second-order relational processing in the face condition but not in the car condition.

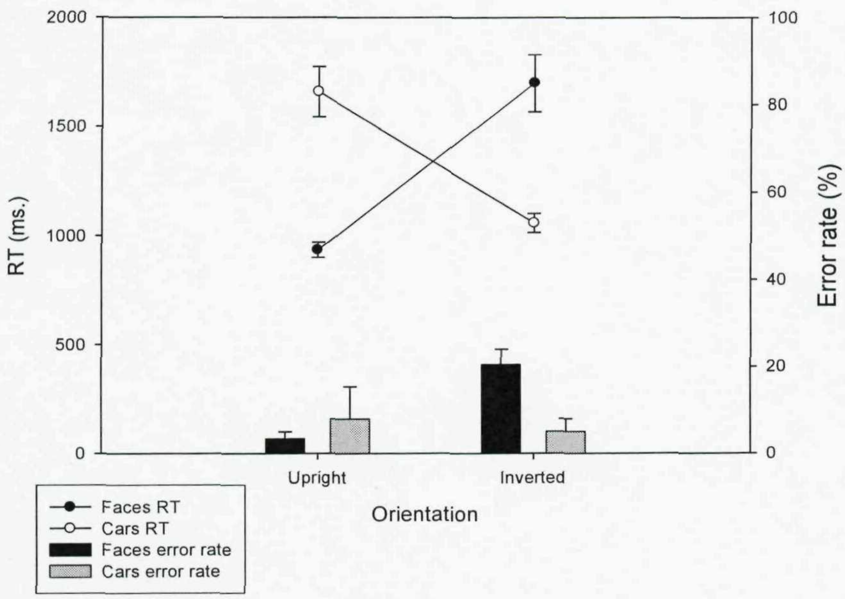


Figure 16. Mean RT and error rates with standard errors for adult participant when presented with upright and inverted faces and cars.

Results for capacity and independence

Before analyses were conducted at the level of the survivor function, it was necessary to investigate whether there was evidence of a redundancy gain (faster performance at the level of the mean in the two feature change condition than in either the eye or mouth condition). All three forms of processing (independent, co-active and global-configural) can account for a redundancy gain; however, the absence of a redundancy gain would immediately rule out coactive and global-configural processing as both forms of processing can predict faster RTs in the two feature change condition relative to the one feature change condition.

Redundancy gain at the level of the mean

The results were analysed for the conditions in which features were manipulated by 14% rather than 9%, as error rates were too high to be able to conduct analyses regarding capacity when features were manipulated by 9% (see Townsend & Wenger, 2004). The results were analysed in the same way as in Chapter 2. RTs and error rates were compared separately in a 3 way (Condition: Two features (CC) versus Eye change (CA) versus Mouth change (AC)) repeated measures ANOVA with age group as a between subjects factor.

RT - The main effects of condition and age group were significant ($F(2, 68)=16.41, p<.01$ and $F(3, 34)=12.81, p<.01$ respectively). Participants were faster in the two feature change condition than in the eye condition and the mouth condition ($t(37)=2.80$, 5.60, both $p<.01$) and were faster in the eye condition than the mouth condition ($t(37)=3.32, p<.01$). The difference between adults and 14-15-year olds approached significance ($t(17)=1.92, p=.07$) and adults were significantly faster than 11-12-year-olds and 8-9-year-olds ($t(20)=6.01, p<.01$ and $t(17)=5.61, p<.01$ respectively). There was no significant difference between the three youngest age groups ($F(2, 24)=1.38$). The interaction between condition and age group was not significant ($F(6, 68)<1$).

Accuracy - The main effect of condition was significant ($F(2, 68)=32.43, p<.01$). Participants were significantly more accurate in the two feature change condition than in either the eye and mouth conditions ($t(37)=2.95$, 9.76, both $p<.01$). Participants were also significantly more accurate in the eye condition than the mouth condition ($t(37)=4.92, p<.01$). The main effect of age group was not significant ($F(3, 34)=1.12$) neither was the interaction between condition and age group ($F(6, 68)<1$).

A redundancy gain has been found for all age groups (see Figure 16). Analyses were, therefore, conducted at the level of the survivor function.

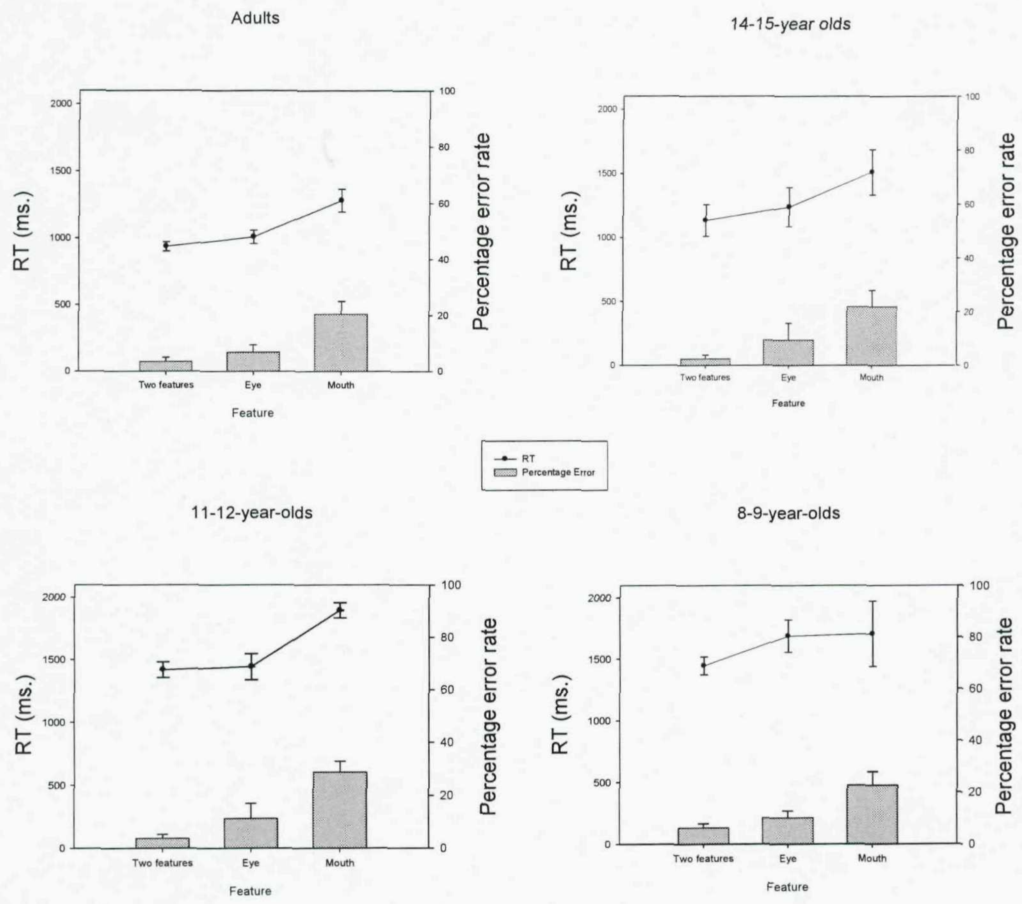


Figure 17. RTs and error rates, with standard errors at the level of the mean for the CC (two features), CA (eye) and AC (mouth) conditions separately for all age groups.

Results at the level of the survivor function

Although at the level of the mean there was no interaction between condition and age group, this does not, however, mean that there will not be differences between the three age groups in terms of their survivor functions. Different means can be produced from different survivor functions (Collett, 1994). For example, two survivor functions that cross over can produce the same mean. It is, therefore, worth exploring the results at the level of the survivor function as differences may still be detected.

Data were vincentized for all age groups according to the procedure used in Chapter 2. The results of the capacity coefficient, Miller and Grice inequality can be seen in Figure 17. Values of the capacity coefficient are displayed on the left hand Y axis and values of the Miller and Grice inequalities on the right hand Y axis.

Figure 17 demonstrates no violation of the Miller inequality for any age group at any time point. It also highlights evidence of a violation of the Grice inequality for all age groups at some time points. In addition, the capacity coefficient was below 1 for all participants at all time points. Importantly, there were no differences between age groups in any of the three measures.

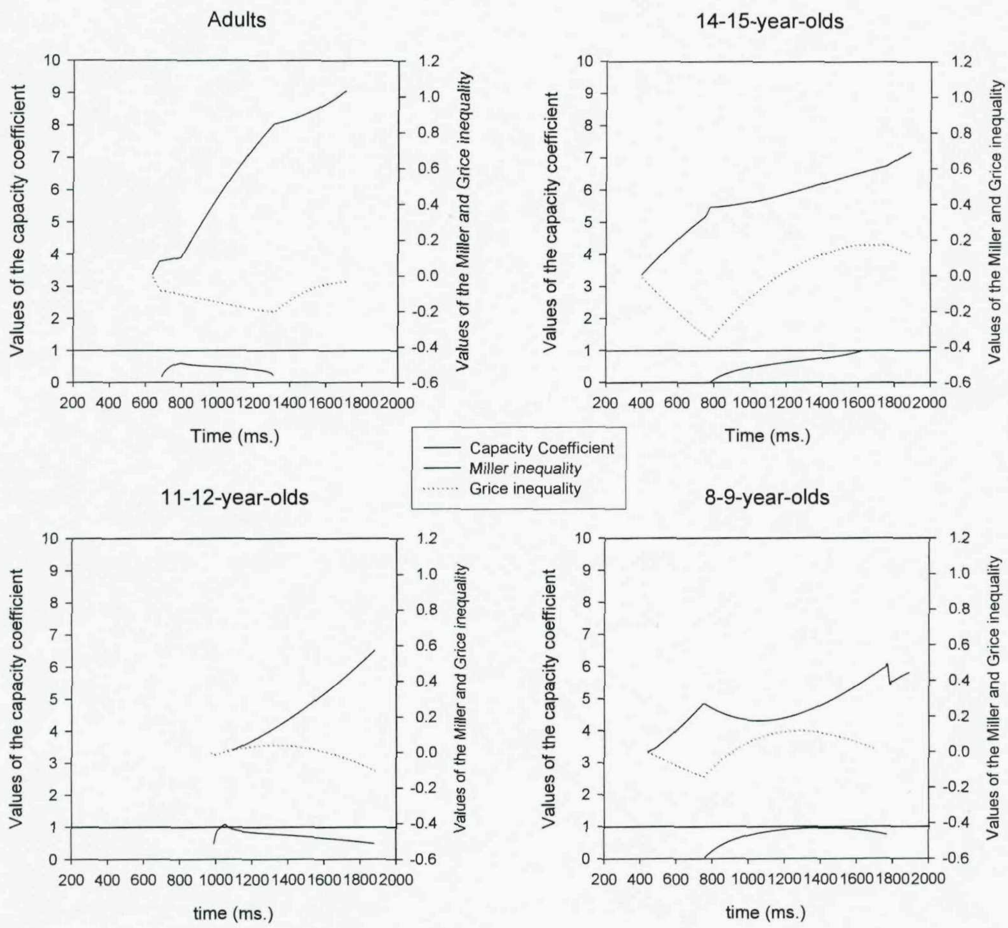


Figure 18. Values of the capacity coefficient, Miller inequality and Grice inequality for all participants. Excursions above the solid reference line for the capacity coefficient is consistent with coactive/global-configural processing. Excursions below 0 for the Miller inequality are also consistent with coactive/global-configural processing.

Results for architecture and stopping rule

In order to reach conclusions regarding the architecture and stopping rule of the face processing system it is necessary to examine the values of the interaction contrasts at the level of the mean and at the level of the survivor function. However, for interaction contrasts to be interpretable, selective influence at the level of the mean and at the level of the survivor function (see p.89) must be confirmed (Ingvalson & Wenger, 2005).

Selective influence at the level of the mean

At the level of the mean, selective influence was investigated by analysing eye and mouth changes in a 2 (Eye change: 9% or 14%) x 2 (Mouth change: 9% or 14%) repeated measures ANOVA with age group as a between subjects factor. Evidence consistent with selective influence would take the form of main effects for each age group for each feature, with 14% manipulations being faster than 9% manipulations.

Means associated with each change are presented in Table 6. Importantly, there was a significant main effect for the eye changes and the mouth changes ($F(1, 37)=12.86, p<.01$ and $F(1, 37)=12.21, p<.01$ respectively). No interactions involving the age group factor were significant ($F(3, 34)=2.06$, 2.01, 1.15 for the interactions between eye and age group, mouth and age group and eye by mouth by age group respectively).

Table 6

Mean Response Times as a Function of Change Type Across All Participants

Eye	Mouth	RT	Standard Error
9%	9%	1368.17	62.67
9%	14%	1305.93	54.83
14%	9%	1306.79	62.44
14%	14%	1236.25	48.80

Now that the assumption of selective influence has been confirmed at the level of the mean it is necessary to confirm selective influence at the level of the survivor function (see Chapter 3 p.89).

Selective influence at the level of the survivor function

Survivor functions for the BB, BC, CB and CC condition were generated in the same way as in Chapter 3. These survivor functions can be seen in Figure 18.

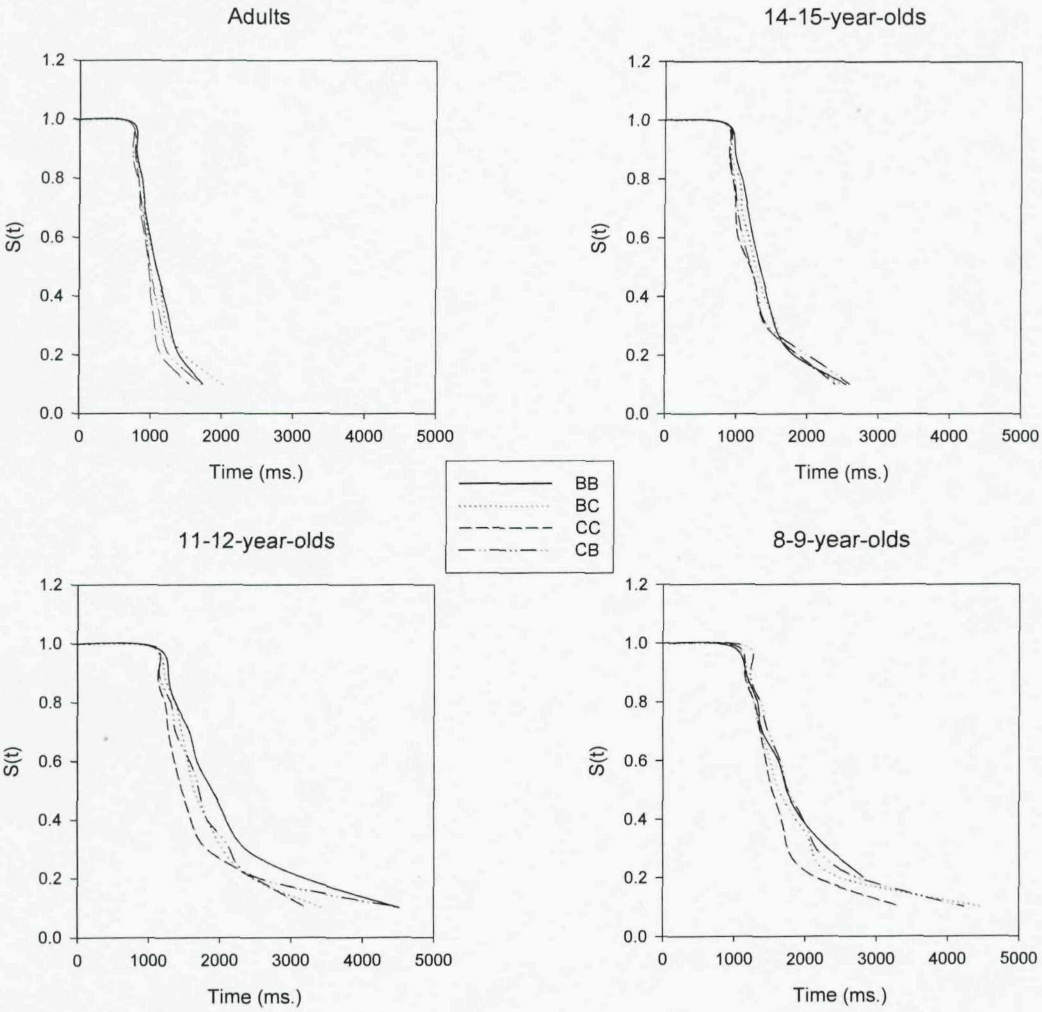


Figure 19. Values of the survivor function for the two feature change conditions (see Table 5 for condition names and descriptions).

For all age groups the survivor function for the condition where both features were manipulated by 14% is below and to the left of the survivor function for the condition where both features were manipulated by 9%. The results are, therefore, consistent with the assumption of selective influence at the level of the mean and at the level of the survivor function. It is now possible to investigate the interaction contrasts at the level of the mean and the survivor function.

Interaction contrasts

The interaction contrasts at the level of the mean were computed in the same way as in Chapter 3 but using group means rather than individual means. Values of IC_m can be seen in Table 7.

Table 7

Interaction Contrasts at the Level of the Mean for All Groups

Group	Interaction contrast at the level of the mean
Adults	28.09
14-15-year-olds	50.22
11-12-year-olds	-85.34
8-9-year-olds	-160.74

The interaction contrasts at the level of the survivor function was calculated in the same way as in Chapter 3 but using vincentized survivor functions. Values of IC_{sf} can be seen in Figure 19.

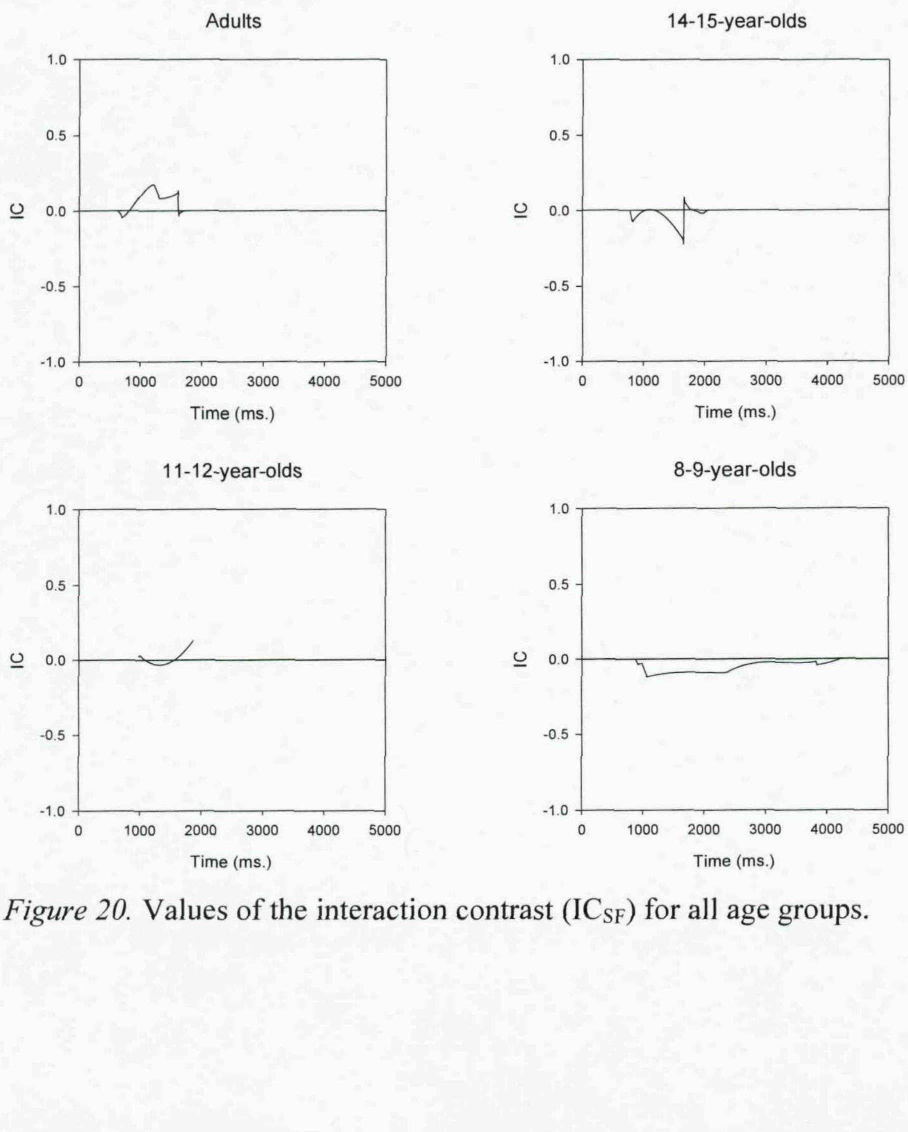


Figure 20. Values of the interaction contrast (IC_{SF}) for all age groups.

The interaction contrasts at the level of the mean and at the level of the survivor function are summarised in Table 8 along with the inferences that they support.

Table 8

Summary of Interaction Contrasts at the Level of the Mean and the Survivor Function and the Inferences Supported

Age Group	IC_M	IC_{SF}	Architecture	Stopping rule
Adults	>0	>0	Parallel	Self-terminating
14-15	>0	<0	Undefined	Undefined
11-12	<0	<0	Parallel	Exhaustive
8-9	<0	<0	Parallel	Exhaustive

The results demonstrate that adults detected differences between faces in parallel using a self-terminating stopping rule, whereas 11-12-year-olds and 8-9-year-olds detected differences between faces in parallel using an exhaustive stopping rule. It was not possible to make any inference for the 14-15-year-old group; this may have been because the combined data resulted from participants using either self-terminating or exhaustive stopping rules.

Results for the allocation of attention across stimuli

The distribution of attention across faces was investigated by examining the gradients and relative positions of the survivor functions. A greater number of correct responses were generated in the conditions in which features were manipulated by 14% than 9% and so the CA and AC survivor functions were compared. Some participants were faster in the eye than the mouth condition and vice versus. Therefore, because data was combined across participants it was important to combine data for the fastest survivor function and compare it to the combined data for the slowest survivor function. Otherwise, the data will be influenced by averaging artefacts. The survivor functions can be seen in Figure 20.

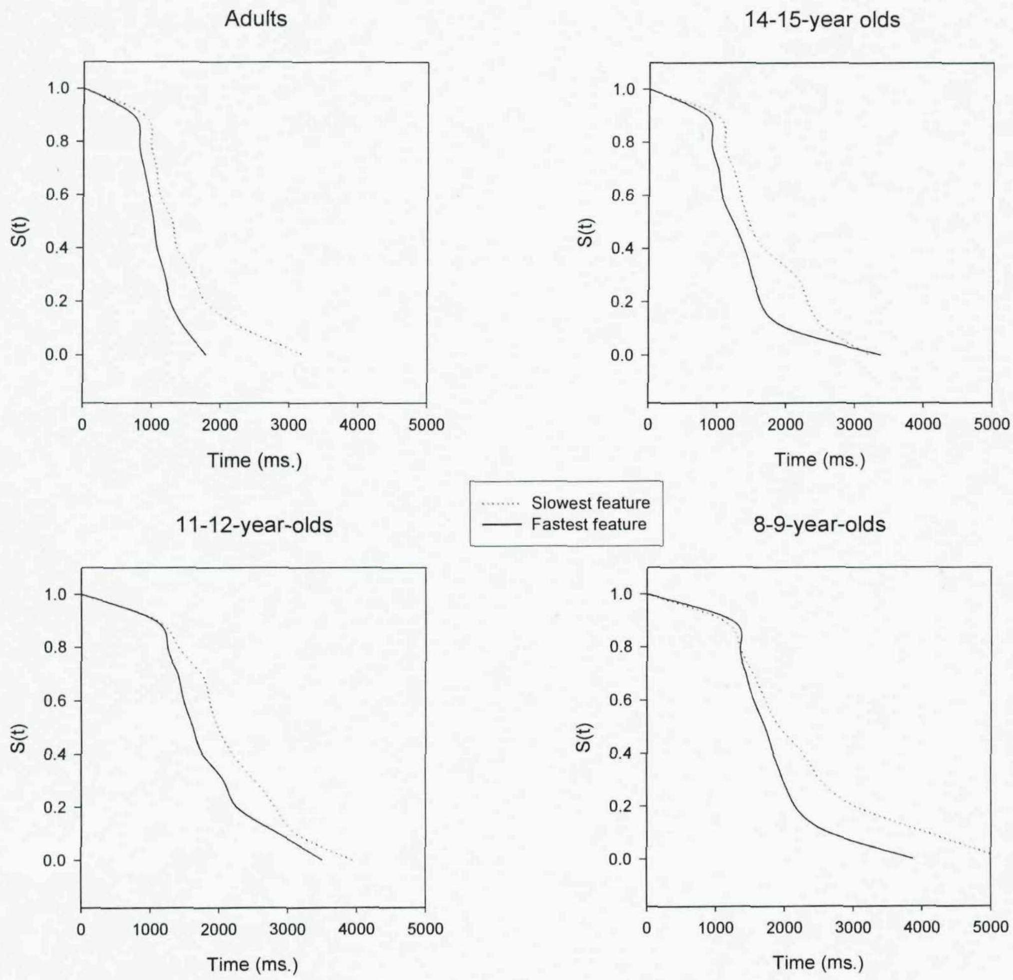


Figure 21. Values of the survivor functions for the fastest and slowest survivor functions in the eye (CA) and mouth (AC) conditions.

The log rank test was performed on the data to investigate whether there was a significant difference between survivor functions for the single feature change conditions. There was no significant difference between the eye and mouth survivor functions for any age group ($\chi^2(1)$=2.76, <1, =1.18, 1.26, for adults, 14-15, 11-12 and 8-9-year-olds respectively.

Discussion

At the level of the mean, RTs decreased with age. Despite the decrease in RT associated with development, RTs for all age groups were faster in the two feature change condition than in the eye or mouth conditions. Evidence of a redundancy gain in all age groups is consistent with the results of Experiments 1-4 and 6. However, despite evidence of a redundancy gain, there was no evidence of a violation of the

Miller inequality at any time points, the capacity coefficient was below 1 at all time points, and there was some evidence of a violation of the Grice inequality at some time points for all age groups. The results showed no support for coactive or global-configural processing. RTs were only as fast in the two feature change condition as would be expected based on performance in the single feature change conditions and were even slower than expected at some time points given the violations of the Grice inequality. Given the presence of significant inversion effects with these stimuli we must, therefore, conclude that all age groups were employing an unlimited or limited capacity independent channels race model which is consistent with local-configural processing. These results suggest that the increase in the efficiency of second-order relational processing associated with development is not underpinned by a decrease in the spatial scale across which second-order relations are computed.

At the group level, the results showed that adults detected differences between faces in parallel using a self-terminating stopping rule. These results are consistent with the results of Chapter 3. Importantly, this suggests that the results were not influenced by combining data across participants. Unfortunately, it was not possible to determine the architecture or stopping rule used by 14-15-year-olds. However, the results suggested that children aged 8-9 and 11-12-years detected differences between faces in parallel using an exhaustive stopping rule.

To date, this is the first demonstration of a developmental differences in the stopping rule participants use when asked to detect differences between pairs of faces and so further research is required in order to replicate this finding. However, it is worth considering this result further now. Given that younger participants are less efficient at encoding second-order relations (e.g. Donnelly & Hadwin, 2003), they may not be able to form such a 'robust' representation of the first face that is processed compared with adults. If this is the case, then younger participants will be less certain that any deviation (in the form of activation building in a response channel to suggest that the two faces are 'different') away from the representation of the first face reflects a difference between the two stimuli. Decreased certainty may mean that participants are not willing to generate their response until all information has finished being processed.

Younger children (8-9 and 11-12-year-olds) could, therefore, be considered as being more conservative (in terms of SDT) than adolescents and adults in the time point at which they generate their response. Adopting a more conservative response criterion in terms of the time point at which participants generate their response may suggest that younger participants may also be conservative in terms of the response that the participant generates. This possibility will be examined as part of Experiment 8.

The final result highlighted by Experiment 7 was that there were no differences in terms of gradient or relative position between the eye and mouth survivor functions. These results suggest that all age groups were capable of distributing their attention equally between eyes and mouths. Perhaps by 8-9-years children have already developed sufficient expertise at processing faces that they are able to split their resources or spread them widely across eyes and mouths. There is, however, one important consideration to note. The analyses conducted on the survivor functions for the eye and mouth conditions showed no difference between the eye and mouth survivor functions. However, at the level of the mean the results showed that the mean RT for the eye condition was faster than the mouth condition. These two results are difficult to reconcile, given that similar survivor functions should produce similar means. One way that these results can be reconciled is by assuming that the log-rank test is a more stringent test of difference than the t-test. This is highly likely given that the t-test is a parametric test and the log-rank test is a nonparametric test. In light of this discrepancy, the conclusion that attention is divided equally will be viewed tentatively. It is, however, clear that resources are divided more evenly for faces than for objects (which did highlight differences between survivor functions in Chapter 3).

Taken together, Experiment 7 showed that there were no developmental differences in the spatial scale over which second-order relations are computed, the time scale over which differences between faces are detected, or the distribution of attention between eyes and mouths. Experiment 7 did, however, highlight developmental differences in RT, accuracy and stopping rule. These results suggest that with development the nature of second-order relational processing does not change, but participants become more efficient at second-order relations with development. The increase in efficiency may mean that participants can develop more 'robust' representation that they can use to match and compare subsequent inputs against.

Chapter 5

The results of Experiments 1-7 have shown that there are no developmental differences in the spatial scale across which second-order relations are computed, the time course over which differences between faces are detected or the distribution of attention across faces when participants are asked to perform a 2AFC 'same'/'different' task. There do, however, appear to be developmental differences in the efficiency of second-order relational processing (in terms of RT and accuracy) and the stopping rule participants use when performing a 2AFC 'same'/'different' task. Experiments 8 and 9 explored whether the increase in the efficiency of second-order relational processing was accompanied by a decrease in the range of orientations that can be processed using second-order relational processing. Experiment 8 additionally examined whether there are developmental differences in the response criterion that participants use to determine the response (either 'odd' or 'normal') that is generated in a 2AFC task with the Thatcher illusion.

Previous research has examined the range of orientation across which adults can process second-order relations (e.g. Sturzel & Spillman, 2000; Lewis, 2001; Martini, McKone & Nakayama, 2005; Marzi & Viggiano, 2007; Collishaw & Hole, 2002; McKone, 2004; Rossion & Boremanse, in press). For example, Lewis (2001) investigated the range of orientations over which adults could perceive the Thatcher illusion (Thompson, 1980, see Figure 1; also see Sturzel & Spillman, 2000; Sjoberg & Windes, 1992; Edmonds & Lewis, 2007). Sensitivity to the Thatcher illusion is an accepted test that has been used to determine whether participants are processing second-order relations (e.g. Bartlett & Searcy, 1993). Lewis (2001), therefore, argued that the range of orientations across which participants were sensitive to the Thatcher illusion represented the range of orientations across which participants were able to process a face using second-order relational processing. Lewis (2001) showed that adults were fast and accurate at discriminating between 'normal' and 'Thatcherised' faces at angles between 0 and 90 degrees, but discrimination was more difficult (i.e. RTs were slower) once faces were oriented past 90 degrees. These results suggest that adults were able to process second-order relations when faces were oriented between 0 and 90 degrees, but were unable to process second-order relations when faces were oriented past 90 degrees.

One study which has investigated whether there are developmental differences in the range of orientations over which faces are processed using second-order relational processing was conducted by Lewis (2003). Lewis (2003) asked adults and children to rotate an inverted 'Thatcher' face to the orientation at which it first appeared grotesque. Lewis (2003) argued that the orientation at which the face was deemed to be grotesque reflected the orientation at which the face was being processed using second-order relational processing. The orientation at which grotesqueness arose varied between 35 and 130 degrees across participants, with a mean angle of 72 degrees. Lewis's (2003) results did not, however, reveal any effect of age on the critical angle at which grotesqueness appeared, except when participants under 25-years and participants over 25-years were compared. No a-priori reason for this comparison was provided, the study employed a single stimulus and only had only 12 participants aged between 10 and 20-years, suggesting that the difference between under and over 25-year-olds should be treated with caution.

Experiment 8

In Experiment 8, adults and participants aged 8-9, 11-12 and 14-15-years were asked to discriminate between 'normal' and 'Thatcherised' faces that were presented at 0, 45, 90, 135 and 180 degrees. It was expected that adults would be highly sensitive at discriminating between 'normal' and 'Thatcher' faces at orientations between 0 and 90 degrees, but would be poor at discriminating between 'normal' and 'Thatcher' faces at orientations beyond 90 degrees (Lewis, 2001). In contrast, children would be less sensitive than adults in discriminating between 'normal' and 'Thatcherised' faces at orientations close to upright (see Donnelly & Hadwin, 2003, described in Chapter 1, p.34). Based on previous developmental research, it was expected that there would be a continuous improvement (i.e. there would be evidence of differences between 8-9 and 11-12-year-olds and between 11-12 and 14-15-year-olds and between 14-15-year-olds and adults) in sensitivity across childhood and adolescence (e.g. Mondloch et al., 2002; Donnelly & Hadwin, 2003). If the range of orientations across which faces can be processed using second-order relational processing decreases with development, as suggested by research conducted with infants (see Chapter 1, p.36) then children would experience a decline in sensitivity to the Thatcher illusion at a later orientation than adults.

In Chapter 1 it was highlighted that a number of experiments that have shown evidence of developmental differences in face processing might have been influenced by differences in response criterion (see Chapter 1, p.24). Given this possibility, Experiment 8 employed a measure of sensitivity that is independent of response bias. D prime was used so that any difference between age groups and across orientations could be localised to differences in perceptual processing rather than to differences in response criterion. Using d' as a measure of sensitivity meant that an associated measure, c, could also be employed to investigate developmental differences in the response criterion used by participants to generate a response. Based on the results from Chapter 4 it was expected that children would adopt a more conservative response criterion compared with adults (see p.113).

In Experiment 8, participants also completed a control condition, so that any developmental differences in the face condition could be localised to face-specific processes rather than more general object processes. Experiment 8 used churches as control stimuli for the same reasons that they were employed in Experiment 5 (see p.74). Based on previous research, which has shown that featural processing is mature by 10-years (Mondloch et al., 2002), it was expected that there would be no evidence of developmental differences between the 11-12-year-old, 14-15-year-old and adult groups in the church condition. In addition, given that the effect of inversion is greater for faces compared with objects (Yin, 1969), it was expected that the effect of orientation on sensitivity would be smaller in the church condition compared with the face condition.

Method

Participants

The same participants who took part in Experiment 7 also participated in Experiment 8. The adult group (N=14) had a mean age of 20.75 years (SD=2.71), 5 were male, all were right handed. The 14-15-year-old group (N=14) had a mean age of 14.2 years (SD=0.1), 9 were male, 11 were right handed. The 11-12-year-old group (N=14) had a mean age of 11.9 years (SD=0.33), 9 were male, all were right handed. Finally, the 8-9-year-old group (N=16) had a mean age of 8.61 years (SD=0.23), 8 were male, 15 were right handed. The order in which the experiments were completed was counterbalanced between participants and all experiments were completed within 72 hours.

Apparatus and Stimuli

Stimuli were presented on a Compaq Evo N400c laptop computer with a screen size of 12 inches and a refresh rate of 60 hertz. The stimuli were presented and responses (percentage correct) were recorded using E Prime software (Psychology Software Tools Inc.). The stimuli were manipulated using Adobe Photoshop software.

Experiment 8 used the same stimuli as in Experiment 7 with the following exceptions. Face stimuli were resized so that they measured 4.8 cm in height by 4 cm wide, corresponding to a visual angle of 3.66 by 3.05 degrees when viewed from a distance of 75 cm. Stimuli were manipulated in the same way as described in Chapter 2 (all 'Thatcherised' stimuli had both the eyes and the mouth inverted). 'Thatcherised' churches were the same as those used in Experiment 5. Churches were resized to 4 cm in height by 4.8 cm wide, corresponding to a visual angle of 3.05 by 3.66 degrees when viewed from a distance of 75 cm. Both 'normal' and 'Thatcherised' versions of faces and churches were presented upright, 45, 90, 135 and 180 degrees creating a total of 160 face trials and 160 church trials.

Design and Procedure

A 2AFC paradigm was employed. Participants were asked to decide whether a face or church was 'odd' or 'normal'. Responses were made using mouse buttons. Button assigned to 'normal' or 'odd' were counterbalanced between participants and labelled with 'N' and 'O' stickers. Faces and churches were presented separately; the face and church conditions were counterbalanced and completed within 24 hours. Each condition was separated into four blocks. The order of blocks was counterbalanced between participants. Each block consisted of 4 faces/churches. In the face condition, two of these faces were female and two were male. Each face/church was presented 10 times in each block; five trials consisted of 'normal' faces and five trials consisted of 'Thatcherised' faces. Faces/churches were presented twice at each orientation, once as a 'normal' face and once as an 'odd' face. The order of 'normal'/'odd' faces/churches was randomised within each block as was the order of orientations.

A fixation cross appeared on the screen for 500 ms before the onset of the stimulus. Stimuli were present on the screen until a response was made. All participants were shown two paper based examples of 'odd' and 'normal' faces/churches that were not included within the experiment. The experimenter described how the 'Thatcherised' faces/churches had been created. Participants were tested in a quiet area of their school, or at the School of Psychology at the University of Southampton. Although participants were free to move their heads they were instructed to maintain an upright head position. Head position was monitored by the experimenter at all times.

Results

For each participant, the number of correct responses at each orientation was calculated separately for faces and churches. The number of correct responses at each orientation was converted into percentage correct (see Table 9). The percentage correct for each orientation was then used to calculate *d'* and *c*. D prime is a measure of sensitivity and *c* is a measure of response criterion. Sensitivity is defined as the ability of the participant to detect a signal (the neural activity elicited by the target, in this case a 'Thatcherised' face) from noise (the neural activity elicited by the distractors, in this case a 'normal' face). Response criterion is the number of times that the participant generates a particular response, for example, the proportion of times that the participant responds 'odd'. Importantly, *d'* is a measure of sensitivity that is independent of response criterion. It is calculated by subtracting the z score (the number of standard deviations from the mean) of the hit rate from the z score of the false alarm rate. In this case, the hit rate was the proportion of trials in which the participants responded 'odd' to 'Thatcherised' trials and the false alarm rate was the proportion of trials in which the participant responded 'odd' to 'normal' trials. A higher value of *d'* indicated higher sensitivity, so that a perfect ability to detect 'odd faces from 'normal' faces would be indicated by a value of 6.18. Chance performance would be indicated by a value of 0.

C values were calculated by multiplying -0.5 by the sum of the z score of the hit rate and the z score of the false alarm rate. A *c* value of 0 indicated that the participant responded 'odd' on 50% of trials. A value of *c* that is below 0 indicated that the participant was more likely to respond 'odd' than 'normal' and a value of *c* that was above 0 indicated that the participant is more likely to respond 'normal' than 'odd'. A participant who responded 'odd' on every trial would have received a *c* value of 3.09.

Table 9

Percentage Correct for 'Normal' and 'Odd' Faces/churches for all Age Groups at each Orientation

Stimulus	Type	Orientation	Adults	14-15	11-12	8-9
Faces	Thatcherised	0	91.5	77.2	77.7	68.4
	Thatcherised	45	91.5	81.2	80.8	74.2
	Thatcherised	90	82.6	75.5	59.8	70.7
	Thatcherised	135	73.6	72.3	65.2	62.5
	Thatcherised	180	56.7	63.8	62.9	61.7
	Normal	0	88.8	71.4	78.6	75.0
	Normal	45	87.1	71.0	83.0	62.9
	Normal	90	87.1	62.1	72.3	47.3
	Normal	135	70.5	54.5	62.1	50.0
	Normal	180	79.5	58.5	67.4	49.6
Churches	Thatcherised	0	78.2	79.5	77.7	78.9
	Thatcherised	45	79.5	77.7	77.7	72.7
	Thatcherised	90	76.8	76.8	72.3	74.7
	Thatcherised	135	74.6	76.4	74.1	72.7
	Thatcherised	180	72.8	67.0	62.1	70.7
	Normal	0	81.3	82.6	79.0	73.3
	Normal	45	81.7	78.6	74.2	74.3
	Normal	90	75.0	68.8	76.8	69.5
	Normal	135	79.5	76.4	72.3	72.7
	Normal	180	73.7	68.8	72.8	73.4

Sensitivity

A 5 (Orientation: 0 versus 45 versus 90 versus 135 versus 180 degrees) by 2 (Stimulus: Faces versus Churches) repeated measures ANOVA was conducted with age group as a between subjects factor. The main effect of stimulus approached significance ($F(1, 54)=2.93, p=.09$). Participants were more sensitive in the face condition than in the church condition. The main effect of age group was also significant ($F(3, 54)=5.54, p<.01$), adults were significantly more sensitive than all other age groups ($t(26)=2.85$, $p<.05$, $t(26)=2.99, p<.05$ and $t(28)=3.75, p<.01$ for adults versus 14-15, 11-12 and 8-9-year-olds respectively), but there was no significant difference between the three youngest age groups ($F(2, 43)<1$). The main effect of orientation was significant ($F(4, 216)=31.98, p<.01$). There was no significant difference between 0 and 45 degrees ($t(57)<1$), but participants were more sensitive at 0 degrees than at 90, 135 and 180 degrees ($t(57)=4.77$, 5.19, 9.37 all $p<.01$ respectively). The interaction between stimulus and age group was significant ($F(3, 54)=3.49, p<.05$); adults were more sensitive in the face condition than the church condition ($t(13)=1.93, p=.07$), but 14-15 and 8-9-year-olds were more sensitive in the church condition than the face condition ($t(13)=-2.82, p<.05$ and $t(15)=-2.19, p<.05$ respectively). There was no significant difference between the face and church condition in the 11-12-year-old group ($t(13)<1$). The interaction between stimulus and orientation was significant ($F(4, 216)=9.10, p<.01$). The effect of orientation was significant in the face condition but not in the church condition ($F(4, 60)=9.61, p<.01$ and $F(4, 60)<1$ for faces and churches respectively). The interaction between orientation and age group was not significant ($F(12, 216)=1.06$), but the three way interaction between stimulus, orientation and age group was significant ($F(12, 216)=1.88, p<.05$). In order to explore the three way interaction, faces and churches were analysed separately (see Figure 21).

Faces

A 5 (Orientation: 0 versus 45 versus 90 versus 135 versus 180 degrees) way repeated measures ANOVA with age group as a between subjects factor was conducted. The main effects of orientation and age group were significant ($F(4, 216)=38.99, p<.01$ and $F(3, 54)=10.28, p<.01$). There was no significant difference between 0 and 45 degrees ($t(57)<1$), but participants were more sensitive at 0 degrees than at 90, 135 and 180 degrees ($t(57)$ all t's >4.64, all p's<.01). Adults were significantly more sensitive than all other age groups ($t(26)=3.79$, $p<.01$, $t(26)=3.71$, $p<.01$ and $t(28)=5.16$, $p<.01$ for 14-15, 11-12 and 8-9-year-olds respectively). There was no significant difference between the three youngest age groups ($F(2, 41)<1$).

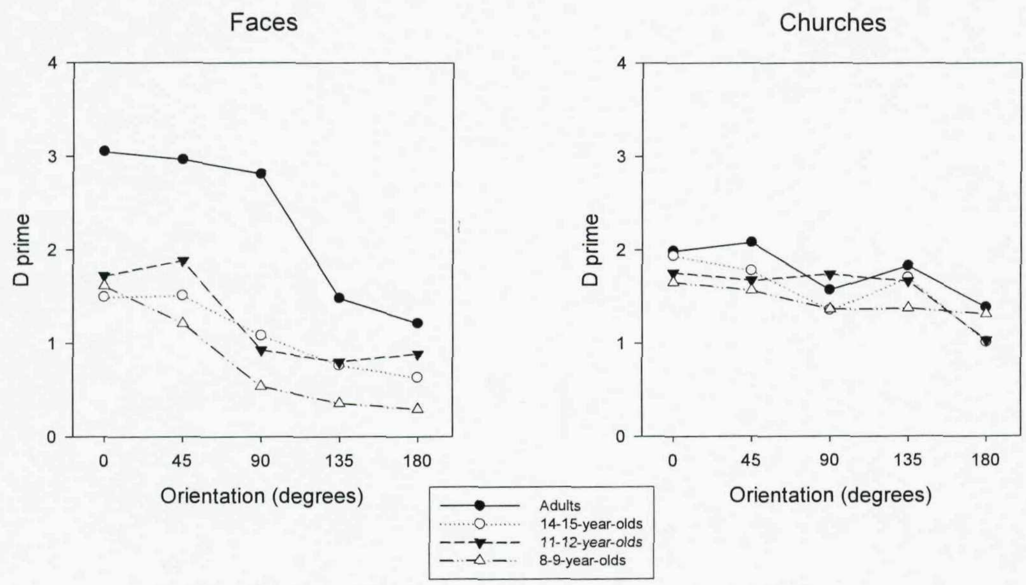


Figure 22. Sensitivity to the Thatcher illusion at each angle of orientation separately for all age groups for the faces condition (left panel) and church condition (right panel).

The interaction between orientation and age group was significant ($F(12, 216)=2.66$, $p<.01$). Adults were significantly more sensitive than 14-15-year-olds at 0, 45 and 90 degrees ($t(26)=3.48$, 3.40, 3.68, all $p<.05$ respectively), but there was no difference at 135 and 180 degrees ($t(26)=1.99$, 1.99). Adults were significantly more sensitive than 11-12-year-olds at 0, 45, 90 and 135 degrees ($t(26)$ all t's >2.12, all p's<.05), but there was no difference at 180 degrees ($t(26)=1.12$). Adults were significantly more sensitive than 8-9-year-olds at all orientations ($t(28)$ all t's >2.66, all p's<.05). The effect of orientation was significant for all age groups ($F(4, 52)=12,35$, $p<.01$, $F(4, 52)=11.45$, $p<.01$, $F(4, 52)=15.70$, $p<.01$ and $F(4, 60)=9.61$ $p<.01$ for adults, 14-15, 11-12 and 8-9-year-olds respectively). To explore the interaction between age group and orientation further, a series of bonferroni corrected two-tailed pair-wise comparisons between orientations were conducted separately for each age group. The results can be seen in Table 10.

Adults experienced a significant decline in sensitivity between 90 and 135 degrees, whereas 14-15, 11-12 and 8-9-year-olds experienced a significant decline in sensitivity between 45 and 90 degrees.

Table 10

T values for Bonferroni Corrected Two Tailed Pair-wise Comparisons between Orientations separately for each Age Group

Orientation	Adults	14-15	11-12	8-9
0 versus 45	<1	<1	<1	<1
45 versus 90	<1	2.25#	5.67**	3.12*
90 versus 135	3.12*	2.02	<1	1.62
135 versus 180	1.09	1.05	<1	<1

#= approaches significance, *=p<.05, **=p<.01

To explore these results further two 2 way repeated measures were conducted across age groups. The first was between 45 and 90 degrees and the second between 90 and 135 degrees. Between 45 and 90 degrees, the main effects of condition and age group were significant ($F(1, 3)=29.62$, 11.56, both $p<.01$) and the interaction between condition and age group was significant ($F(3, 54)=2.77$, $p<.05$). Between 90 and 135 degrees the main effects of condition and age group were significant ($F(1, 3)=16.23$, 11.96, both $p<.01$) and the interaction between condition and age group was significant ($F(3, 54)=5.30$, $p<.05$).

Churches

The main effect of orientation was significant ($F(4, 216)=6.31$, $p<.01$). Pair-wise comparisons showed no significant decline in sensitivity between 0, 45, 90 or 135 degrees ($t(57)<1$, =2.10, <1 respectively), but there was a significant decline in sensitivity between 0 and 180 degrees ($t(57)=5.63$, $p<.01$). The main effect of age group was not significant ($F(3, 54)<1$). Importantly, the interaction between orientation and age group was not significant ($F(3, 54)<1$).

Response Criterion

A 5 (Orientation: 0 versus 45 versus 90 versus 135 versus 180 degrees) by 2 (Stimulus: Faces versus Churches) repeated measures ANOVA was conducted with age group as a between subjects factor. The main effect of stimulus approached significance ($F(1, 54)=3.61$, $p=.06$). Participants were more conservative in the church condition than in the face condition. Neither the main effect of group, nor the main effect of orientation were significant ($F(3, 54)=1.20$ and $F(4, 216)=2.06$ respectively). The interaction between orientation and age group was significant ($F(12, 216)=2.78$, $p<.01$). There was a significant effect of orientation for adults and 8-9-year-olds ($F(4, 52)=4.30$, 3.50, $p<.01$, <.05 respectively), but not for the 14-15 and 11-12-year-olds ($F(4, 52)=1.45$, 1.88 respectively). The interactions between stimulus and age group and stimulus and orientation were not significant ($F(3, 54)<1$ and $F(4, 216)=1.35$). The three way interaction between stimulus, orientation and age group approached significance ($F(12, 216)=1.76$, $p=.056$). This three way interaction was broken down by analysing faces and churches separately (see Figure 22).

Faces

Neither the main effects of orientation or age group were significant ($F(4, 216)=2.16$ and $F(1, 54)=3.03$ respectively). However, the interaction between orientation and age group was significant ($F(12, 216)=3.78$, $p<.01$). There was no significant difference in response criterion between the three youngest age groups ($F(2, 41)=1.53$), but adults were significantly more liberal in their responses than all other age groups at 0 degrees ($t(26)=2.14$, $p<.05$, $t(16)=2.65$, $p<.05$ and $t(28)=2.77$, $p<.05$ for adults versus 14-15, 11-12 and 8-9-year-olds respectively).

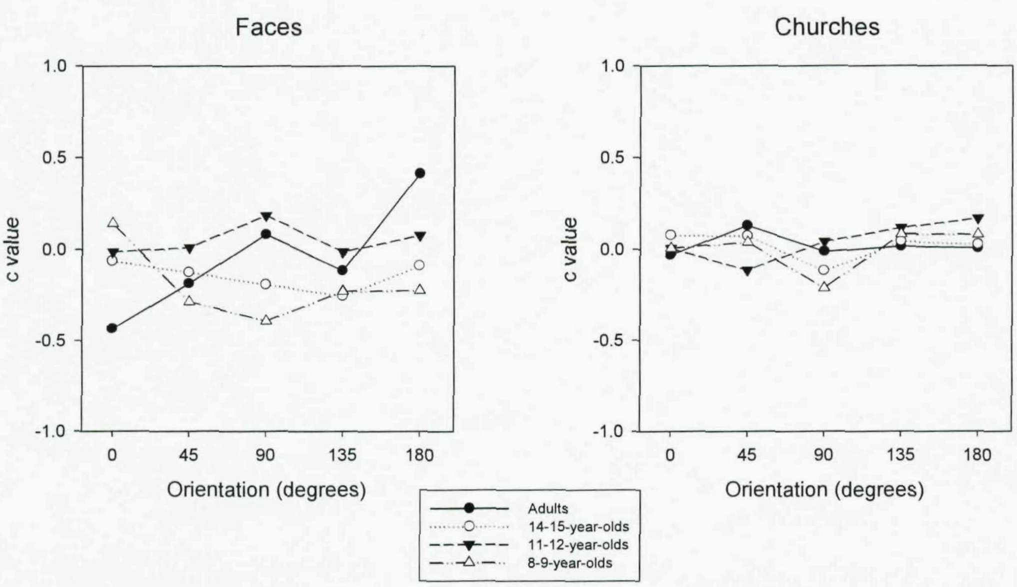


Figure 23. C values for the face condition (left panel) and church condition (right panel) at all orientations separately for each age group.

Churches

The main effect of orientation and age group were not significant ($F(4, 216)=1.18$ and $F(12, 216)<1$ respectively). The interaction between orientation and age group was also not significant ($F(12, 216)<1$).

Discussion

Experiment 8 highlighted two novel findings. First, the range of orientations across which participants were sensitive to the Thatcher illusion increased with development. Adults were equally sensitive at discriminating between 'normal' and 'Thatcherised' faces when faces were oriented between 0 and 90 degrees and only experienced a significant decline in sensitivity when faces were oriented between 90 and 135 degrees. In contrast, 8-9, 11-12 and 14-15-year-olds were equally sensitive at discriminating between 'normal' and 'Thatcherised' faces when faces were oriented between 0 and 45 degrees but experienced a decline in sensitivity when faces were oriented between 45 and 90 degrees. These results suggest that adults were able to process faces using second-order relational processing until they were oriented to 90-135 degrees, whereas younger age groups were only able to process faces using second-order relational processing until they were oriented to 45-90 degrees, suggesting that with development the range of orientations over which second-order relations can be computed broadens.

The second novel finding from by Experiment 8 was that adults were significantly more likely to report that a face was 'odd' compared with adolescents and younger children when faces were upright (as shown by lower *c* values for adults than for adolescents and younger children at 0 degrees). These results suggest that adults adopted a more liberal response criterion than adolescents and younger children. This is the first direct demonstration of developmental differences in the response criterion adopted when participants are asked to make a 2AFC 'odd'/'normal' discrimination. These results are consistent with the idea that with the development of expertise at face processing participants adopt a more liberal response criterion. Given that participants are described as being expert at processing faces compared with objects, the finding that participants were more conservative in the church condition than the face condition is consistent with this interpretation. This result will be discussed further in the general discussion (see p.143).

Adults were significantly more sensitive at discriminating between 'normal' and 'Thatcherised faces' than younger participants at orientations between 0 and 90 degrees, suggesting that they were more efficient at encoding second-order relations compared with adolescents and younger children across these orientations. Interestingly, there were no significant differences in sensitivity between 8-9, 11-12 or 14-15-year-olds at any orientation. One possible explanation of these results is that development is characterised by a discontinuous change (i.e second-order relational processing becomes much more efficient over a short period of development), with a sharp increase in the efficiency of second-order relational processing occurring between 14-15-years and adulthood. This conclusion is not consistent with previous research which suggests a more gradual increase in the efficiency of second-order relational processing (e.g. Itier & Taylor, 2004; Donnelly & Hadwin, 2003). This possibility is examined further in Experiment 9.

The effect of orientation on sensitivity was significantly larger for faces than for churches, suggesting qualitative differences between stimulus types. This is in line with previous research (e.g. Bartlett & Searcy, 1993) and suggests that participants switched from using second-order relational processing to featural processing in the face condition, but used featural processing across all orientations in the church condition (see Yin, 1969). There were no developmental differences in the church condition, suggesting that featural processing is mature by 8-9-years, somewhat earlier than suggested by Mondloch et al. (2002).

Experiment 9

Experiment 8 showed that adults were more efficient at encoding second-order relations than adolescents and younger children when faces were oriented between 0 and 90 degrees. In addition, adults were sensitive to the Thatcher illusion over a greater range of orientations than adolescents and younger children. The aim of Experiment 9 was to investigate whether similar results could be found using a different paradigm. Experiment 8 relied on the phenomenology of an illusion: the Thatcher illusion. In contrast, Experiment 9 employed a task relying on the resolution of a figure ground problem. The figure ground problem is the problem of separating objects from their background (Rubin, 1915). The task used in

Experiment 9 has previously been used by Donnelly et al. (2003) (also McKone Martini & Nakayama, 2003; Boutet & Chaudhuri, 2001). Donnelly et al. (2003) presented participants with a series of pairs of overlapping faces; one face was always anchored upright whilst the other was oriented 45, 90, 135, and 180 degrees. Participants were asked to select the face that dominated the composite image. Importantly, the oriented face contributed 55% of the stimulus energy to prevent the upright face capturing attention at each orientation. In adult participants, the oriented face was selected as being most dominant (compared with the upright face) at orientations between 45 and 90 degrees, but selection of the oriented face declined sharply between 90 and 135 degrees, before flattening off to 180 degrees. Donnelly et al. (2003) argued that up to 90 degrees, adults were able to process the oriented face using second-order relational processing and so it effectively competed with the upright face for attention. When the oriented face was rotated past 90 degrees it was not processed using second-order relational processing and so it did not compete with the upright face for attention.

Experiment 9 used the figure ground face paradigm developed by Donnelly at al. (2003) to investigate whether there are developmental differences in the range of orientations over which faces can be processed using second-order relational processing. Participants were presented with a series of overlapping faces and asked to decide which face dominated a composite image. One face was always anchored upright, whilst the other face was oriented 23, 45, 68, 90, 113, 135, 157 and 180 degrees. If the range of orientations that can be processed using second-order relational processing broadens with development, as suggested in Experiment 8, then adults should select the oriented face as being dominant over a greater range of orientations compared with adolescents and younger children.

Experiment 9 used a greater range of orientations compared with Experiment 8 to try to localise the range of orientations across which faces could be processed using second-order relational processing with more precision. Scrambled faces were employed in Experiment 9 as control stimuli. Scrambled faces are ideal control stimuli to use as they contain the same low level featural information as intact faces. Any differences between the intact and scrambled face conditions can be attributed to the facial-configuration rather than low level differences between stimuli. Based on research suggesting that the magnitude of the inversion effect is greater for faces than for other objects (e.g. Yin, 1969), it was expected that the effect of orientation on the selection of the oriented face would be greater for intact faces than for scrambled faces. It was also expected that there would be no main effect of age on the selection of the oriented scrambled face (Mondloch et al., 2002) between adults, 14-15 and 11-12-year-olds.

Method

Participants

Participants who took part in Experiments 7 and 8 also took part in Experiment 9. The order in which the experiments were completed was counterbalanced between participants and all experiments were completed within 72 hours.

Apparatus and Stimuli

All details of Experiment 9 were the same as Experiment 8 with the following exceptions. Stimuli were resized to 6.8 cm in width by 8.7 cm in height so that each face subtended a visual angle of 6.64 by 5.19 degrees when viewed from a distance of 75 cm. Faces were sorted into pairs, approximately matched for luminance. Each face-pair were used to create 16 composite images. The first face in the pair was used as the upright face whilst the second face was oriented 23, 45, 68, 90, 113, 135, 157 and 180 degrees. The two faces were then swapped so that the second face was used as the upright faces and the first face was oriented. Re-combination resulted in a set of 64 composite images. To avoid upright faces dominating perception at all angles of orientation, images were manipulated using a weighted linear algorithm, such that oriented faces contributed 55% of the available stimulus energy to the final face pair image (see, Donnelly et al., 2003; McKone et al., 2003). This adjustment meant that the contrast (i.e. the relative difference between the light and dark areas of the image) of the upright face was lower than the contrast of the oriented face. All composite images were pasted into an annulus with a radius of 70 pixels. The visual angle inside the annulus was 3 degrees (see Figure 23).

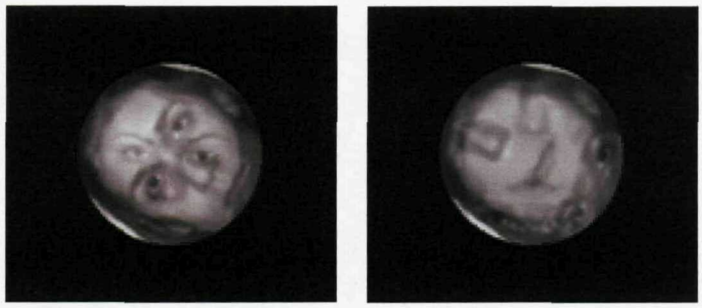


Figure 24. An example of the composite image in the intact face condition (left panel) and the scrambled face condition (right panel).

A set of scrambled faces were created by re-arranging the facial features in the face with the order of features (from top-to-bottom) being noses, mouths and eyes. Faces were scrambled using Adobe Photoshop. The smudge and Gaussian blur (1 pixel radius) tool was used to remove sharp boundaries in the images. Having created a set of scrambled faces, a set of composite scrambled faces images were generated in the same was as for the intact faces (see Figure 23).

Design and Procedure

Participants were asked to determine whether the upright or oriented stimulus dominated the image on each trial. Responses were made using the left and right mouse keys. Response buttons were labelled with a 'U' (upright) and 'O' (oriented) sticker and were counterbalanced across participants.

Each trial began with a 500 ms fixation cross, followed by the stimulus image for 1000 ms and then a mask for 500 ms. The mask was made from scrambled facial features and was used to prevent any after image. After the mask disappeared a series of question marks were displayed on the screen until the participant responded.

Results

The results were analysed according to the percentage of times the oriented face was selected as being dominant at each angle of stimulus rotation. Following the procedure used by Donnelly et al. (2003), the dependent variable (DV) was calculated by transforming the percentage of times that the oriented face was chosen as being most dominant using the formula DV=log(choice of oriented face/(100-

choice of oriented face)). The transformation was required because the choice of the oriented face is a bounded variable (at each orientation the oriented face can be selected a minimum of 0 and a maximum of 16 times) and it was not normally distributed.

Previous research using this task has used 45 degrees as the smallest orientation (Donnelly et al., 2003; McKone et al., 2003; Boutet & Chaudhuri. 2001). The results of Experiment 9 showed that performance at 23 degrees was not significantly different from chance ($t(57)<1$, <1 for intact and scrambled faces at 23 degrees). Conditions in which the oriented face was oriented 23 degrees were, therefore, excluded from further analysis. It may have been that participants were unable to complete the task when the oriented face was oriented 23 degrees because it was too close in orientation to the upright face. Participants may have, therefore, been unable to solve the figure ground problem because the two faces overlapped so to such a high degree.

The transformed data was analysed in a 7 (Orientation: 45 versus 68 versus 90 versus 113 versus 135 versus 157 versus 180 degrees) x 2 (Stimulus: Intact faces versus Scrambled faces) way repeated measured ANOVA with age group (Adults versus 14-15-year-olds versus 11-12-year-olds versus 8-9-year-olds) as a between subjects factor. The main effect of orientation was significant ($F(6, 324)=21.36$, $p<.01$). There was no significant difference between 45 and 68 degrees ($t(47)<1$), but participants selected the oriented stimulus significantly more frequently at 45 degrees compared with 90, 113, 135, 157 and 180 degrees ($t(57)$ all t's >2.68, all p's $<.05$). The main effects of age group and stimulus were not significant ($F(3, 54)=1.65$ and $F(1, 54)<1$).

The interactions between stimulus and age group, stimulus and orientation were significant and the interaction between orientation and age group approached significance ($F(3, 54)=6.32$, $p<.01$, $F(6, 324)=10.20$, $p<.01$ and $F(18, 324)=1.58$, $p=.06$ respectively). The interaction between stimulus and age group was caused by a effect of age in the face condition but not in the scrambled face condition ($F(3, 54)=4.76$, $p<.01$ and $F(3, 54)<1$). This interaction will be analysed further in the next section. The interaction between stimulus and orientation was caused by a greater effect of orientation in the intact face condition than the scrambled face condition ($F(6, 324)=21.33$, $p<.01$ and $F(6, 324)=6.91$, $p<.01$ for the effect of orientation in the intact and scrambled face condition respectively). The interaction between orientation and age group was caused by a significant effect of orientation in the adults, 14-15 and 8-9-year-olds ($F(6, 78)=9.06, p<.01$, $F(6, 78)=6.92, p<.01$ and $F(6, 90)=5.51, p<.01$, for adults, 14-15 and 8-9-year-olds respectively), whereas the effect of orientation only approached significance in the 11-12-year-old age group ($F(6, 78)=2.23, p=.07$). The three way interaction between stimulus, orientation and age group was also significant ($F(18, 324)=2.02, p<.01$). In order to understand this three way interaction the results were analysed separately for intact and scrambled faces (see Figure 24).

Intact Faces

A 7 (Orientation: 45 versus 68 versus 90 versus 113 versus 135 versus 157 versus 180 degrees) way repeated measures ANOVA with age group as a between subjects factor was conducted. The main effect of orientation was significant ($F(6, 324)=21.33, p<.01$). There was no significant difference between 45 degrees and 68 degrees or between 45 degrees and 90 degrees ($t(57)<1$, $=2.15$ respectively), but participants selected the oriented face significantly more often at 45 degrees compared with 113, 135, 157 and 180 degrees ($t(57)$ all t's >4.23, all p's$<.01$). The main effect of age group was also significant ($F(3, 54)=4.76, p<.01$). Adults selected the oriented face significantly more often than all other age groups ($t(26)$ all t's>2.71, all p's$<.01$ for adults compared with 14-15, 11-12 and 8-9-year-olds). There were no significant differences between the three youngest age groups ($F(2, 43)<1$). The interaction between orientation and age group was significant ($F(18, 324)=2.24, p<.01$).

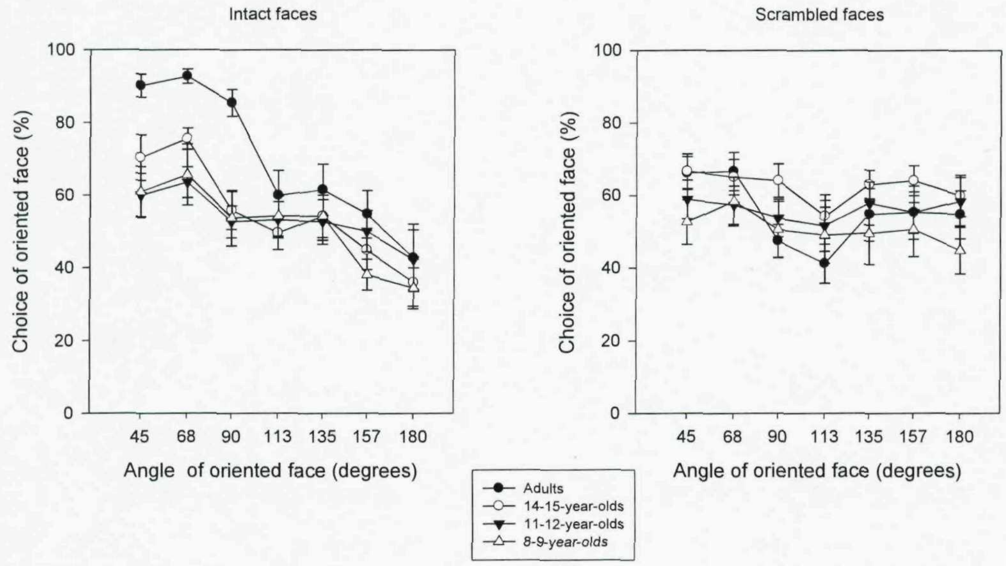


Figure 25. Percentage of times that participants selected the oriented face as being dominant at each angle of orientation in the intact and scrambled face condition separately for each age group.

To explore the interaction between orientation and age group a series of Bonferroni corrected two tailed paired t tests were conducted separately for each age group. The results can be seen in Table 11. For adults there was no decline in the selection of the oriented face until between 90 and 113 degrees. However, for 14-15, 11-12 and 8-9-year-olds there was a significant decline in the selection of the oriented face between 68 and 90 degrees.

Table 11

T values for Two Tailed Bonferroni-Corrected Pairwise t tests for all Age Groups

Orientation	Adults	14-15	11-12	8-9
45 versus 68	<1	<1	-1.02	-1.02
68 versus 90	1.63	4.08**	2.65#	2.27#
90 versus 113	2.25#	1.58	<1	1.35
113 versus 135	<1	<1	<1	1.10
135 versus 157	1.12	1.13	<1	2.62
157 versus 180	1.82	1.69	1.58	1.61

** = p<.01, # = approaches significance

The interaction between orientation and age group was explored further by conducting two 2 way repeated measures ANOVAs across age group. The first

ANOVA examined performance between 68 and 90 degrees and the second examined performance between 90 and 113 degrees. Between 68 and 90 degrees, the main effects of orientation and age group were significant ($F(1, 54)=11.03$, 6.85, both $p<.01$ respectively). However, the interaction between orientation and age group was not significant ($F(3, 54)<1$). Between 90 and 113 degrees, the main effect of orientation was significant ($F(1, 3)=7.46$, $p<.01$) and the main effect of group approached significance ($F(3, 54)=2.59$, $p=.06$). The interaction between orientation and group approached significance ($F(3, 54)=2.20$, $p=.09$).

Scrambled faces

A 7 (Orientation: 45 versus 68 versus 90 versus 113 versus 135 versus 157 versus 180) way repeated measures ANOVA with age group as a between subjects factor was conducted. The main effect of orientation was significant ($F(6, 324)=2.64$, $p<.01$), highlighting that participants selected the oriented scrambled face significantly more often at 45 degrees compared with 90, 157 and 180 degrees ($t(57)$ all t's >2.30, all p's<.05); but the main effect of age group was not significant ($F(3, 54)<1$) and the interaction between orientation and age group was not significant ($F(18, 324)<1$).

Discussion

The most important result to arise from Experiment 9 was that adults did not experience a decline in the selection of the oriented face until between 90 and 113 degrees. In contrast, all three younger age groups evidenced a decline in the selection of the oriented face between 68 and 90 degrees, suggesting that oriented faces were processed using second-order relational processing over a greater range of orientation for adults compared with children and adolescents. This is consistent with the results of Experiment 8 and suggests that the range of orientations across which the orientated face could be processed using second-order relational processing increased with development.

In addition, Experiment 9 also highlighted that the selection of the oriented face was influenced more by orientation in the intact face condition than in the scrambled face condition. This result is consistent with Experiment 8, which also showed that orientation had a greater impact on faces compared with non-face objects (churches) and also with previous research (e.g. Yin, 1969). Experiment 9 found evidence of developmental differences in the intact face condition, but not in the scrambled face condition. This is also consistent with the results of Experiment 8 and supports the argument that second-order relational processing matures later than featural processing (Mondloch et al., 2002).

In contrast to previous research (e.g. Donnelly & Hadwin, 2003; Mondloch, et al., 2002), the results of Experiment 9 found no evidence of developmental differences between the three youngest age groups that were tested, and so demonstrated a discontinuous improvement in the efficiency of second-order relational processing. This finding implies that face processing does not undergo developmental changes between 8 and 15-years. This possibility is discussed further in the general discussion.

General Discussion

Two interesting and novel findings have arisen from Experiments 8 and 9. First, both experiments demonstrated that the range of orientations over which second-order relations can be computed broadens with development.
This is in direct contrast to work conducted with infants, which suggested that the range of stimuli that can be processed using second-order relational processing decreases with development (see Chapter 1 p.36). It seems that between adolescence and adulthood the face processing system becomes more flexible and less constrained in terms of the types of faces that can be processed using second-order relational processing. The increase in the efficiency of second-order relational processing is not, therefore, made possible by a reduction in the range of stimuli that can be processed using second-order relational processing.

The second novel finding to emerge from these experiments was that when faces were upright, adolescents and younger children adopted a more conservative response rule compared with adults. As suggested in Chapter 4, one explanation of these results is that the increase in efficiency that is seen between childhood and adulthood leads to an increase in certainty as to what constitutes an 'odd' face. Adults are more certain that they will be able to detect second-order relational differences between faces (i.e. manipulations made by 'Thatchersing' a face) and so they are willing to adopt a less conservative response criterion.

Across Experiments 8 and 9, churches and scrambled faces demonstrated no main effect of age, suggesting that featural processing is mature by 8-9-years, somewhat earlier than previously thought (e.g. Mondloch et al., 2002). In contrast, faces showed evidence of developmental differences in both Experiments 8 and 9. More specifically, adults were more efficient at processing second-order relations than younger participants when faces were oriented between 0 and 90 degrees. Interestingly, there was no difference between 8-9, 11-12 and 14-15-year olds in either experiment. The only developmental difference found in Experiments 8 and 9 occurred between 14-15-years and adulthood. Both experiments, therefore, highlighted discontinuous improvements in the efficiency of second-order relational processing with development.

In summary, the results of both Experiments 8 and 9 have highlighted that the range of orientations across which faces can be processed using second-order relational processing increases with development. In addition, the response criterion adopted by participants becomes less conservative with development. Across both experiments, an increase in the efficiency of second-order relational processing was only demonstrated between 14-15-years and adults. In contrast, there were no developmental differences between children, adolescents and adults in the church/scrambled face conditions highlighting the late maturation of face processing compared with object processing.

Chapter 6

Although there is a great deal of research that has investigated face processing in adults there are only a handful of studies which have examined the development of face processing using the same task and conditions with children of different ages (e.g. Carey & Diamond, 1994; Carey & Diamond, 1977; Schwarzer, 2000; Mondloch et al., 2002; Hay & Cox, 2000; Donnelly & Hadwin, 2003). The majority of this research has supported the idea that there is a gradual increase in the efficiency of second-order relational processing across childhood and adolescence (e.g. Mondloch et al., 2002; Donnelly & Hadwin, 2003; Hay & Cox, 2000). Indeed, second-order relational processing has been shown to be adult-like only in late adolescence or early adulthood (e.g. Itier & Taylor, 2004). The motivation behind this thesis was to examine whether improvements in the efficiency of second-order relational processing are underpinned by changes in the spatial scale, time course and orientation range across which second-order relations are computed.

Summary of the findings for adult participants

The lack of clarity regarding the spatial scale and time course over which adults process second-order relations meant that it was necessary to examine adult face processing before the development of face processing could be explored. In Chapter 2, a formal test was used to investigate the spatial scale across which adults process second-order relations. Specifically, the formal test sought to investigate whether there was any evidence of co-active or global-configural processing. Chapter 2 showed no evidence that participants used co-active or global-configural processing to discriminate between 'odd' and 'normal' faces. The failure to find evidence of co-active or global-configural processing, in a task which demonstrated clear evidence of second-order relational processing (in the form of an inversion effect), suggested that participants were using a locally based form of second-order processing to detect the Thatcher illusion. This is the first time that formal tests have been employed to explore the spatial scale of second-order relational processing. Importantly, support for local-configural processing is consistent with research conducted by Boutsen and Humphreys (2003) and Macho and Leder (1998) among others.

The demonstration of local-configural processing in Chapter 2 raised the question as to whether adults detect differences between pairs of faces simultaneously (in parallel) or sequentially (in serial). The time course across which adults process second-order relations was, therefore, examined in Chapter 3 along with the stopping rule that participants use when asked to decide whether two simultaneously presented faces/objects (churches in Experiment 5 and cars in Experiment 6) are the 'same' or 'different'. Architecture and stopping rule were examined using a cueing paradigm (Experiment 5) alongside a formal test of system architecture and stopping rule. The results demonstrated that adult participants detected differences between pairs of faces in parallel using a self-terminating stopping rule. Adult participants also detected differences between pairs of objects (churches and cars) in parallel, but, interestingly, there was a tendency for participants to use an exhaustive stopping rule with objects (cars). The tendency to use a self-terminating stopping rule for faces and an exhaustive stopping rule for objects (cars) may have resulted from participants forming more 'robust' representations of faces compared with objects (cars). The formation of a 'robust' representation would mean that participants have a more detailed representation that they can use to use to match and classify subsequent inputs against. This would mean that participants could be more certain that any deviation away from the representation (in the form of activation building in favour of a difference between the stimuli being processed and the representation) actually reflected a difference between the two stimuli opposed to noise between the representation and the incoming input. A more 'robust' representation for faces compared with objects may, therefore, have meant that participants were more willing to generate their response before all information had been processed in the face condition compared with the object (car) condition.

The results of Chapter 3 additionally highlighted that adults tended to extract information from eyes and mouths at a similar rate and time, but tended to preferentially extract information from one feature (headlight or number plates or windows or doors) in objects (churches or cars). To date, this is the first demonstration of this effect and it is worth considering further now. There are at least two possible ways in which the differences in the rate and time course of processing between stimulus types can be accounted for. Both of these accounts assume that the rate and time course of processing a feature is dependent on whether or not the feature falls within an attentional spotlight (Posner, 1980). According to the first explanation, participants are able to adjust the size of the attentional spotlight (see LaBerge, 1983) and the spotlight is set at a larger size for faces compared with objects. In faces, both features fall within the spotlight and so they are processed at a similar rate and time. In contrast, the attentional spotlight for objects is too small to be able to encapsulate both features and so one feature falls within the spotlight and is processed at a fast rate, whereas the other falls outside the spotlight and is processed at a slower rate. A second possible explanation for differences in the rate of processing between stimulus types assumes that participants are able to divide their attentional spotlight (see Castiello & Umilta, 1992) for faces, but not for objects. Dividing the spotlight for faces would mean that one spotlight could be focused on the eyes and another spotlight focused on the mouth. In this circumstance, eyes and mouths could be processed at the same rate. In contrast, participants may only have one attentional spotlight for objects. One feature would, therefore, fall within the spotlight and the other in the periphery, resulting in different rates of processing between features. Differences in the size of the attentional spotlight or the number of attentional spotlights may arise because adults are expert at processing facial features (e.g. Le Grand et al., 2003; Schwaninger et al., 2003) and so participants find them easier to process compared with object features. It may be that expertise necessitates fewer resources, and so resources can be spread more widely, or be divided, for faces but not for objects.

Finally, Experiments 8 and 9 demonstrated that adults are able to process second-order relations over a relatively broad range of orientations. Specifically, Experiment 8 showed that participants were equally sensitive to the Thatcher illusion between 0 and 90 degrees. Similarly, Experiment 9 showed that the oriented face was signalled equally strongly between 0 and 90 degrees, suggesting that it was being processed using second-order relational processing across this range of orientations. These results are consistent with previous research conducted by Lewis (2001) and also Sturzel and Spillmann (2000) who also showed that participants were able to process second-order relations until faces were oriented beyond approximately 90 degrees.

Summary of the findings for children and adolescents

Once the adult face processing system had been understood it was possible to explore whether there are developmental differences. Chapter 4 used a single experiment to examine whether there are developmental differences in the spatial scale across which children and adolescents processed second-order relations. Furthermore, it examined whether there were developmental differences in the architecture and stopping rule used when participants are asked to detect differences between pairs of faces and also whether there were developmental differences in the distribution of attention across faces. The results showed no evidence of developmental differences in the spatial scale over which second-order relations are computed, the time course over which differences between pairs of faces are detected or the distribution of attention across faces. The results of Experiment 7 did, however, highlight four interesting differences between children and adults.

First, Experiments 7-9 demonstrated improvements in the efficiency of second-order relational processing with development. In Experiment 7, this was highlighted by adults performing faster than all younger age groups. In Experiment 8, the improvement in the efficiency of second-order relational processing with development was demonstrated by higher sensitivity for adults compared with younger age groups when faces were upright. Finally, in Experiment 9 improvements in the efficiency of second-order relational processing were demonstrated by adults selecting the oriented face more frequently at upright orientations compared with younger age groups. More efficient processing of second-order relations in adult participants compared with younger participants is consistent with previous literature (e.g. Mondloch et al., 2002; Donnelly & Hadwin, 2003). However, previous literature has highlighted that there are continuous improvements in the efficiency of second-order relational processing across development (i.e. 11-12-year-olds are more efficient that 8-9-year-olds and 14-15-year-olds are more efficient that 11-12-year-olds etc.). The results of Experiments 8 and 9 only demonstrated improvements in the efficiency of second-order relational processing between children under 14-15-years and adults. In other words, there was no evidence of a continuous increase in the efficiency of second-order relational processing between 8 and 15-years. Rather, the results demonstrated a discontinuous improvement in the efficiency of second-order relational processing.

Second, the results of Experiment 8 highlighted that children adopt a more conservative response criterion compared with adults. In other words, younger participants were more likely to respond that a face is 'normal' compared with 'odd'. One possible explanation of the difference in stopping rule between younger children and adults is that adults are able to form a more 'robust' representation of a face compared with younger children and adolescents because they are more efficient at processing second-order relations. The formation of a more 'robust' representation would mean that participants have a more detailed representation that they can use to match and classify subsequent inputs against. This would mean that participants could be more certain that any deviation away from the representation (in the form of activation building in favour of a difference between the stimulus being processed and the representation) actually reflected a difference between the two stimuli opposed to noise between the representation and the incoming input. Young children and adolescents may, therefore be less certain that activation building in favour of an 'odd' face is caused because the face is 'odd'. Younger participants appear to cope with this uncertainty by adopting a more conservative response criterion. Interestingly, if percent correct had been used as the dependent measure in Experiment 8, the results would have demonstrated significant differences between the three youngest age groups ($F(2, 41)=3.57, p<.05$). By removing the influence of response bias, by using *d'* as the dependent measure, the results showed no developmental differences between the three youngest age groups. This demonstrates the importance of using measures that are independent of response bias so that we can be certain that effects are driven by differences in encoding strategy rather than decisional factors. It also raises the possibility that the results of many other experiments, which have highlighted continuous developmental differences in second-order relational processing, may in fact have been underpinned by differences in response criterion rather than differences in the processing strategy used. This possibility requires further research.

Third, the results of Experiment 7 provided evidence to suggest that children used an exhaustive stopping rule when detecting differences between pairs of faces, whereas adults tended to use a self-terminating stopping rule. Interestingly, this result suggests that young children tend to process faces in the same way that adults process objects. This result may also arise because children and adolescents are not able to form such 'robust' representations of faces. Given the increased uncertainty as to whether activation represents a difference between the stimulus and the representation or noise between the input and the representation, children and adolescents may choose to wait until all information has finished being processed before generating their response so that they minimise the likelihood of generating a false alarm.

Finally, Chapter 5 demonstrated that the range of orientations across which a face can be processed using second-order relational processing increases with development. This was achieved using a 2AFC paradigm with the Thatcher illusion (Experiment 8) and a paradigm that relied on the resolution of a figure ground problem (Experiment 9). The results showed that the range of orientations across which participants were sensitive to the Thatcher illusion increased with development and the range of orientation across which the oriented face dominated perception increased with development. These results suggest that across development the face processing system becomes more broadly tuned so that faces of different orientations can be processed using second-order relational processing.

In sum, the research presented in this thesis has shown no evidence for developmental differences in the spatial scale across or time course across which second-order relations are computed and there are no developmental differences in the distribution of attention across faces. However, there is evidence of developmental differences in the efficiency of second-order relational processing (shown Experiments 7-9), the stopping rule used (shown in Experiment 7) before a response is generated, the response criterion used to determine which response to generate and the range of orientations that can be processed using second-order relational processing (shown in Experiments 8 and 9). Taken together, these results suggest that the increase in the efficiency of second-order relational processing seen across development is not underpinned by changes in the spatial scale across which second-order relations are computed or by changes in the time course across which second-order relations are processed. Neither are these changes brought about by a decrease in the range of stimuli that can be processed using second-order relational processing. Across development, individuals simply get better at processing second-order relations. The increase in the ability to encode second-order relations appears to facilitate the formation of a more 'robust' representation. A more 'robust' representation means that participants terminate processing earlier and so they tend to use a self-terminating stopping rule rather than an exhaustive stopping rule. It also means that participants set a less conservative response criterion. Alongside the increase in efficiency there is also an increase in the range of orientations that can be processed using second-order relational processing. The face processing system appears to become more flexible with development, allowing a broader range of orientations to be processed using second-order relational processing.

Independence versus non-independence of measures

Given that a subset of the participants completed multiple experiments in this program of research it is possible to compare performance across tasks. Specifically, we can investigate whether development in the sensitivity to second-order relations (as measured by *d'* values in Experiment 8) is associated with the range of orientations across which faces can be processed using second-order relational processing (as measured by the range of orientations across which the oriented face dominated the composite image in Experiment 9) and with participants' response bias (as measured by c values in Experiment 8). It may be that the response criterion becomes more liberal as sensitivity to second-order relations increases. If this is the case, then it should be possible to predict response criterion from sensitivity. Similarly, it may be that the as participants become more sensitive to second-order relations the range of stimuli that can be processed using second-order relational processing increases. In Chapter 1 it was argued that development might be understood as a point moving through a multi-dimensional space, with the dimensions of 1) sensitivity to second-order relations 2) response criterion and 3) the range of orientation over which second-order relations can be processed. The validity of the multi-dimensional space as a descriptive framework for locating mechanisms responsible for encoding faces, and the tracking of the developmental shift through the space, can now be examined.

In order to compare the range of orientations across which participants could compute second-order relations a single dependent measure was required for range, sensitivity and response criterion for each participant. It was decided to use the results of Experiment 9 as the measure of range as a greater range of orientations were employed in Experiment 9 compared with experiment 8. Range was calculated by taking the orientation at which the selection of the oriented face declined by 50%. This was achieved by taking the maximum number of times that the oriented face was selected as being dominant and subtracting the minimum number of times that the oriented face was selected as being dominant and dividing this difference by 2. The orientation that sensitivity reached this point was calculated by plotting the data for each participant in SigmaPlot and fitting a quadratic function. Regression analyses showed that the function was a good fit to the data (range 0.93 to 0.98). The coefficients for the function were extracted and used to calculate the percentage of times the oriented face was selected at each degree of orientation. The orientation at which the selection of the oriented declined by 50% was taken and used as the dependant measure of range. D prime values for each participant when faces were oriented 0 degrees in Experiment 8 were used as the measure of sensitivity to second-order relations. Finally, *c* values for each participant when faces were oriented 0 degrees in Experiment 8 were used as a measure of response criterion.

The data were plotted in a three dimensional space. The dependent variable of range was plotted on the x axis, sensitivity on the y axis and response criterion on the z axis. The data for all participants who completed both experiments 8 and 9 are shown in Figure 29.

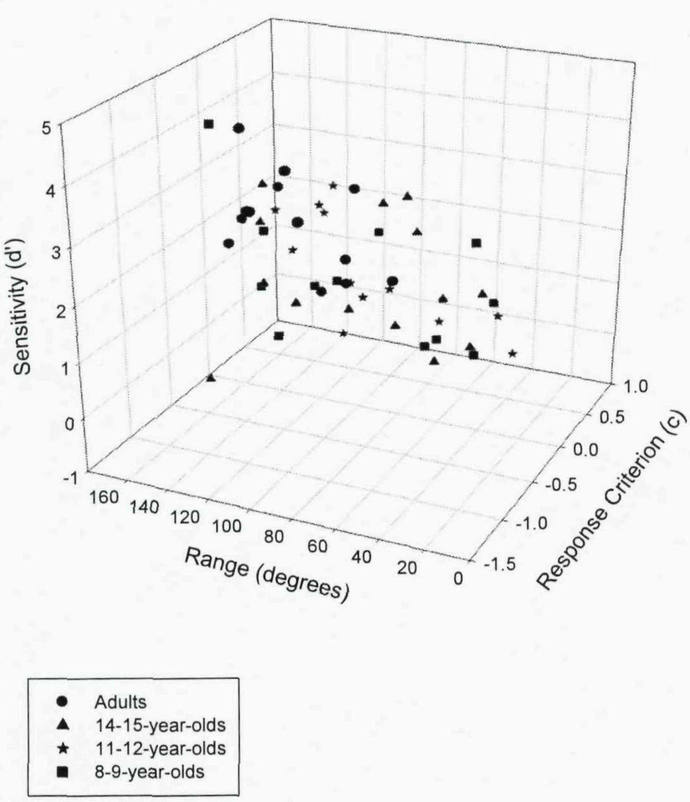


Figure 30. The relationship between sensitivity (at 0 degrees from Experiment 8), range (from Experiment 9) and response criterion (at 0 degrees from Experiment 8).

Analysis aimed to investigate whether sensitivity was a significant predictor of response criterion and whether sensitivity was a significant predictor of range. The results showed that sensitivity was a significant predictor response criterion (β = -1.33, $t(51) = -4.35$, $p < .01$), also a significant predictor of the range of orientations across which the oriented face dominated perception ($\beta = .011$, $t(51) = 2.85$, $p < .01$). These results suggest that as a participant becomes more sensitive to the Thatcher illusion they also become less conservative. In other words, participants generate fewer incorrect responses, but the incorrect responses that they do generate are false alarms (i.e. they report that 'normal' faces are 'odd'). This is consistent with the idea that as participants become more efficient at second-order processing they are able to generate more 'robust' representations which allows them to reject 'normal' faces as 'normal' with more precision. Sensitivity was also a significant predictor of the range of orientations across which participants were sensitive to second-order relations. This suggests that as the face processing mechanism becomes more efficient at processing second-order relations the range of orientations across which they can be processed also increases. Taken together these results suggest that sensitivity to second-order relations can be used to predict the response criterion that participants use and also the range of orientations across which participants can use second-order relational processing. Interestingly, Figure 29 demonstrates that there is a high degree of overlap between age groups. Indeed, some adults perform at the same level as 11-12-year-olds. This highlights the large individual differences that exist between participants of the same age.

<u>Tasks which require exhaustive versus self-terminating processing</u>

The experiments investigating the spatial scale of second-order relational processing in this thesis (Experiments 1-4, 6 and 7) could all have been completed using a self-terminating stopping rule (i.e. on some trials participants could have generated their response after processing one feature). It is interesting to consider whether the spatial scale of second-order relational processing is dependent on the nature of the stopping rule that participants use. An additional experiment was conducted to investigate whether the spatial scale of second-order relational processing changes if participants are required to use an exhaustive stopping rule. Data collection and analysis is still being carried out for this experiment. However, the method and results are worth outlining now. In order to enforce an exhaustive stopping rule, it was necessary to change the paradigm and the method of analysing the data. Like Experiments 1-4, 6 and 7, participants were presented with 'normal' and 'Thatcherised' faces that had the eyes inverted, the mouth inverted or the eyes and mouth inverted. In addition, whole faces, both 'normal' and 'Thatcherised' were presented upright and inverted. However, unlike Experiment 1-4, 6 and 7 a complete identification paradigm (Ashby & Townsend, 1986) was employed. Participants were asked to decide whether the outline of the face was upright or inverted, whether the eyes were upright or inverted and whether the mouth was upright or inverted.

Instead of calculating the capacity coefficient, the Miller inequality and the Grice inequality, the data were analysed using General Recognition Theory (GRT) analysis (Ashby & Townsend, 1986). GRT is a multivariate version of signal detection theory. According to GRT, global-configural processing, can be defined in terms of violations of perceptual independence, violations of perceptual seperability or violations of decisional seperability. Two dimensions are said to be perceptually independent when the perceptual effects of one dimension are statistically independent of the perceptual effects of the other dimension. In the case of the Thatcher illusion, the perceptual effects of the eyes would be statistically independent of the perceptual effects of the mouth. Statistical independence can be thought of as a correlation between dimensions. If the eyes and mouth are statistically dependent, the perceptual effect of the eyes would be more 'odd' when the mouth was 'Thatcherised' compared to when it was 'normal'. Two dimensions are said to be perceptually separable when the distribution of perceptual effects for one dimension do not vary across the levels of the other dimension. In the Thatcher illusion, if a face shows perceptual seperability, then the distribution of perceived 'oddity' for the eyes would be unaffected by whether the mouth was 'odd' or 'normal'. Two dimensions are said to be decisionally separable when the decision criterion for decisions about one dimension are not affected by the level of the other dimension. In the Thatcher illusion, if the face shows decisional seperability, then the decision boundary for the eyes will be the in same place regardless of whether the mouth is 'odd' or 'normal'.

The results of the additional experiment that was conducted showed that there were violations of perceptual seperability, perceptual independence and decisional independence, supporting the idea that faces are processed using global-configural processing. These results are in direct contrast to those found in Experiment 1-4 and 6-7 of this thesis. One way that these results can be reconciled is to assume that when participants can complete a task using a self-terminating stopping rule they use local-configural processing. Only when participants are required to process eyes and mouths exhaustively do they use global-configural processing.

It is interesting to consider how these results tie in which previous research which has shown evidence of local-configural processing. Have other experiments, which have shown evidence of local-configural processing, allowed participants to use a self terminating stopping rule? First, Boutsen and Humphreys (2003) required that participants judged whether two faces were the 'same' type (i.e. both were 'normal' or both were 'Thatcherised') or 'different' types (i.e. one 'normal' and one 'Thatcherised'). Participants would have been able to terminate their search as soon as a difference between either eyes or mouths was found and so they could have employed a self-terminating stopping rule. Second, Leder et al. (2001) asked participants to judge inter-ocular distance when different areas of the face were present. Again, participants could have completed the task by processing the eye area and then generating their response, indicating that they could have employed a self-terminating stopping rule. Third, Leder and Bruce (2000) asked participants to name a previously learnt feature that was presented either in isolation or in the face context. Participants were only required to judge one feature and so they could have completed the task using a self-terminating stopping rule. Given that several of the experiments that have shown evidence consistent with local-configural processing could have been completed using a self-terminating stopping rule, future research should investigate whether global-configural processing is used in situations where participants have to employ an exhaustive stopping rule and local-configural processing is used in situations where participants can employ a self-terminating stopping rule. The association between local-configural processing and a self-terminating search and between global-configural-processing and an exhaustive search is a theoretically important idea. It suggests that when participants are able to complete a task using a self-terminating search they are able to break faces down in to their component parts and then process these parts using local-configural relations. If this is the case, then there is no reason to believe that faces are automatically processed as unparsed templates as suggested by Tanaka and Farah (1993). Rather, participants can choose whether to break faces down into their component parts or not depending on the task that they are required to complete.

Future research

In the future, it would be very interesting to investigate whether there are developmental differences in the exhaustive processing task described above. Given that children process faces exhaustively, even in situations when they can complete the task using self-terminating processing, based on the experiment described above, it would have been expected that young children would have employed global-configural processing in Experiment 7. Conversely, the results of Experiment 7 showed that children used local-configural processing. It may, therefore, be that children are unable to employ global-configural processing regardless of whether they are using self-terminating or exhaustive processing, whereas adults switch between local and global-configural processing depending on the demands of the task. It is possible that the ability to switch between processing styles develops with experience with faces. This possibility requires future empirical investigation.

Finally, in Chapter 1 it was suggested that testing participants on an individual level is beneficial when investigating atypical populations. One example of such a population is individuals with Asperger Syndrome Disorder (ASD). ASD is characterised by impairments in social interaction and the development of restricted and repetitive patterns of behaviour, interests and activities (DSM-IV). Some researchers have shown that individuals with ASD have deficits in face processing (e.g. Joseph & Tanaka, 2003; Teunisse & de Gelder, 2003). Conversely, other researchers have shown that there are no differences between typically developing participants and participants with ASD (e.g. Rouse, Donnelly, Hadwin & Brown, 2004; Lahaie, Mottron, Arguin, Berthiaume, Jemel & Saumier, 2006; Lopez, Hadwin, Donnelly & Leekam, 2004). Research that has examined face processing in individuals with ASD has used different paradigms and tested different populations making it difficult to reconcile these results. One potential benefit of testing participants on an individual level would be that it would be possible to identify whether all participants with ASD performed differently to all typically developing participants. If all typically developing participants perform differently to all participants with ASD then we would have very strong evidence to suggest that deficits in face processing are indeed associated with ASD. Alternatively, if some participants with ASD performed in the same way as typically developing participants or vice versa, then we would have no evidence that a deficit in face processing is key to the aetiology of ASD. Future research should use the paradigms developed in this thesis to examine atypical development.

Conclusions

To conclude, the research presented in this thesis has shown that the increase in the efficiency of second-order relational processing that is seen across development is not underpinned by changes in the spatial scale or time course across which second-order relations are computed. Rather, with development participants move from processing faces under an exhaustive stopping rule to a self-terminating stopping rule. In addition, the range of stimuli that can be processed using second-order relational processing increases with development and the participant adopts a less conservative response criterion.

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Appendix A

Experiment 2: Analysis conducted at the level of the mean

The presence of a redundancy gain was examined by computing RT and percentage error data in the same way as in Experiment 1. RTs and errors were compared separately in a 3 way (Condition: Eye versus Mouth versus Two features) repeated measures ANOVA.

RTs - The main effect of condition was significant ($F(2, 22)=13.59, p<.01$). Participants responded significantly faster when two features were changed compared to when either the eyes or the mouth were changed ($t(11)=-6.91, -4.14$, both $p<.01$ respectively). There was no significant difference between the eye and the mouth conditions ($t(11)=-2.27$).

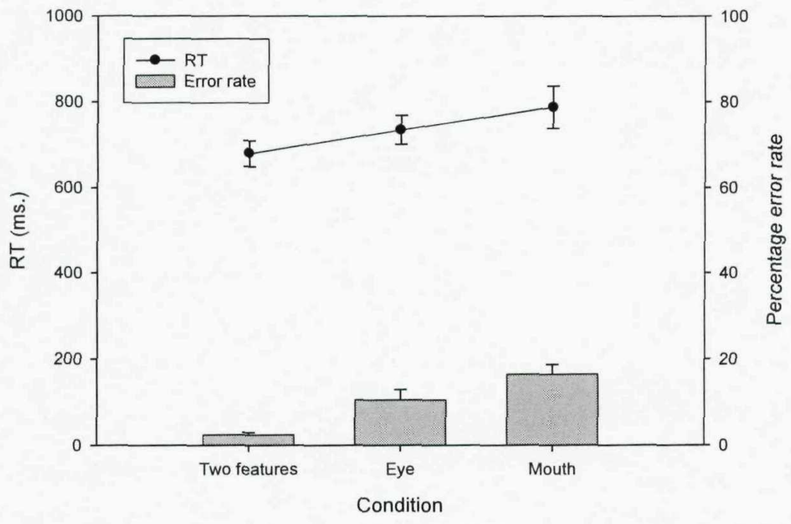

Figure 31. Reaction time and percentage error, with standard errors in all conditions.

Accuracy –The main effect of condition was significant ($F(2, 22)=25.83, p<.01$. Participants made significantly fewer errors when two features were changed compared with when only the eye or the mouth were changed ($t(11)=-5.78, -5.57$, both $p<.01$ respectively). There was no difference between the number of errors made in the eye and mouth conditions ($t(11)=-2.43$).

Appendix B

Experiment 3: Analysis conducted at the level of the mean

The presence of a redundancy gain was examined by computing RT and percentage error data in the same way as in Experiment 1. RTs and errors were compared separately in a 3 way (Condition: Eye versus Mouth versus Two features) repeated measures ANOVA.

RTs – The main effect of condition was significant ($F(2, 22)=3.81, p<.05$). Participants were significantly faster in the two feature change condition than in the mouth condition ($t(11)=3.10, p<.01$) and the difference between the two feature change condition and the eye condition approached significance ($t(11)=1.88, p=.08$). There was no significant difference between eye and mouth conditions ($t(11)=1.04$).

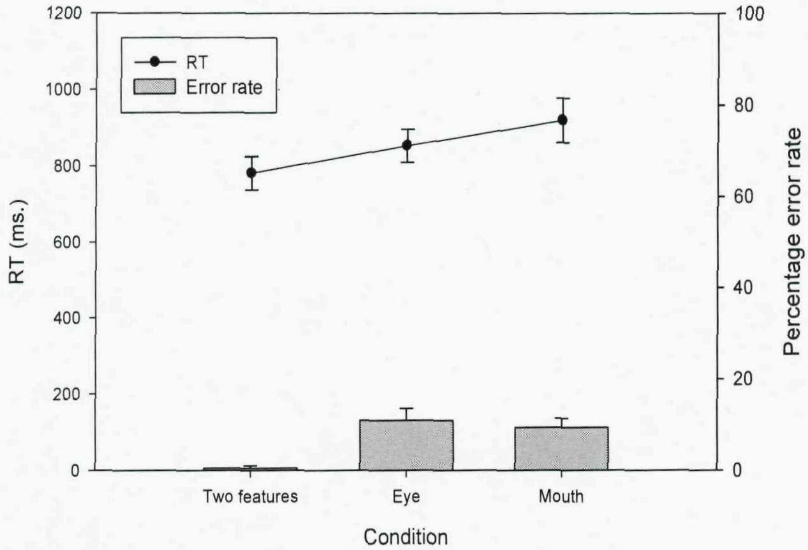

Figure 32. Reaction time and percentage error in all conditions with standard errors.

Accuracy – The main effects condition was significant ($F(2, 22)=14.62, p<.01$. Participants were significantly more accurate in the two feature change condition than in either the eye condition or the mouth condition ($t(11)=4.98$, 5.99 both $p<.01$ respectively). There was no significant difference between the eye and mouth conditions ($t(11)<1$).

Appendix C

Experiment 4: Analysis conducted at the level of the mean

The presence of a redundancy gain was examined by computing RT and percentage error data in the same way as in Experiment 1. RTs and errors were compared separately in a 3 way (Condition: Eye versus Mouth versus Two features) repeated measures ANOVA.

RTs – The main effect of condition was significant ($F(2, 22)= 5.29, p<.01$). Participants responded significantly faster when two features were changed compared to when either the eyes or the mouth was changed ($t(11)=3.06, 3.32$, both $p<.01$ respectively). There was no significant difference between the eye and the mouth conditions ($t(11)<1$).

Accuracy – The main effect of condition was not significant (F(2, 22)=2.31).

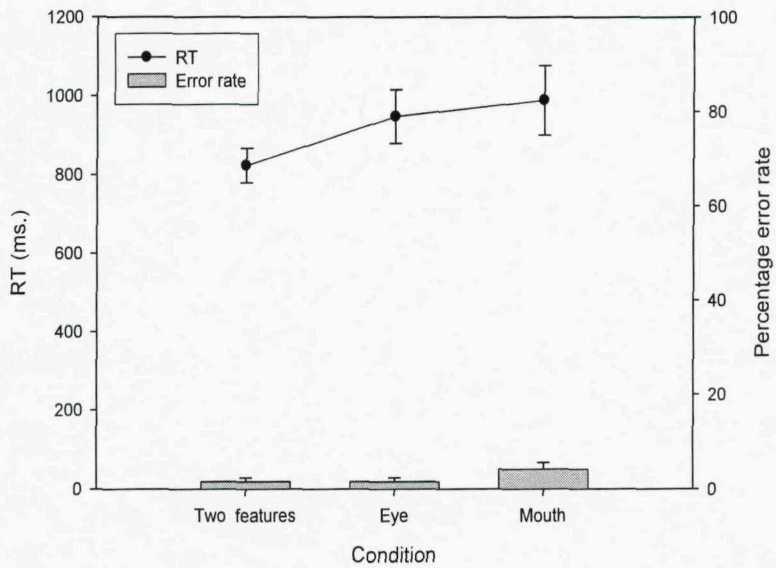

Figure 33. Reaction time and percentage error in all conditions with standard errors.

Appendix D

Experiment 6: Analysis conducted at the level of the mean

The presence of a redundancy gain was examined by computing RT and percentage error data in the same way as in Experiment 1. RTs and errors were compared separately in a 3 way (Condition: Eye versus Mouth versus Two features) repeated measures ANOVA. Analyses were conducted when features were manipulated by 7% and by 12%.

RT - The main effect of level was significant ($F(1, 11)=31.61, p<.01$), participants were faster when faces were manipulated by 12% compared with 7%. The main effect of condition was also significant ($F(2, 22)=9.52, p<.01$). Participants were significantly faster to respond when two features were manipulated compared with when either the eyes or the mouth was manipulated ($t(11)=3.15, 4.28$, both $p<.01$). There was no significant difference between the eye and mouth conditions ($t(11)=1.57$). The interaction between level and condition was not significant ($F(2, 22)=1.91$).

Accuracy - The main effect of level was significant ($F(1, 11)=60.47, p<.01$), participants were more accurate when faces were manipulated by 7% compared with 12%. The main effect of condition was significant ($F(2, 22)=32.74, p<.01$) as was the interaction between level and condition ($F(2, 22)=14.16, p<.01$). When features were manipulated by 7%, the main effect of condition was significant ($F(2, 22)=30.78, p<.01$). Participants were more accurate when two features were manipulated compared with when either the eyes or the mouth was manipulated ($t(11)=8.56, 8.14$, both $p<.01$ respectively). There was no significant difference between eyes and mouths ($t(11)=1.53$). When features were manipulated by 12%, the main effect of condition was also significant ($F(2, 22)=7.90, p<.01$). Participants were more accurate when two features were manipulated compared with when the mouth was manipulated ($t(11)=3.28, p<.01$). Participants were also more accurate when the eyes were manipulated compared with the mouth ($t(11)=2.74, p<.05$). There was no significant difference between the two feature change condition and the eye condition ($t(11)=1.08$).

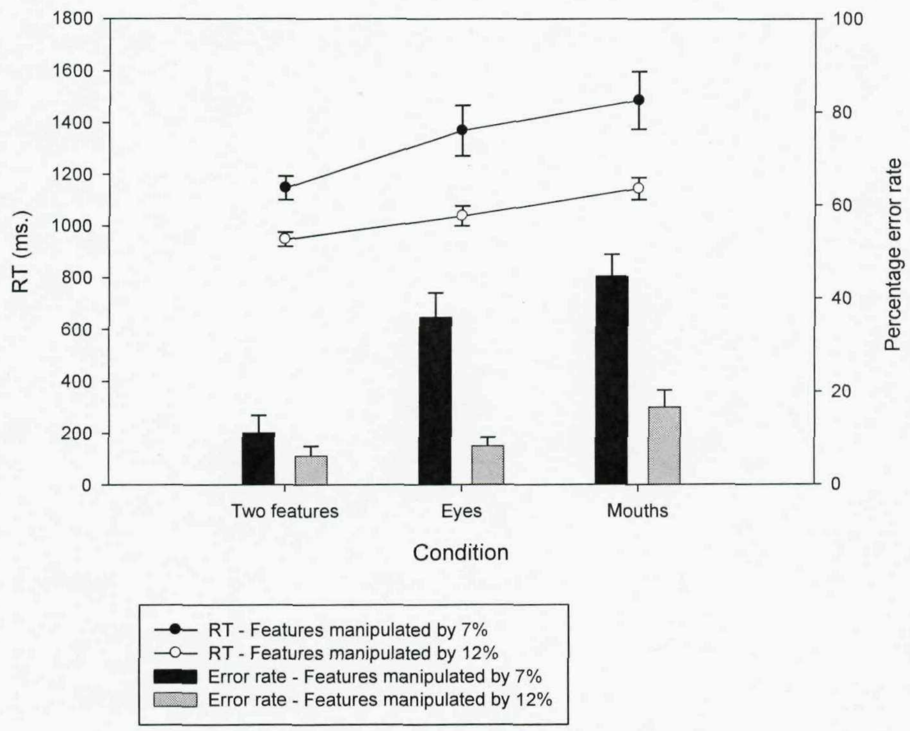

Figure 34. RTs and error rates in the CC, CA and AC conditions (see Table 1 for condition names and descriptions) with standard errors.

Appendix E

Experiment 6: Analysis conducted at the level of the survivor function

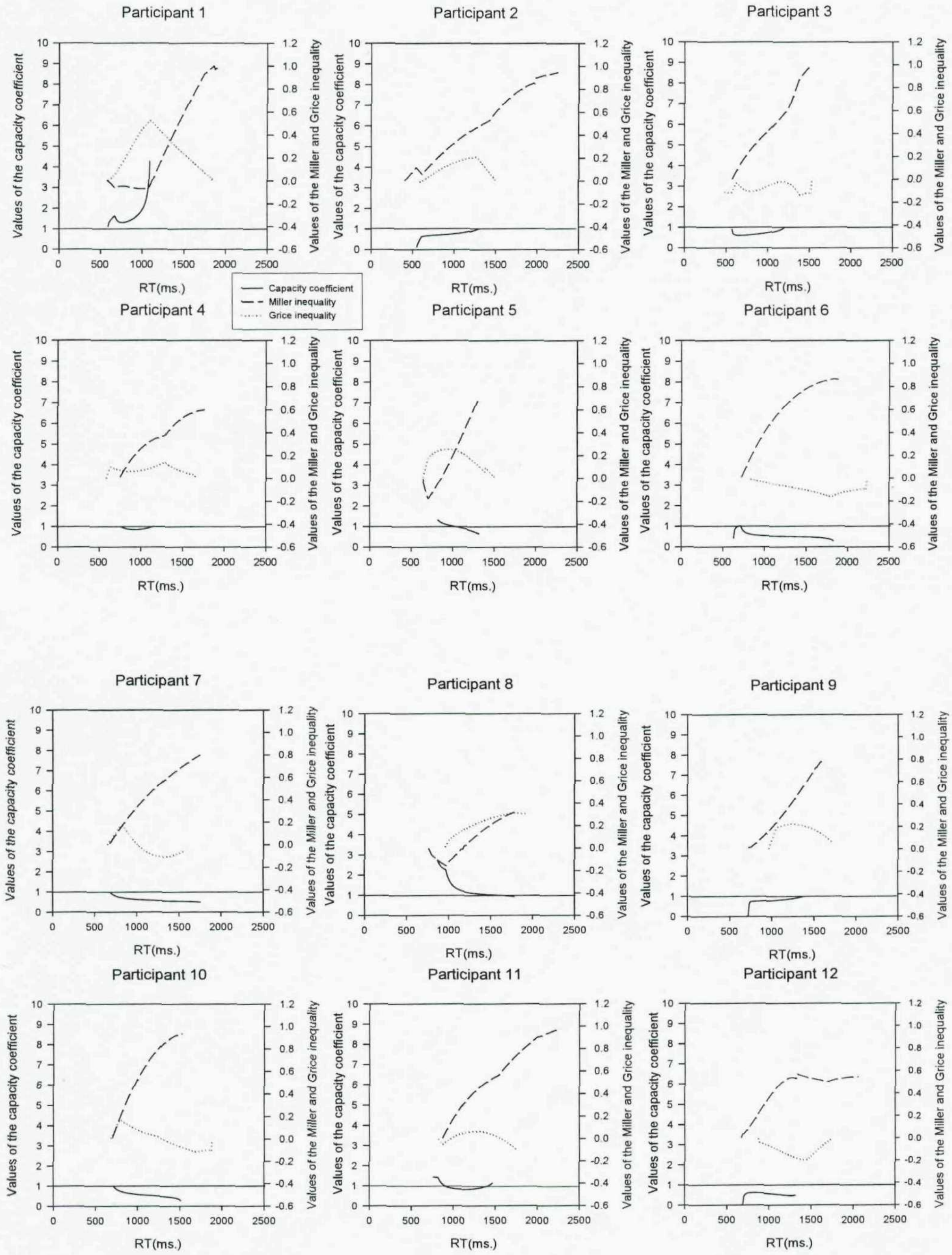

Figure 35. Values of the capacity coefficient, Miller inequality and Grice inequality for all participants. Excursions above the solid reference line for the capacity coefficient is consistent with coactive/global-configural processing. Excursions below 0 for the Miller inequality is also consistent with coactive/global-configural processing.

<u>Appendix F</u>

Experiment 6: Mean RTs presented separately for each participant for the eye and mouth conditions where features were manipulated by 7% and 12%

Table 12

Table of means for conditions where eyes and mouths were manipulated by 7% and 12% required for the assumption of selective influence

Participant	Eye	Mouth		
	7%	12%	7%	12%
1	2186.57	1153.81	996.64	1265.89
2	1056.44	978.31	1167.70	1015.15
3	1108.22	910.28	1164.39	1008.82
4	1267.76	924.11	1386.13	1124.90
5	1207.28	1055.94	1308.16	1032.22
6	1548.39	1055.94	1313.90	1069.12
7	1154.62	989.83	1472.83	1223.55
8	1819.02	1357.13	1736.31	1458.29
9	1483.70	1127.65	1371.30	1125.24
10	1179.55	898.90	1207.92	936.61
11	1267.48	1099.35	1275.63	936.61
12	1155.28	914.55	2439.78	1279.67

Appendix G

Experiment 6: Mean RTs presented separately for each participant for the headlight and number plate conditions where features were manipulated by 7% and 12%

Table 13

Table of means for conditions where headlights and number plates were manipulated by 7% and 12% required for the assumption of selective influence

Participant	Headlights		Number plate	
	7%	12%	7%	12%
1	2186.57	1153.80	1996.64	1265.89
2	1056.44	978.31	1167.70	1015.15
3	1108.22	910.28	1164.39	1008.82
4	1267.76	924.11	1386.13	1124.90
5	1207.28	1055.87	1308.16	1032.22
6	1548.39	1055.94	1313.90	1069.12
7	1154.62	989.83	1472.83	1223.55
8	1819.02	1357.13	1736.31	1458.29
9	1483.70	1127.65	1371.30	1125.24
10	1179.55	898.90	1207.92	936.61
11	1267.48	1099.35	1275.63	1195.20
12	1155.28	914.55	2439.78	1279.67

Appendix H

Experiment 6: Survivor functions for the two feature change face conditions

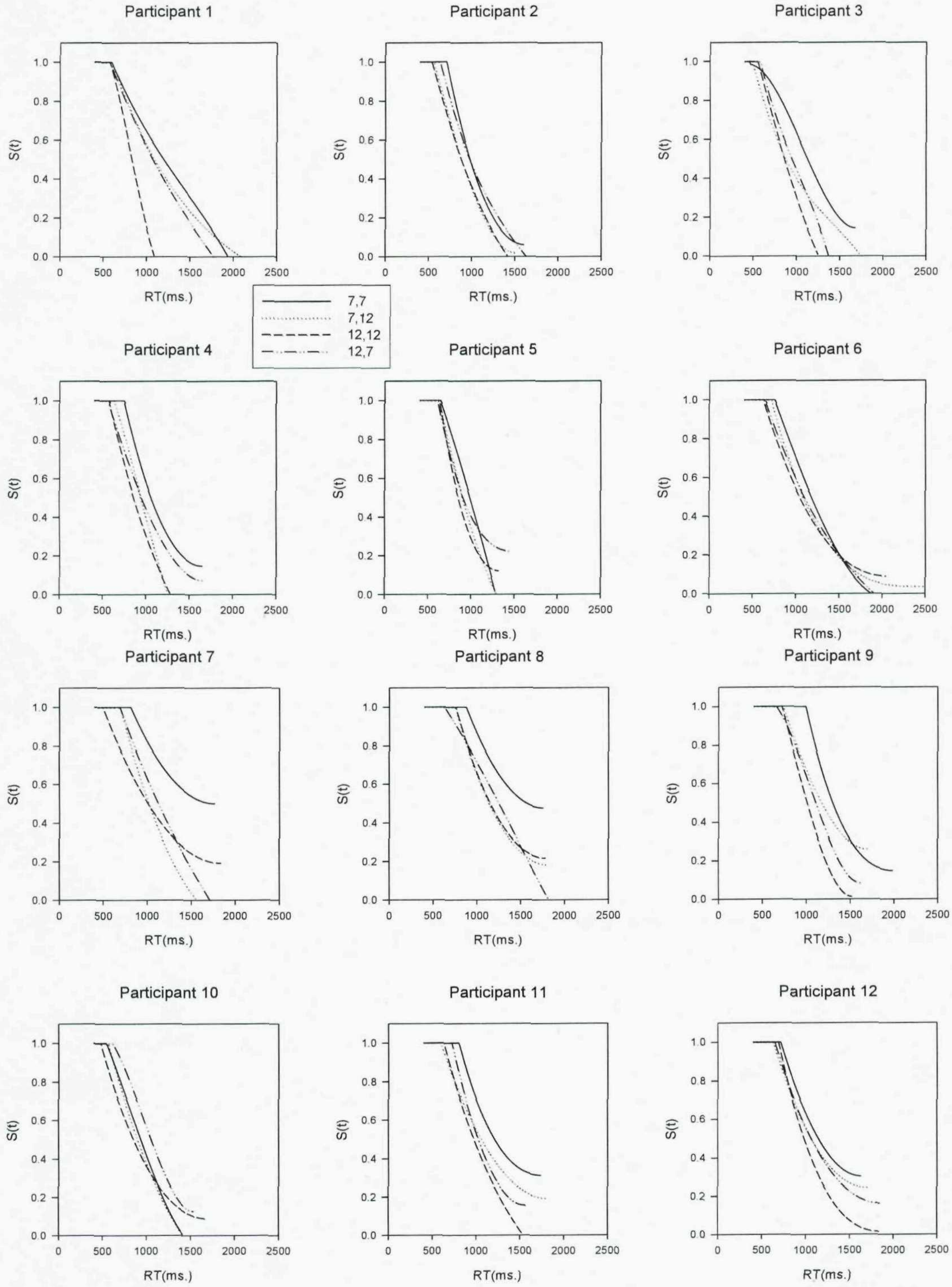

Figure 36. Survivor functions for the double target trials in the face condition.

Appendix I

Experiment 6: Survivor functions for the two feature change cars conditions

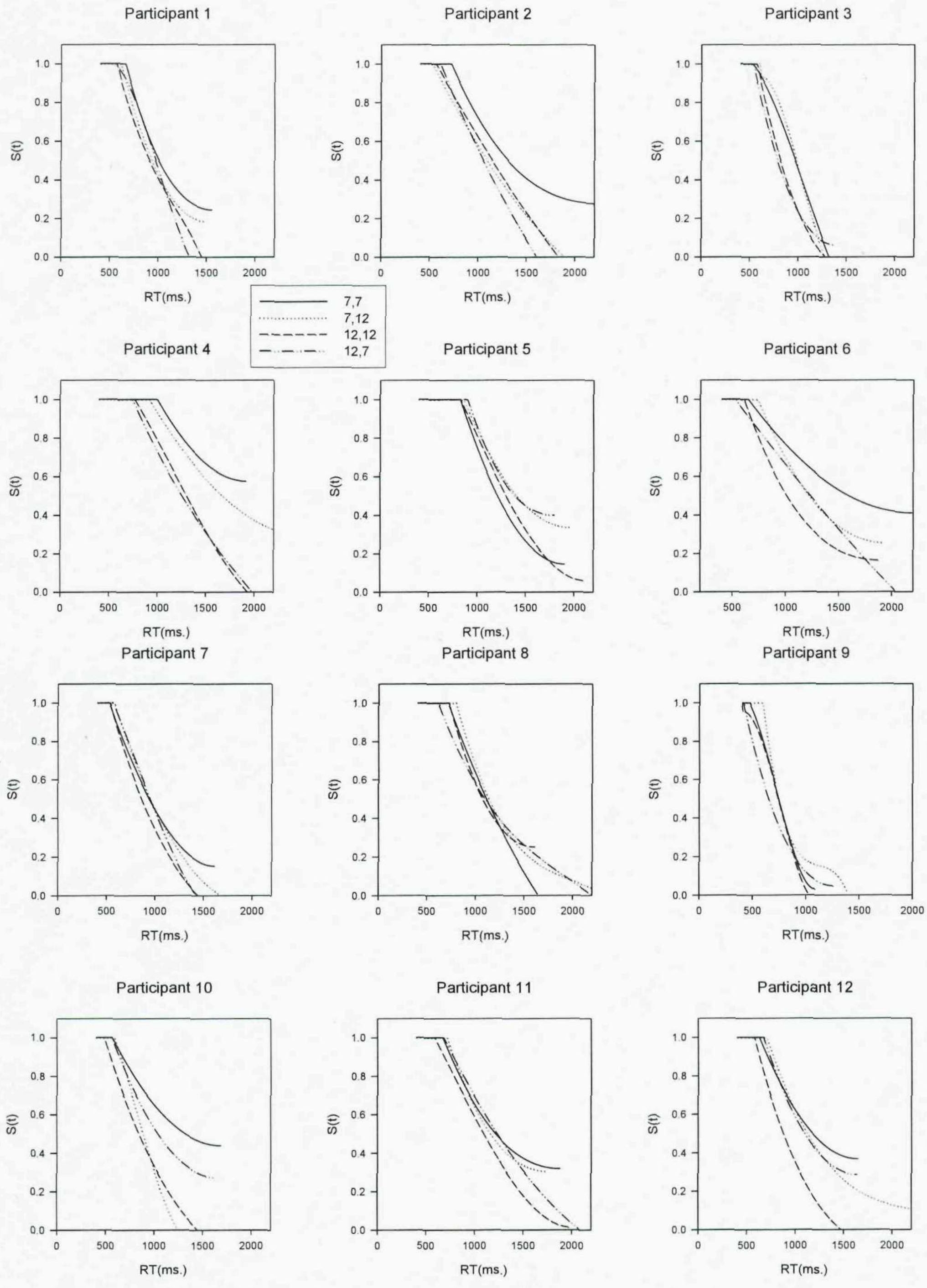

Figure 37. Survivor functions for the double target trials in the car condition.

Appendix J

Experiment 6: Interaction contrasts at the level of the mean for faces and cars

Table 14

Interaction contrasts at the level of the mean for all participants

Participant	Interaction Contrast	
	Faces	Cars
1	-71.99	278.61
2	19.06	126.01
3	21.06	-162.57
4	104.15	-12.97
5	-112.18	-315.97
6	42.30	22.76
7	346.32	-177.35
8	8.65	-76.16
9	121.99	118.75
10	-48.38	117.11
11	122.84	-77.68
12	152.43	-175.62

Appendix K

Experiment 6: Interaction contrasts at the level of the survivor function for faces

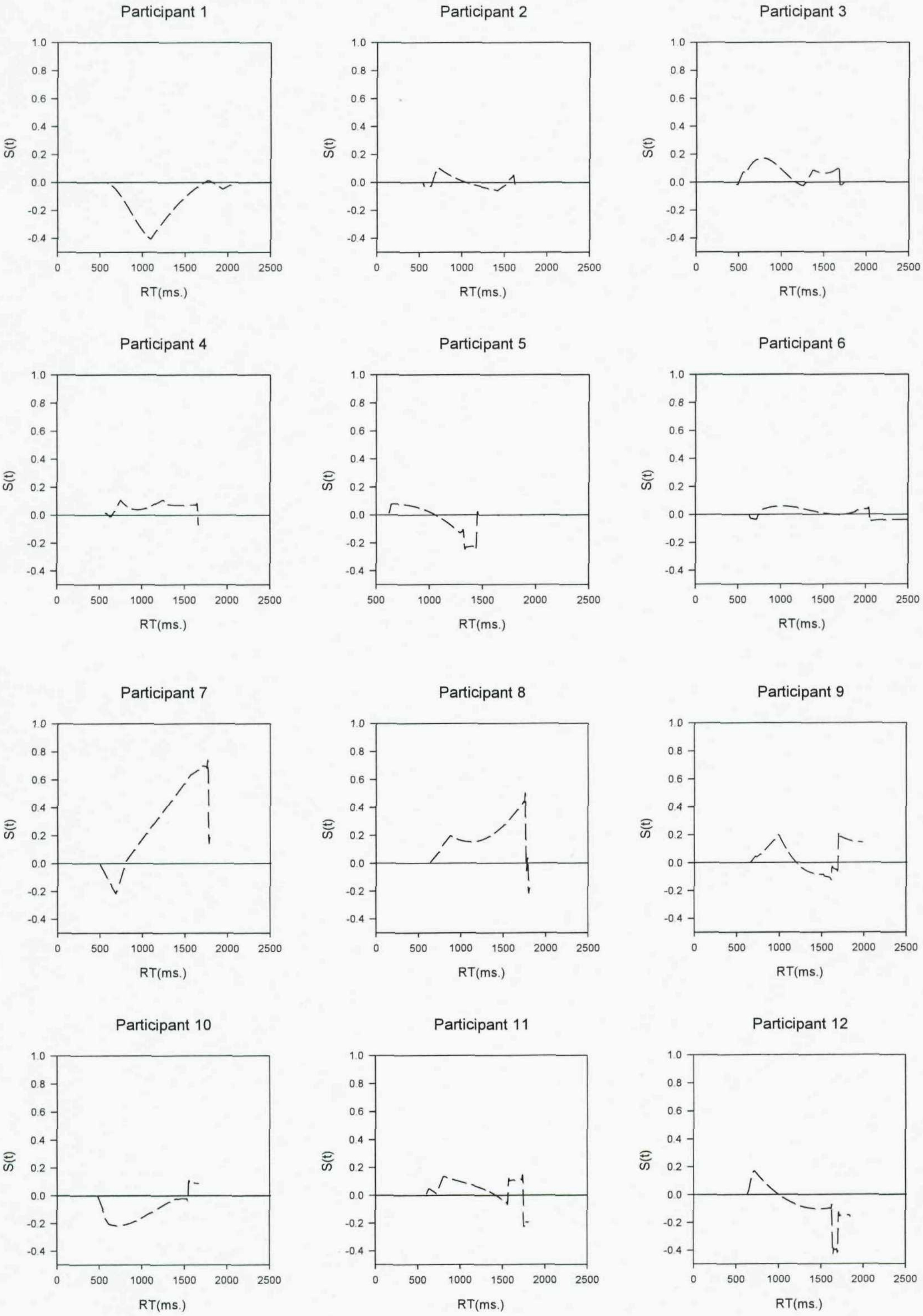

Figure 38. Interaction contrast (IC_{SF}) for all participants in the face condition.

<u>Appendix L</u>

Experiment 6: Interaction contrasts at the level of the survivor function for cars

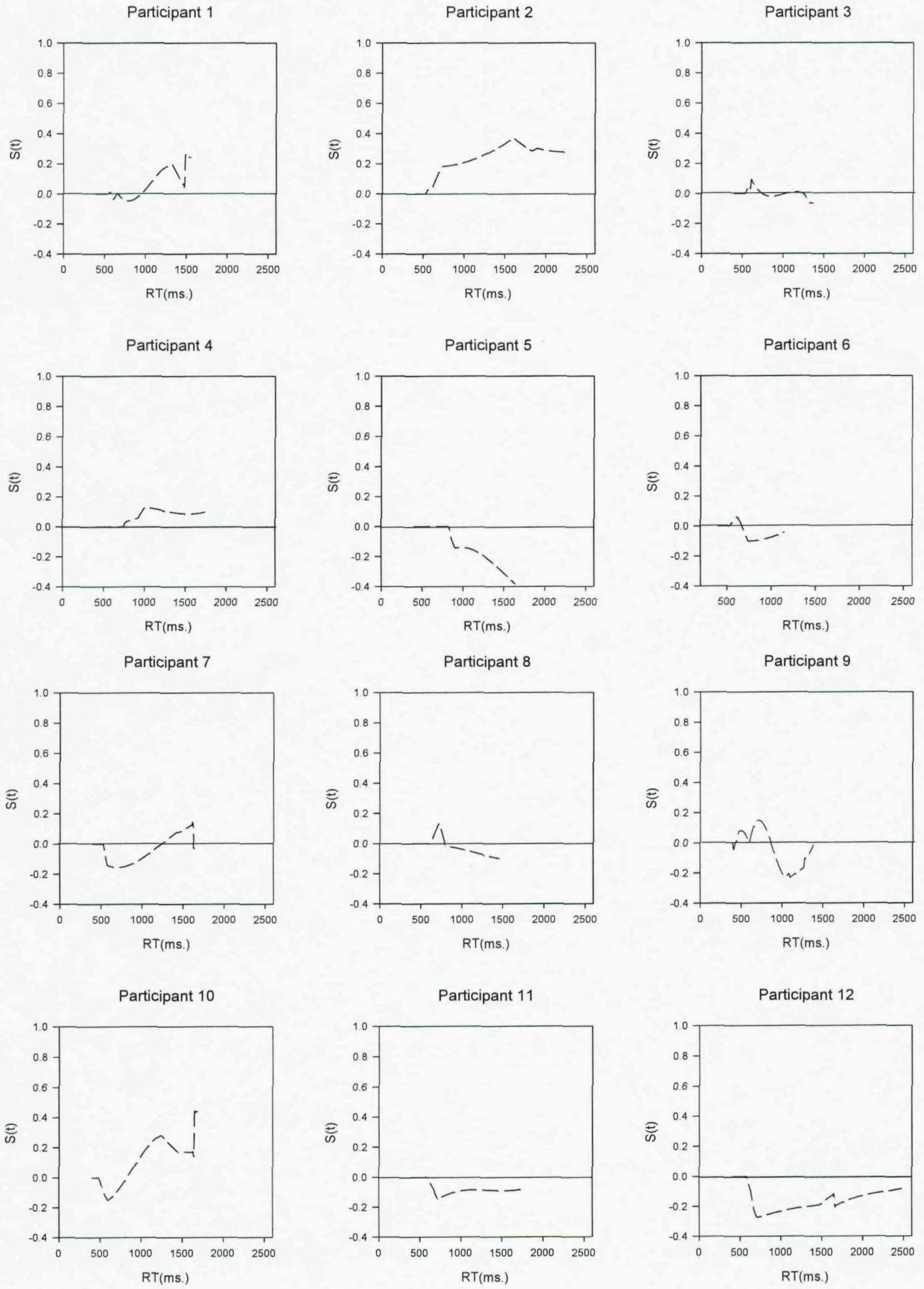

Figure 39. Interaction contrast (IC_{SF}) for all participants in the car condition.

Appendix M

Experiment 6: Survivor functions for the eye and mouth conditions

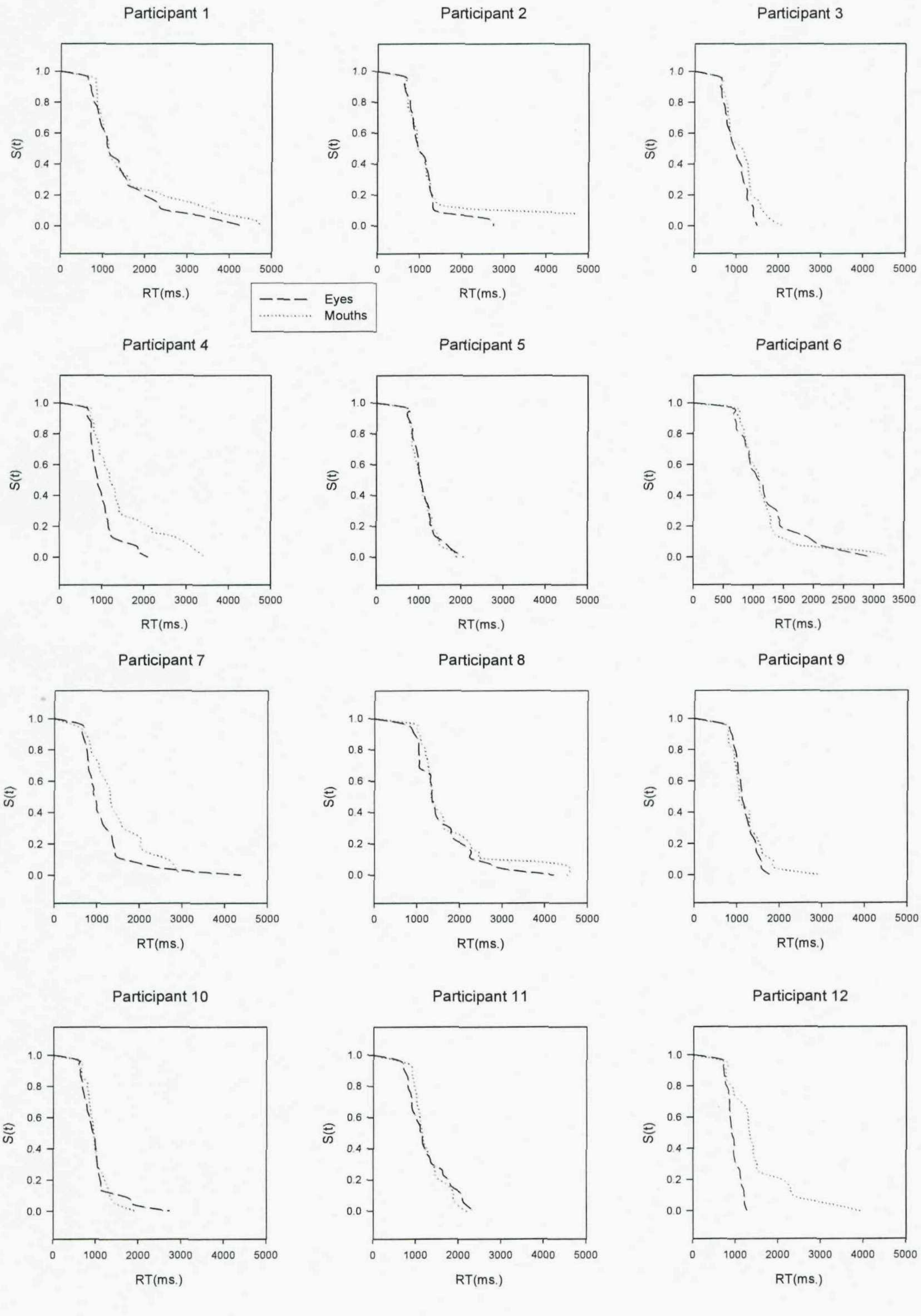

Figure 40. Survivor functions for the eye and mouth conditions.

Appendix N

Experiment 6: Survivor functions for headlights and number plate conditions

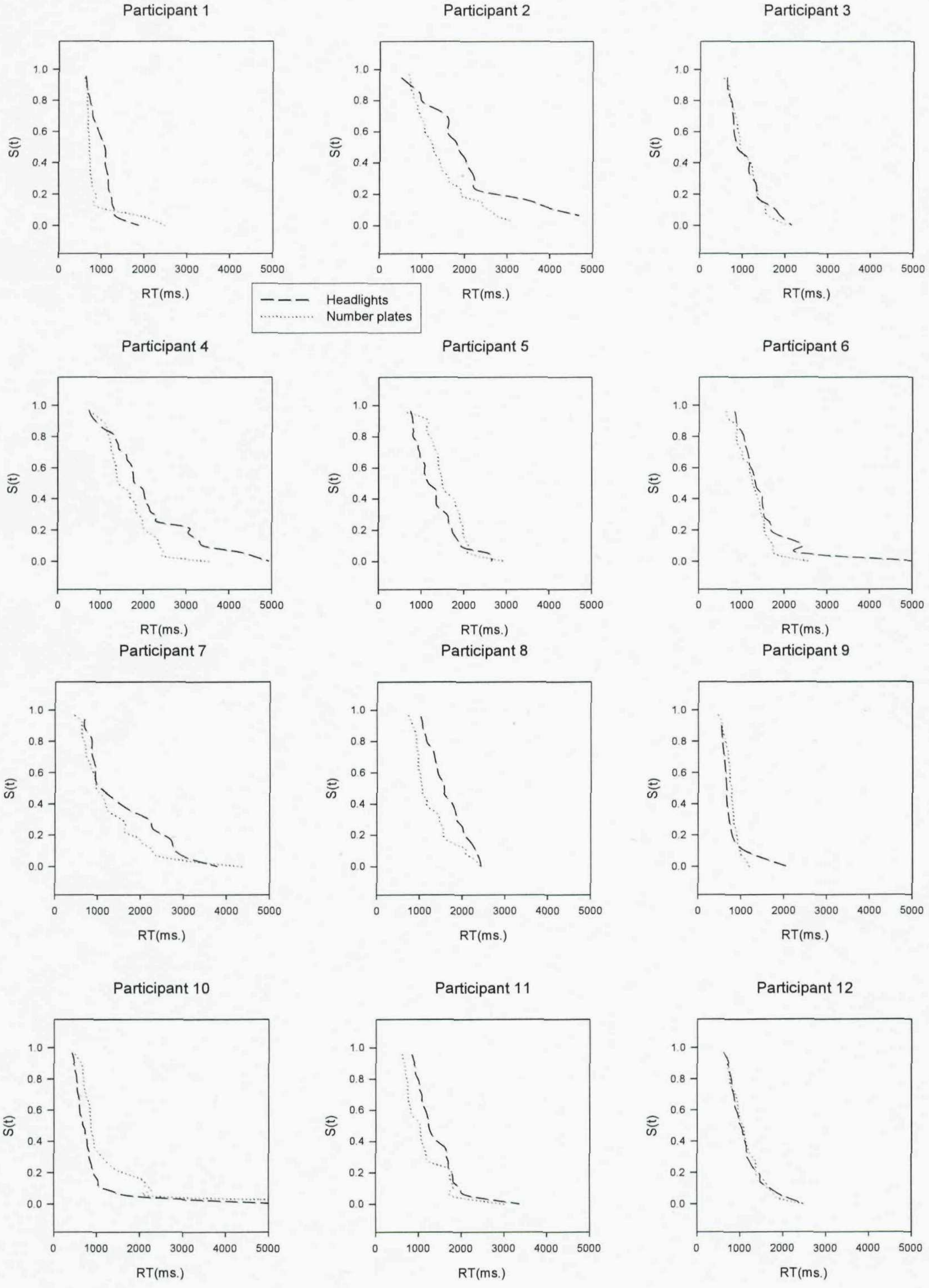

Figure 41. Survivor functions for the headlight and number plate conditions.