

A spatial frequency account of the detriment that local processing of Navon letters has  
on face recognition

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## **Abstract**

Five minutes of processing the local features of a Navon letter causes a detriment in subsequent face recognition performance (Macrae & H. Lewis, 2002). We hypothesise a perceptual after-effect explanation of this effect in which face recognition is less accurate after adapting to high spatial frequencies at high contrasts. Five experiments were conducted in which face recognition performance was compared after processing high contrast Navon stimuli. The standard recognition deficit was observed for processing the local features of Navon stimuli, but not if the stimuli were blurred (Experiment 1) or if they were of lower contrast (Experiment 2). A face recognition deficit was observed after processing small high contrast letters equivalent to local processing of Navon letters (Experiment 3). Experiments 4 and 5 demonstrated that recognition of bandpass filtered faces interacted with the type of Navon processing, whereby the recognition of low-pass filtered faces was better following local rather than global processing. These results suggest that the Navon effect on subsequent face recognition is a perceptual phenomenon.

Key Words: Face Recognition, Navon Letters, Spatial Frequency Adaptation, global and local processing.

## Introduction

Face recognition takes its place at the acme of all human visual abilities (Ellis, 1986). This expert ability (e.g., Farah, Wilson, Drain, & Tanaka, 1998) is often experimentally tested by presenting a series of faces or single face to be learnt and after some distraction phase, tested intermixed with new faces either in an old/new recognition paradigm or in a line-up procedure. The activity that participants undertake in the interval between learning faces and their subsequent retrieval or recognition is directly related to the accuracy with which the faces are recognised (see e.g., M. Lewis, 2006). Macrae and H. Lewis (2002) found that during the interval between watching a video of someone committing a crime and a line-up, processing the global figure in a Navon letter improved accuracy in the line-up. A Navon letter (Navon, 1977) is a global figure made up of local features. Examples of the Navon stimuli used in these experiments are presented in Figure 1. Whereas control participants (who read a magazine) had an accuracy of 63% in the line-up, participants asked to identify the global letters for ten minutes had an accuracy of 83%. Furthermore, participants asked to identify the local letters for ten minutes had reduced performance, at an accuracy level of 30%. Processing the local features of a Navon letter depreciates recognition accuracy by 33% in this study.

This pattern of results has been subsequently replicated using line-up paradigms (e.g., Hills & M. Lewis, 2008; Perfect, 2003; Weston & Perfect, 2005) and recognition paradigms (e.g., Hills & M. Lewis, 2007), although many researchers report failing to find the effect (e.g., Lawson, 2006, 2007; Ryan, Aulenbach, Becker, Johnson, Christman, Murray, & Bergmaier, 2006). The overall effect size for these studies has been calculated by Brand (2005) to be  $r = .10$ . If this effect is valid, it would be both practically important (for improving eye-witness accuracy) and theoretically interesting. However, the link between Navon stimuli and face recognition is not obvious. Macrae and H. Lewis (2002) and Perfect (2003) hypothesised that this link is due to the type of processing (featural and configural) involved in both face perception and identification of Navon stimuli. An alternative explanation is offered here based upon the perceptual make-up of Navon stimuli and how this may overlap with perceptual features of faces. The present work tests the low-level perceptual effects of Navon stimuli on face recognition.

*Figure 1 about here*

## Global and Local Processing

Face recognition is often considered to involve a form of “holistic” processing (e.g., Farah, et al., 1998; Tanaka & Farah, 1993), whereby faces are recognised without any explicit recognition of their constituent features. This holistic processing is demonstrated through participants’ difficulty in selectively attending to a facial feature when it is presented in its intact facial configuration relative to a disrupted configuration or in isolation (Boutet, Gentes-Hawn, & Chaudhuri, 2002; Gauthier, Curran, Curby, & Collins, 2003; Richler, Gauthier, Wenger, & Palmeri, 2008). It may be that this holistic processing is due to a reliance on configural processing (Richler, Tanaka, Brown, & Gauthier, 2008). Configural processing refers to the relations between features (e.g., distance between the eyes) and is often contrasted with featural processing (that is each feature in isolation). The expert nature of face recognition is based upon this configural processing and it is this that differentiates it from object processing (Tanaka & Farah, 1993). Disruption to configural processing leads to poorer face recognition.

The face inversion effect is often used as evidence for the expert nature of face recognition (Valentine, 1988). Inverted faces are selectively harder to recall than upright faces (Goldstein, 1965; Hochberg & Galper, 1967), however, inversion does not lead to the same recognition deficit in objects (e.g., aeroplanes, houses, and visual scenes; Leder & Bruce, 2000; Yin, 1969). This may lead to the conclusion that the processing of inverted faces is similar to that of processing objects. Freire, Lee, and Symons (2000) suggest that inversion disrupts the expert configural processing important for face recognition. Indeed, M. Lewis and Glenister (2002) define configural encoding as that “which is disrupted by inversion” (p. 8) and featural encoding as that “which can occur for inverted faces” (p. 8). Thus, inversion is the benchmark for disrupting configural processing and the expertise in face recognition. For reviews of inversion and configural processing, see Maurer, Le Grand, and Mondlock (2002) and Rossion and Gauthier (2002).

The recognition benefit offered by configural processing has been used to account for the verbal overshadowing effect. First studied by Schooler and Engstler-Schooler (1990), verbal overshadowing is where describing a face in the interval

between witnessing an event (in their case a mock crime) and a recognition phase (a lineup) disrupts recognition. Those participants who have verbalised a face are less accurate in their recognition of the face. Schooler and Engstler-Schooler (1990) suggested that the perceptual memory of the face has been overshadowed by a verbal memory. This verbal memory causes a mismatch between perceptual and verbal knowledge and is known as the modality mismatch hypothesis (Schooler, Fiore, & Brandimonte, 1997). Alternatively, a transfer-inappropriate shift explanation has been put forward.

When one verbalises a face, it is often the case that people describe features and use a feature-matching strategy (Dodson, Johnson, & Schooler, 1997). Since face recognition is primarily a configural process as described above, verbalisation causes faces to be processed featurally. This is a non-optimal process (see Roediger, 1990) and does not match the encoding conditions of the original face. This mismatch reduces recognition performance.

Fallshore and Schooler (1995) indicate that the verbal overshadowing effect will only occur for tasks involving a high degree of perceptual expertise, which explains why no verbal overshadowing effect was found for car memory (Brown & Lloyd-Jones, 2003). Fallshore and Schooler also noted that verbalising an inverted face caused it to be recognised more accurately. Since an inverted face is best processed featurally, the verbalisation has increased the use of featural information to be used. This would, therefore, be a transfer-*appropriate* shift.

Like the effect of Navon stimuli on faces, the verbal overshadowing effect has proven difficult to replicate and several authors have failed to find an effect of verbal overshadowing (e.g., Lyle & Johnson, 2004; Memon & Bartlett, 2002). A meta-analysis conducted by Meissner and Brigham (2001), revealed the effect size of the verbal overshadowing effect was small, around  $r = 0.12$ . This is similar to the effect size of the effect of Navon stimuli on face recognition as calculated by Brand (2005), which was  $r = 0.10$ . Moreover, the verbal overshadowing effect appears to wear off during an experimental session (Brown & Lloyd-Jones, 2003), although Schooler and Engstler-Schooler (1990) suggest that the effect can last for up to two days. Hills and Lewis (2007) have demonstrated that the detrimental effect of processing the local features of a Navon letter on face recognition wears off during the recognition phase of an experiment. It can be reinstated successfully with additional presentation of Navon stimuli between the faces in the recognition phase of an experiment.

Macrae and H. Lewis (2000) and Perfect (2003) have used the transfer-inappropriate shift explanation of verbal overshadowing effect to explain the Navon effect. Since a Navon letter contains both local and global components, it is assumed that it can influence featural and configural processing. The local features of a Navon letter make up a global configuration which is the large letter. As such, processing the local features causes a transfer-inappropriate shift to featural information. Since the original face will be processed configurally, the shift to local processing causes a mismatch between the stored memory trace and the subsequent encoding. As such, the explanation based on the verbal overshadowing effect could be applied to the detrimental effect of local Navon processing.

### Perceptual Properties of Global and Local Processing

Configural and featural processing are constructs that may be high-level or they may rely on low-level perceptual processing. Ward (1982) suggested that information considered to be processed globally was carried by low spatial frequency channels. Conversely, local information is carried by high spatial frequency channels (see also, Bruce, 1988). This result has received much empirical support both directly and indirectly in the way both Navon and face stimuli are processed.

There are two key effects regarding the way Navon stimuli are processed. The first is that the global shape is identified quicker than the local shapes (Navon, 1977). This is the global precedence effect. There is also an interference effect, whereby processing the global component of a Navon figure causes the response time for a subsequent local feature to be significantly greater. These effects are dependent on subtle changes in the environment. Changes in the size (Kinchla & Wolfe, 1979) and spatial frequency (Badcock, Whitworth, Badcock, & Lovegrove, 1990; Hughes, Nozawa, & Ketterle, 1990; La Gasse, 1993; Lamb & Yund, 1993; 1996a, b; Robertson, 1996; Sierra-Vazquez, Serrano-Pedraza, & Luna, 2006) of the Navon stimuli can remove or reverse the global precedence effect. It must be noted that not all changes to Navon stimuli affect the global precedence effect – colour, polarity, nor contrast have any effect on the global precedence effect.

Shulman, Sullivan, Gish, and Sakoda (1986) demonstrated that adaptation to low spatial frequency sine-wave gratings prior to identifying global figures in Navon stimuli made such identification significantly more difficult than without such

adaptation. Furthermore, following the processing of the global component of a Navon stimulus, high spatial frequency sine-wave gratings were more easily detected than low spatial frequency sine-wave gratings (Shulman & Wilson, 1987). These results indicate that the processing of the global and local features of a Navon stimulus requires different spatial frequency channels. These spatial frequency channels may in turn be related to configural and featural processing.

A direct test of this correlation was performed by Han, Yund, and Woods (2003) in which Event Related Potentials (ERPs) were recorded for the processing of local and global targets in the left and right visual fields that were either high- or low-pass filtered. The ERP Nd190 usually observed when processing global targets was eliminated when the targets had their low spatial frequencies removed. This suggests a direct link between spatial frequency channels and the type of processing of Navon stimuli. Similar results have been observed in fMRI and PET studies (Sasaki, Hadjikhani, Fischl, Lie, Marret, Dale, & Tootell, 2001), whereby activation for low spatial frequencies and global targets is in the right lateral areas of the occipital cortex and activation for high spatial frequencies and local targets is in the left medial areas of the occipital cortex (see also Peyrin, Chokron, Guyader, Gout, Moret, & Marendaz, 2006).

Boeschoten, Kemner, Kenemans, and van Engeland (2005) demonstrated that the removal of high spatial frequencies in Navon stimuli decreased identification performance for local not global targets. Conversely, removal of low spatial frequencies decreased identification performance for global but not local targets. The ERP P150 indicates the relationship between processing global/local and low/high spatial frequency. The temporal nature of this ERP indicates that global and local processing is mediated by the spatial frequency information.

There is some evidence that different brain regions are associated with the processing of high and low spatial frequency information. On average, the left hemisphere is designed to process high spatial frequency information and the right hemisphere is designed to process low spatial frequency information (Christman, Kitterle, & Niebauer, 1997; Kitterle & Selig, 1991). This correlates with research on featural and configural information that suggests the left and right hemisphere dominate processing for each respectively (Delis, Robertson, & Efron, 1986; Lamb, Robertson, & Knight, 1989; 1990; Robertson, Lamb, & Knight, 1988; Robertson, Lamb, & Zaidel, 1993).

There has been a great deal of evidence suggesting the importance of certain spatial frequency channels in face recognition. A multitude of methods have been used to determine the critical spatial frequencies involved in the identification of faces including selectively removing spatial frequency channels until identification is near impossible. These studies have indicated that spatial frequencies between 8 and 16 cycles per face are the most critical in recognition of faces (Bachmann, 1991; Costen, Parker, & Craw, 1994, 1996; Fiorentini, Maffei, & Sandini, 1983; Ginsburg, 1978, 1986; Gold, Bennett, & Sekuler, 1999; Konorski & Petersik, 2003; Näsänen, 1999; Parker & Costen, 1999; Tieger & Ganz, 1979), though some suggest spatial frequencies of 25 cycles per face are crucial to recognition of faces (Hayes, Morrone, & Burr, 1986).

The involvement of spatial frequency channels in face recognition is not as simple as just described, however. The spatial frequency channels involved in the identification of faces are higher than those used in gender classification (Schyns, Bonnar, & Gosselin, 2002, see also Schyns & Oliva, 1999). This difference is borne out in ERP studies also, whereby the face selective ERP N170 responds according to the spatial frequencies required by the task, in that for identification it reacts to high spatial frequencies, but for gender classification it reacts to low spatial frequencies (Goffaux, Gauthier, & Rossion, 2003). Furthermore, high-spatial frequency information appears to be used at the early stages of face perception (Halit, de Haan, Schyns, & Johnson, 2006).

Absolute spatial frequencies are less important than the differences in spatial frequencies seen in the face at learning from those seen in the face at test. If the spatial frequencies in the test faces do not match those learnt by a single octave, recognition performance is reduced by 20% (Liu, Collin, Rainville, & Chaudhuri, 2000). This matching of spatial frequencies at learning and at test is more important for faces than objects and is similar for upright and inverted faces (Collin, Lie, Troje, McMullen, & Chaudhuri, 2004). Indeed, it is possible to recognise faces that do not contain the critical spatial frequencies at high levels of accuracy if they have been learnt and are tested containing the same spatial frequencies (Konorski & Petersik, 2003).

There is, therefore, a correlation between local and global processing of Navon stimuli, local and global processing of faces, and the spatial frequency channels employed in perception. Whether local and global processing of Navon

stimuli is the same as local and global processing in faces is up for debate (Weston & Perfect, 2005). The local features of a Navon stimulus are of high spatial frequency. These spatial frequencies are critically important for the identification of faces. Since processing of Navon stimuli can cause perceptual after-effects, it is entirely possible that the cause of the recognition deficit for faces following the processing of the local features of a Navon stimulus is due to perceptual adaptation to high spatial frequencies. The main issues concerning how this perceptual adaptation may relate to the current tasks are described below.

### Perceptual Adaptation

Perceptual adaptation is when the perceptual system is altered following constant stimulation of a particular characteristic (Blakemore, Nachmias, & Sutton, 1970). It is possible to adapt to specific spatial frequencies (e.g., Menees, 1998), whereby these become harder to discriminate following adaptation. In practice, this means the visual cortex can become adapted to, for example, high resolution images, causing an after-effect in which it is easier to identify objects in low resolution images. An adaptation of three minutes will only affect a very narrow band of spatial frequencies (Menees, 1998, Webster & Mollon, 1999) such as causing visual fatigue for text on a computer screen (Lunn & Banks, 1986).

In a test of detection thresholds of spatial frequencies in natural images, Webster and Miyahara (1997) adapted participants to a particular spatial frequency for five minutes. Subsequently, identification of spatial frequencies was tested in a sequential test, with a further 6 seconds adaptation between each test stimulus. Their results noted that threshold for detecting similar spatial frequencies to the adaptor is much higher following adaptation.

Adaptation to spatial frequencies is dependent on contrast (Heinrich & Bach, 2002; Snowden & Hammett, 1996). Georgeson and Harris (1984) have noted that contrast threshold elevation functions are neither straight nor parallel at different spatial frequencies. In other words, the increase in contrast required after adaptation to detect a sine-wave is dependent on the spatial frequency of the adaptor. A high contrast high spatial frequency adaptor causes detection thresholds to be raised more than an adaptor that is of the same spatial frequency but low contrast. This makes it more difficult to detect a sine-wave grating of a high spatial frequency following

adaptation. This adaptation took two minutes to produce (roughly the same time as required to produce the detriment on face recognition using the local Navon task).

## The Present Work

The perceptual experience of processing the global feature of a Navon stimulus is very different to the experience of processing the local features of a Navon stimulus. In a classic Navon letter, the global figure is of low contrast and low spatial frequency, whereas the local features are of high contrast and high spatial frequency. Attention is directed (e.g., Baars, 1997) to one or other of these spatial frequency channels, possibly inhibiting the other. Shulman and Wilson (1987), amongst others, have shown that adaptation to Navon stimuli is possible. Thus, processing the local features of a Navon stimulus causes adaptation in the high spatial frequency channels, making them more difficult to detect. White faces require high spatial frequency channels to be accurately recognised if they have been learnt with all spatial frequency available (Schyns et al., 2002; Collin et al., 2004).

This discussion has therefore led to the suggestion that there are two possible explanations for the detrimental effect of processing the local features of a Navon letter on face recognition. First, an explanation based on transfer-inappropriate processing shift from expert configural coding to inexpert featural coding is the first. Second, a hypothesis based on contrast and spatial frequency adaptation interactions producing a mismatch in the perceptual experience of the faces post adaptation to the Navon stimuli. These two hypotheses shall be referred to as the cognitive transfer-inappropriate processing shift and the perceptual processing mismatch respectively.

To test between these two hypotheses five experiments were conducted. These involved manipulating both the face stimuli and the Navon stimuli to assess whether the effect is due to a cognitive processing shift or a perceptual mismatch. Experiments 1 to 3 manipulated the Navon stimuli, by reducing the contrast of the Navon stimuli by blurring (Experiment 1) or direct adjustment (Experiment 2). Experiment 3 removed all aspects of local and global processing and compared face recognition following read of large and small letters of high and low spatial frequency. These 3 experiments also tested whether the effect of Navon processing on upright and inverted faces.

Experiments 4 and 5 manipulated the face stimuli by presenting faces that were: high-pass filter; low-pass filtered, or broadband (unfiltered) at learning and at test. In Experiment 4, there was no mismatch in the actual visual make-up of the faces from learning to test, whereas in Experiment 5, faces were learnt in one format and were tested in all three formats, thus assessing actual mismatch and perceived mismatch.

## **Experiment 1**

Experiment 1 employed a mixed design whereby participants were either told to identify the global or local components of either unadjusted or blurred Navon letters. The faces participants were tested on were either upright or inverted and this was matched at learning and at test. Distinct predictions based upon the cognitive transfer hypothesis and the perceptual after effect hypothesis can be made. These shall be spelt out individually and are represented in Figure 2.

Recall that the cognitive processing shift explanation suggests that local processing of Navon letters causes local processing to be used in the subsequent faces. Given that inverted faces are better processed using featural information, this explanation suggests local Navon processing will lead to improved recognition of inverted faces and a detriment to the processing of upright faces. Additionally, blurring the Navon letters should not have an influence on this effect. Thus, the cognitive processing shift explanation predicts that there will be an interaction between the orientation of the face and the type of processing undertaken. This hypothesis also would not predict a significant face inversion effect given the interaction, or any effects involving the type of Navon stimuli.

The perceptual mismatch hypothesis makes different predictions from those of the cognitive processing. Given that inverted faces and upright faces are not perceptually different, they will not be affected differently by the type of Navon processing undertaken: Local Navon processing will cause a deficit in the recognition of both upright and inverted faces. Instead, the make-up of the Navon stimuli, in terms of contrast and spatial frequency, will affect whether they lead to an improvement or reduction in face recognition. Blurring the Navon stimuli will remove the recognition deficit caused by local Navon processing and the recognition advantage caused by global Navon processing. Thus, this explanation predicts an

interaction between the type of processing undertaken and the type of Navon stimuli. Additionally, this hypothesis also predicts that there will be a significant face inversion effect, but there will not be an interaction between inversion and the other factors.

*Figure 2 about here*

## **Method**

### **Participants**

Forty participants selected from a population of psychology undergraduates at Cardiff University and Anglia Ruskin University, all with normal vision, took part in this study as partial fulfilment of a course requirement.

### **Materials**

One-hundred-and-twenty-eight faces were collected from the Stirling face database (available at [www.pics.stir.ac.uk](http://www.pics.stir.ac.uk)). These are of male and female faces presented in frontal views in greyscale with resolution of 72 dpi. Two sets of these images were used, one with dimensions 100 mm by 110 mm and one with dimensions 200 mm by 220 mm. One set was used for learning and the other set used for the recognition test. This was counterbalanced across participants. Half of the 64 faces were targets and half were distractors. This was counterbalanced across participants. Half of the target faces were upright and half were inverted. This was counterbalanced across participants. Half of the distractor faces were upright and half were inverted and this was counterbalanced across participants.

In addition to the face stimuli, two sets of Navon stimuli were used. One was an unadjusted set created by Brand (2005), which has been shown to produce a reliable effect on face recognition (Hills & Lewis, 2007, 2008)<sup>1</sup>. These were 157 mm wide by 243 mm high, black text on white background. The second set of Navon stimuli were a blurred version of the first set. These were low-pass filtered using Adobe™ Photoshop™ with a cut off of 1.5 pixels (see Badcock et al., 1990, for a

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<sup>1</sup> These Navon stimuli are available on CD from PJH.

more detailed description of this procedure). The adjustments were made to the original Navon stimuli, as such all other variables were kept constant. An example of the blurred Navon letter is shown in Figure 1.

All the materials were presented using an RM PC onto a high-resolution colour monitor using DirectRT™ Research Software (Empirisoft™). Participants sat 50 cm from the computer screen, and this was kept constant across all conditions.

## **Design**

There were two between-subjects variables in this Experiment. These were the type of crucial Navon processing (either global or local) and the type of Navon stimulus (unadjusted or blurred). Orientation of the faces (upright or inverted) was manipulated within-subjects. This led to a 2 x 2 x 2 mixed factorial design. The dependent variable in this Experiment was recognition accuracy measured in terms of the Signal Detection Theory (SDT: e.g., Swets, 1966) measure of stimulus discriminability,  $d'$ . Counterbalancing was implemented such that the faces appeared as a target or a distractor an equal number of times in each between-subjects condition. Further counterbalancing was implemented as described in the materials section. The faces were presented in a random order during the learning and the recognition phases of the experimental procedure. Participants were randomly allocated to one of 4 experimental conditions (global unaltered Navon processing, local unaltered Navon processing, global blurred Navon processing, local blurred Navon processing) with the condition that there was an equal number of participants in each condition (N = 10).

## **Procedure**

Participants were seated in a darkened laboratory 50 cm from the computer screen. They were instructed not to move their head. A microphone was attached near to the participants' mouths to encourage them to respond accurately to the Navon stimuli. Participants were introduced to Navon stimuli. The experiment had three phases: learning, Navon, and recognition.

In the learning phase, participants saw each of 32 target faces for 2500 ms. Participants were instructed to view each face, but were not explicitly told to learn the faces. Between each face there was a blank screen inter-stimulus interval of 150 ms.

Immediately following the learning phase, the critical Navon phase began. Participants were instructed that they would see a series of Navon letters and were told to read aloud either the global or the local letters depending on the condition. Each Navon stimulus was on screen for 5000 ms and the participant had to respond within this time. There was no inter-stimulus interval between each Navon stimuli. After five minutes, the experimenter instructed the participant to swap from either the global or the local task to the opposite task for the final five minutes. This is a replication of Weston and Perfect's (2005) procedure and controls for task difficulty effects (Perfect, 2003)<sup>2</sup>. The second five minutes of Navon processing is considered the crucial five minutes for any effect Navon processing will have on face recognition (c.f., Perfect, 2003).

Finally, participants underwent an old/new recognition test. Participants saw all 128 faces. Half were the targets they had learnt previously and half were distractors. Participants were instructed to respond as to whether the face was a target or a distractor as quickly and as accurately as possible using the appropriate keys on a standard computer keyboard. The faces were presented sequentially and were on screen until the participant responded. Between each face, four more Navon stimuli were presented for 5000 ms each to reinstate the effect (see Hills & Lewis, 2007). Participants were instructed to read aloud either the global or the local letters depending on their designated condition.

## Results

Old/new responses were combined to form the SDT measure,  $d'$ , as a measure of recognition accuracy using the Macmillan and Creelman (2005) method: the measure  $d'$  is the difference between the inverse normal distribution function of hits and that of false hits. It produces similar data to a hit minus false hit analysis, though is widely accepted as a more accurate method (Macmillan & Creelman, 2005). We used Snodgrass and Corwin's (1988) method for dealing with low error rate. These two

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<sup>2</sup> Swapping from reading the Global letters to the Local letters is unlikely to completely control for task difficulty if reading Local letters is more difficult than processing the Global letters. Nevertheless, this is the procedure adopted by previous researchers.

methods also deal with low N in each cell. We also conducted analyses on hit rate and false alarm rate for this and all subsequent experiments. These are not presented here but are available from the correspondence author (PJH). Mean  $d'$  accuracy is represented in Figure 3. Accuracy is greater for upright faces than inverted faces and this is consistent across all types of Navon stimuli and processing.

The  $d'$  recognition accuracy data was subjected to a 2 x 2 x 2 ANOVA with the factors: type of Navon stimuli (unadjusted or blurred); type of Navon processing (global or local); and orientation of the face (upright or inverted). This revealed a significant effect of facial orientation,  $F(1, 36) = 23.407$ ,  $MSE = 0.860$ ,  $p < .001$ , partial  $\eta^2 = 0.394$  whereby upright faces were recognised more accurately than inverted faces (mean difference = 1.004). There was also a significant type of Navon stimulus by type of processing interaction,  $F(1, 36) = 18.460$ ,  $MSE = 0.760$ ,  $p < .001$ , partial  $\eta^2 = 0.339$ . Simple effects were used to explore this interaction and these revealed that global unaltered Navon processors had significantly greater recognition accuracy than local unaltered Navon processors (mean difference = 1.057,  $p < .005$ ) whereas local blurred Navon processors had greater recognition accuracy than global blurred Navon processors, though this difference was not significant (mean difference = 0.618,  $p > .09$ ). No other main effects nor interactions were significant, largest  $F(1, 36) = 1.992$ ,  $p > .16$ , partial  $\eta^2 = 0.052$ .

*Figure 3 about here*

One possible explanation of these effects is task difficulty, since the local Navon task may be more difficult than the global Navon task, and processing blurred Navon stimuli may be more difficult than processing unadjusted Navon stimuli. Such a suggestion is unlikely, since it is easy to detect the local features of an unadjusted Navon letter and less so for a blurred Navon letter. Nevertheless, the reaction time data for participants to respond to the Navon letters was assessed. The response time to identify the global letter in an unadjusted Navon stimulus was 754 ms compared to 796 ms (standard error = 23 ms) to identify the local letters in an unadjusted Navon stimulus. The response time was 640 ms to identify the global letter in a blurred Navon stimulus compared to 706 ms (standard error 23 ms) to identify the local letters in a blurred Navon stimulus.

The response time data was subjected to a 2 x 2 ANOVA with the factors: type of Navon stimulus (unadjusted or blurred) and type of Navon processing (global or local). This analysis revealed an effect of processing,  $F(1, 36) = 5.606$ ,  $MSE = 5019$ ,  $p < .05$ , partial  $\eta^2 = 0.135$ , whereby response times to the global letter were lower than response times to the local letters (mean difference = 53 ms). There was also a significant main effect of type of Navon stimulus,  $F(1, 36) = 20.661$ ,  $MSE = 5019$ ,  $p < .005$ , partial  $\eta^2 = 0.365$ , whereby processing blurred Navon stimuli was faster than processing unadjusted Navon stimuli (mean difference = 102 ms). The interaction between the type of Navon stimulus and the processing type was not significant,  $F(1, 36) = 0.267$ ,  $MSE = 5019$ ,  $p > .60$ , partial  $\eta^2 = 0.007$ .

## **Discussion**

The results from Experiment 1 show that the recognition advantage after processing the global letter in a Navon stimulus occurs after processing unaltered Navon stimuli but not after processing blurred Navon stimuli. The standard effect of global Navon processing is actually reversed by blurring the Navon stimuli, albeit there was no significant difference in accuracy in the face recognition test following local and global blurred Navon processing. Removal of the high spatial frequencies of the Navon letter prevented the detriment in subsequent face recognition when processing the local letters of the Navon stimulus. This interaction between type of Navon and processing type is not consistent with the cognitive transfer explanation of why Navon stimuli affect face recognition.

Crucially for the test of the mechanism behind this effect is the fact that the effect of facial orientation occurred independently of the type of Navon processing undertaken. The hypothesis that inverting a face would result in better recognition following local Navon processing based on the cognitive shift explanation was not borne out by this experiment. Local processing of unadjusted Navon stimuli led to lower recognition performance of all faces, irrespective of orientation. According to the cognitive shift explanation, blurring the Navon stimuli should not alter the effect they have on subsequent face recognition performance. The results from this Experiment clearly demonstrated that blurring Navon stimuli negates the detrimental effect of local processing in face recognition.

These two findings are inconsistent with a cognitive transfer explanation for the effect of Navon processing on face recognition. They are consistent with a perceptual account of the effect of Navon processing on face recognition, whereby processing the local features of Navon stimuli causes adaptation in high contrast high spatial frequency channels that are critical for the identification of faces. These findings demonstrate that removal of high spatial frequencies from the Navon stimuli is sufficient to remove the detrimental effect they have on face recognition.

There is a minor concern with the data, however. The reaction time data for processing the Navon stimuli indicates that the blurred Navon stimuli are significantly quicker to process than the unadjusted Navon stimuli. Due to the fact that the stimuli are quicker to process, they may have less effect on subsequent face recognition (c.f., the revelation effect, e.g., Bornstein & Wilson, 2004). As such, it is possible that the speed of processing of the blurred Navon stimuli may account for the failure to find a detriment in recognition performance post local processing of blurred Navon stimuli. Experiment 2 was thus run to address this concern.

## **Experiment 2**

Experiment 1 showed that the face inversion effect was independent of the type of Navon processing undertaken by participants. Additionally, local processing of blurred Navon stimuli does not lead to a face recognition deficit. These results are consistent with a perceptual adaptation explanation of the mechanism of how Navon stimuli affect a subsequent face recognition test. Adaptation to specific spatial frequencies is dependent on contrast, such that adaptation to high spatial frequencies leads to greater adaptation if the adaptor is of high contrast (Snowden and Hammett, 1996). The process of blurring a Navon stimulus removes the high-spatial frequencies, but also reduces the contrast of the stimulus. Thus, the adjustments made to the Navon stimuli in Experiment 1 altered both contrast and spatial frequency. Experiment 2 thus aimed to replicate the results of Experiment 1 using Navon stimuli that had their contrast adjusted more directly.

A direct contrast manipulation will interfere with after-effects of spatial frequency. If the Navon stimuli are of lower contrast, adaptation to high spatial frequencies will be weaker than in a Navon stimulus of high contrast. However, the adjustments do not alter the fact that the Navon stimuli contain local and global

components. Thus, the perceptual adaptation explanation and the cognitive processing transfer explanation make distinct predictions as to the results in Experiment 2, as shown in Figure 2. The cognitive shift explanation maintains that adjusting the Navon stimuli in this way will not alter the detrimental effect on face recognition that processing the local letters of the Navon stimuli will have. Furthermore, local processing of either Navon stimuli will lead to an improved recognition performance of inverted faces. Thus, if the cognitive processing shift explanation is the most parsimonious then we would predict an interaction between the processing type and face inversion but no interactions involving the type of Navon stimuli. The perceptual adaptation account, however, predicts that the face inversion effect will be independent of the Navon processing style. As such, in all conditions, inverted faces will be less well recognised than upright faces. However, the recognition deficit caused by local Navon processing will not be observed for reduced contrast Navon stimuli. Thus, if the perceptual adaptation explanation is the most parsimonious then we would predict a significant main effect of facial orientation and a significant type of Navon by processing type interaction.

## **Method**

### **Participants**

Forty participants selected from a population of psychology undergraduates at Cardiff University and Anglia Ruskin University, all with normal vision, took part in this study as partial fulfilment of a course requirement.

### **Materials**

The same face database was used in Experiment 2 as in Experiment 1. In addition, two sets of Navon stimuli were used. One was the unadjusted set created by Brand (2005). The other was an adjusted set, which had the contrast reduced by 75% (using CorelDraw™). The resulting stimuli were darker than the original set. This was compensated by increasing the luminance by 25%. The adjustments were made to the original Navon stimuli, as such all other variables were kept constant. An example of a reduced contrast Navon stimulus is shown in Figure 1.

## Design and Procedure

All aspects of the design and procedure were identical to Experiment 1: participants saw a set of faces then went under the Navon manipulation, followed by the recognition test intermixed with additional Navon stimuli.

## Results

As in Experiment 1, old/new responses were converted to form the SDT measure,  $d'$ , as a measure of recognition accuracy using the Macmillan and Creelman (2005) method and Snodgrass and Corwin's (1988) correction for low error rates. Figure 4 shows the distribution of  $d'$  recognition accuracy scores according to the type of Navon, type of processing, and the orientation of the face. The results are comparable to those found in Experiment 1. For the unaltered Navon stimuli, accuracy was greater for when participants were processing the global letters than when they were processing the local letters. For the participants who had processed reduced contrast Navon stimuli, there is no difference in accuracy between global processors and that of the local processors.

As in Experiment 1, the  $d'$  recognition accuracy data was subjected to a 2 x 2 x 2 ANOVA with the factors: type of Navon stimuli (unadjusted or contrast-adjusted); type of Navon processing (global or local); and orientation of the face (upright or inverted). This revealed a significant main effect of facial orientation,  $F(1, 26) = 62.099$ ,  $MSE = 0.341$ ,  $p < .001$ , partial  $\eta^2 = 0.633$ , whereby upright faces were recognised more accurately than inverted faces (mean difference = 1.029). There was also a significant type of Navon by processing type interaction,  $F(1, 36) = 32.173$ ,  $MSE = 0.390$ ,  $p < .001$ , partial  $\eta^2 = 0.472$ . Simple effects were used to explore this interaction and these revealed that global unadjusted Navon processors had significantly higher recognition accuracy than local unadjusted Navon processors (mean difference = 0.985,  $p < .005$ ) whereas local contrast reduced Navon processors had higher recognition accuracy than global contrast reduced Navon processors (mean difference = 0.600,  $p < .05$ ).

*Figure 4 about here*

As in Experiment 1, the response time to identify the global and local letters in both types of Navon stimuli were compared to assess the effects of task difficulty. The mean response time to identify the global letter in an unadjusted Navon stimulus was 750 ms (standard error 25 ms) which was less than the response time to identify the local letter in an unadjusted Navon stimuli (mean = 799 ms, standard error = 25 ms). The response time to identify a global letter in a reduced contrast Navon stimulus was 795 ms and was less than the response time to identify the local letter in a reduced contrast Navon stimulus (mean = 776 ms). The response time data was subjected to a univariate ANOVA, which failed to reveal any significant effects, largest  $F(1, 36) = 1.805$ ,  $MSE = 6470$ ,  $p > .18$ , partial  $\eta^2 = 0.048$ .

## **Discussion**

The results from Experiment 2 are consistent with those of Experiment 1: there was a significant face inversion effect independent of processing type. The recognition advantage following global Navon processing occurred for unaltered Navon stimuli, but the same processing caused a recognition deficit when reduced contrast Navon stimuli were used. The reduced contrast Navon stimuli maintained the same spatial frequency components as the unadjusted Navon stimuli. This suggests that the effect that Navon stimuli have on face recognition is due to the interaction between contrast and spatial frequency. The detriment in face recognition performance after processing the local letters of the Navon stimuli is due to the high contrast high spatial frequency components of these stimuli. If either were removed then the effect that Navon stimuli have on face recognition is removed.

In Experiment 2, the speed of identification to the unaltered Navon stimuli was comparable to that of the reduced contrast Navon stimuli. This is indicative that these stimuli are equally easy to identify, and that the local and global components within them are equally easy to identify. In other words, the reduced contrast Navon stimuli do not make the global or local components more or less obvious than the unaltered Navon stimuli. Thus, the results from the present experiment cannot be due to ease of processing of one set of Navon stimuli over the other or one component of one set of Navon stimuli.

Since the effect of processing the local letters in Navon stimuli is removed by reducing the contrast of the Navon stimuli and this effect remains irrespective of the orientation of the faces, these results are incompatible with the cognitive shift explanation. These results are consistent with a perceptual adaptation account. The detriment in face recognition performance after processing the local features of Navon stimuli only occurs when they are of high contrast and high spatial frequency. The perceptual account suggests that no local or global components are required to produce this effect. Experiment 3 thus aimed to produce a recognition deficit using letters of high contrast and high spatial frequency that do not contain local or global components.

### **Experiment 3**

While maintaining a letter identification task akin to the Navon task, Experiment 3 aimed to test whether other stimuli of similar perceptual make-up to Navon stimuli can cause detriment in facial recognition. Instead of identifying Navon stimuli, participants in Experiment 3 were presented with letters. These were big (low spatial frequency) or small (high spatial frequency), with contrast adjusted to mimic that of the Navon stimuli. This is an extension of a study conducted by Brand (2005). Brand found a marginal reduction in facial identification performance after processing small high contrast letters akin to processing the local letters in a Navon stimulus. If the effect of processing local letters in a Navon stimulus is due the spatial frequency and contrast components of the letters, then simply reading small high contrast letters will cause a detriment in subsequent face recognition. Processing large low contrast letters will cause a slight improvement in face recognition, akin to global processing of Navon stimuli. Two additional conditions were implemented where low contrast high spatial frequency letters were used, which are akin to the local features in reduced contrast Navon stimuli used in Experiment 2. The final type of stimuli will be low spatial frequency low contrast letters, akin to the global features in reduced contrast Navon stimuli. Reading these letters should not have an effect on subsequent face recognition if the basis for the effect of local processing of Navon stimuli on face recognition is due to a cognitive processing shift. Examples of the stimuli and the predictions based on the cognitive processing shift and the perceptual after effect explanations are presented in Figure 5.

*Figure 5 about here*

## **Method**

### **Participants**

Forty participants selected from a population of psychology undergraduates at Cardiff University and Anglia Ruskin University, all with normal vision, took part in this study as partial fulfilment of a course requirement.

### **Materials**

Thirty faces from the NimStim Face Database<sup>3</sup> were used for this experiment. This database contains two colour images of the same face in neutral expression frontal poses. One of these images was used for the learning phase, and the other used for the test phase. This was counterbalanced across participants. The images were cropped to remove the background and any clothes. All the face stimuli had the dimensions 200 mm by 220 mm.

Four new sets of “Navon” stimuli were created. These were single letters, either of high or low size (spatial frequency) and high or low contrast designed to mimic the basic perceptual properties of the Navon stimuli. The size of the large letters was set at 157 mm wide by 243 mm high. The size of the small letters was size 12 Times New Roman font (2 mm wide by 4 mm high). The contrast of the high contrast letters was set at 100% (black on white). The contrast of the low contrast letters was set at 80% (grey on white). As such, one set was large letters with the contrast of the global Navon figure. One set was large letters with the contrast of the local Navon features. One set was small letters with the contrast of the local Navon features. The final set was small letters with the contrast of the global Navon feature. Each stimulus was made of a single letter, thus 26 were created in each set. These were created in CorelDraw™.

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<sup>3</sup> Development of the MacBrain Face Stimulus Set was overseen by Nim Tottenham and supported by the John D. and Catherine T. MacArthur Foundation Research Network on Early Experience and Brain Development. Please contact Nim Tottenham at [tott0006@tc.umn.edu](mailto:tott0006@tc.umn.edu) for more information concerning the stimulus set.

## Design and Procedure

A 2 x 2 between-subjects design was employed whereby the independent variables were the contrast (high or low) and the size (high or low)<sup>4</sup> of the letters to be identified. A similar old/new recognition paradigm was employed here as in Experiment 1. In the learning phase, participants saw half of the faces for 2500 ms each. Following this they were presented with a set of the letters to which they had been allocated. They saw each letter for 5000 ms and were required to identify the letter. Following five minutes of this task, participants were then given the recognition test in which they were required to state whether each face was a target or a distractor. Between each face, participants saw four further letters for 5000 ms each and were required to identify each.

## Results

As in Experiments 1 and 2, the old/new responses were converted into the SDT measure  $d'$  using the Macmillan and Creelman (2005) method and Snodgrass and Corwin's (1988) correction for low error rate. The mean  $d'$  recognition accuracy data is presented in Figure 6. This shows that accuracy was lower for high contrast stimuli than low contrast stimuli and accuracy was lower for high spatial frequency stimuli than lower spatial frequency stimuli.

The  $d'$  recognition accuracy data was subjected to 2 x 2 ANOVA with the factors contrast (high and low) and spatial frequency (high and low) of the letter stimuli. This revealed a significant effect of letter size,  $F(1, 36) = 4.332$ ,  $MSE = 0.337$ ,  $p < .05$ , partial  $\eta^2 = 0.107$ , whereby accuracy was higher following identification of big letters than small letters (mean difference = 0.382). There was also a significant effect of letter contrast,  $F(1, 36) = 5.114$ ,  $MSE = 0.337$ ,  $p < .05$ , partial  $\eta^2 = 0.124$ , whereby accuracy was higher following identification of low contrast letters than high contrast letters (mean difference = 0.415). The interaction was not significant,  $F(1, 36) = 0.490$ ,  $MSE = 0.337$ ,  $p > .48$ , partial  $\eta^2 = 0.013$ .

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<sup>4</sup> We only indirectly manipulated spatial frequency by having two sizes of stimuli (big – low spatial frequency) and small (high spatial frequency).

*Figure 6 about here*

## **Discussion**

Experiment 3 found that identifying small high contrast letters caused a subsequent face recognition deficit similar in nature to that observed following identification of the local components of a Navon letter. These results indicate that the detrimental effects of processing the local features of a Navon letter on face recognition can be found in non-Navon letters that are of the same spatial frequency and contrast as the local features of a Navon letter. In other words, the spatial frequency and contrast components of the Navon stimuli are most crucial in their effect on face recognition. Thus, it is not the hierarchical nature of the Navon stimuli that causes processing them to influence face recognition, but simply the spatial frequency and contrast components that make up the stimuli. This theoretical analysis suggests that the effects Navon stimuli have on face recognition is due to perceptual after-effects following adaptation to high-spatial frequencies at high contrast.

The data from the first three experiments indicate that it is the perceptual make-up of the Navon stimuli that causes their effects on face recognition. The hypothesis posited is that processing the local features of a Navon stimulus causes the high spatial frequency channels to become adapted. Since it is the higher spatial frequencies that are crucial for face identification (Schyns et al., 2002), face recognition performance is significantly reduced following local Navon processing due to adaptation to the high spatial frequency channels. This theoretical analysis is consistent with the data presented thus far, but has not been directly tested. Experiment 4 aims to explore the perceptual experience following adaptation to Navon stimuli.

## **Experiment 4**

Experiments 1 to 3 indicate that processing the local features of a Navon letter cause a detriment in face recognition performance due to the fact that the local features are of high contrast and high spatial frequency. Processing these high-contrast high-spatial frequency images causes adaptation to the high-contrast high-spatial frequency

perceptual channels. This adaptation causes high-spatial frequencies to be less discriminable post adaptation. These high spatial frequencies are important for facial identification (Schyns et al., 2002). Removal of these spatial frequencies will thus make facial identification less accurate. Indeed, faces that have high-spatial frequencies removed are recognised less readily than broadband faces (e.g., Gold et al., 1999).

Experiment 4 takes these lines of evidence and combines them, by testing this directly by presenting participants with a series of faces that were low-pass filtered, high-pass filtered, or broadband faces and asking them to identify either the local or the global components of a series of Navon stimuli. If a face is filtered such that it contains only high spatial frequencies then adaptation to high spatial frequencies (processing the local features of a Navon letter) will cause these faces to be very difficult to recognise. Likewise, adaptation to low spatial frequencies (processing the global feature of a Navon letter) will cause a face that is filtered such that it contains only low spatial frequencies to be very difficult to recognise. However, adaptation to high spatial frequencies will not cause a recognition deficit in faces containing only low spatial frequencies. Likewise, adaptation to low spatial frequencies will not cause a recognition deficit in faces containing only high spatial frequencies. Statistically, we would predict an interaction between type of filtering and processing type based on the perceptual adaptation account.

## **Method**

### **Participants**

Twenty participants selected from a population of psychology undergraduates at Cardiff University and Anglia Ruskin University, all with normal vision, took part in this study as partial fulfilment of a course requirement.

### **Materials**

Sixty faces from the Minear and Park (2004) face database were used in this Experiment. This database contains two frontal views of male and female faces. The faces used were of male and females aged in their early 20s. The stimuli were 130

mm by 140 mm in size and had a resolution of 72 dpi. A mask was put around the face, such that all backgrounds were the same and no clothing was visible. All images were converted to 256 greyscale format. All were equated for mean luminance and the root-mean square contrast. Two bandpass filtered faces were created from this original set, one was high-pass filtered and the other low-pass filtered. This spatial-frequency filtering was conducted with MATLAB™ (Version 7.2) software for the PC. To create the filtered version, the original broadband faces were put through a bandpass filter by multiplying together a low-pass and high-pass Butterworth filter. Images were then inversely transformed into the spatial domain. The filtered faces had centre frequencies of 7.08 or 14.15 cycles per face, with a bandwidth of 0.5 octaves. This method of stimulus generation is based on that used by Collin et al. (2004). An example of each type of filtered face is presented in Figure 7. The unadjusted Navon stimuli from Experiment 1 were used in this study. All presentation software and equipment was the same as that used in the previous Experiments.

*Figure 7 about here*

## **Design and Procedure**

This experiment employed a 2 x 3 mixed design, whereby the type of Navon processing (global or local) was manipulated between-subjects and the bandpass filtered faces (high-pass, low-pass, or broadband) were manipulated within-subjects. The bandpass filtering was matched at learning and at test, such that the spatial frequency overlap was 100%. The faces were counterbalanced, such that each face appeared as a target and as a distractor an equal number of times and they also appeared in each class of bandpass filtering a roughly equal number of times. The presentation order of the faces was randomised. The procedure for this Experiment was identical to that in Experiment 1.

## **Results**

As in experiments 1 and 2, the old/new recognition data was converted into the SDT measure,  $d'$  using the MacMillan and Creelman (2005) method and Snodgrass and Corwin's (1988) method for dealing with low error rate. Figure 8 presents the mean

$d'$  recognition accuracy data from Experiment 4. This shows that the accuracy was higher for global Navon processors for high-pass faces than local Navon processors and higher local Navon processors than global Navon processors for low-pass faces, and for global processors for broadband faces over local processors.

The  $d'$  recognition accuracy data was subjected to a 2 x 3 ANOVA with the factors: type of Navon processing (global or local) and type of bandpass filtering of the faces (high-pass, low-pass, or broadband). This revealed a main effect of type of filtering,  $F(2, 36) = 10.681$ ,  $MSE = 0.345$ ,  $p < .001$ , partial  $\eta^2 = 0.372$ . Tukey *post hoc* pairwise comparisons revealed that broadband faces were recognised more accurately than high-pass filtered faces (mean difference = 0.368,  $p < .05$ ) and low-pass filtered faces (mean difference = 0.747,  $p < .001$ ). There was no significant difference in the recognition of low-pass and high-pass filtered faces (mean difference = 0.379,  $p > .14$ ). The main effect of processing type was significant,  $F(1, 18) = 7.744$ ,  $MSE = 0.457$ ,  $p < .05$ , partial  $\eta^2 = 0.301$ . These main effects were qualified by an interaction between them,  $F(2, 36) = 14.009$ ,  $MSE = 0.345$ ,  $p < .001$ , partial  $\eta^2 = 0.438$ . Simple effects were used to explore this interaction and revealed that global processors were more accurate than local processors when recognising high-pass filtered faces (mean difference = 1.190,  $p < .01$ ) and broadband faces (mean difference = 0.933,  $p < .05$ ). For low-pass filtered faces, however, local processors were more accurate than global processors (mean difference = 0.915,  $p < .05$ ).

*Figure 8 about here*

## **Discussion**

These results show that recognition of high-pass filtered faces and broadband faces are influenced in a similar manner by Navon stimuli. However, low-pass filtered faces are better recognised following processing of the local components of Navon stimuli. These results are consistent with the hypothesis that processing the Navon stimuli causes spatial-frequency adaptation. Processing the local components of a Navon letter causes adaptation in the high-spatial-frequency channels. Thus, recognition of faces containing only high-spatial frequencies (high-pass faces), will be virtually impossible following processing of the local components of the Navon stimuli. Processing of the global component in Navon stimuli will cause adaptation in the low

spatial frequency channels that are less useful for face identification. A low-pass face contains only these spatial frequencies, and thus after adaptation to the low spatial frequencies, these faces will become virtually impossible to recognise. This is indeed what is observed.

One interesting point regarding the experimental method employed here is that processing the Navon stimuli may be causing a mismatch in the bandpass frequencies available to process the faces from learning to test. Consider the case with a face than is learnt broadband. Processing the local features of a Navon letter causes adaptation to high spatial frequency channels. Thus, subsequent presentation of the face will be a mismatch from learning (from broadband to having no high spatial frequencies). Experiment 5 aimed to explore the effect of Navon stimuli when there is a mismatch in available spatial frequencies in the face from learning to test.

## **Experiment 5**

Experiment 4 demonstrated that faces containing only high spatial frequencies are virtually impossible to recognise following the processing of the local features of the Navon stimuli. It was hypothesised that the processing of Navon stimuli selectively removes part of the spatial frequency channels available for recognition. A face learnt at high-spatial frequency is better recognised at high spatial frequency (Liu et al., 2000; Collin et al., 2004). Thus, a face learnt at high spatial frequency will be more accurately recognised in a broadband face following global Navon processing than local Navon processing. Similarly, it was hypothesised that local processing of a Navon stimulus may actually benefit the recognition of broadband faces if the face had been originally learnt without any low spatial frequencies. Experiment 5 tested this by presenting participants with a series of high-pass, low-pass, or broadband faces to learn followed by the standard Navon identification task. During the test phase, the faces were always broadband. The predictions for this Experiment are the same as those in Experiment 4.

## **Method**

### **Participants**

Twenty participants were selected from the participation panel at Cardiff University, all with normal vision. Participants were paid for their time.

## **Materials**

The same materials used in Experiment 4 were used in Experiment 5.

## **Design and Procedure**

A 2 x 3 mixed design was employed whereby participants were either instructed to identify the global Navon letter or the local Navon letter, and all learnt faces that were: high-pass filtered; low-pass filtered; or broadband. Faces were counterbalanced, such that each appeared as a target the same number of times as it appeared as a distractor. Moreover, faces were counterbalanced such that each was learnt high-pass, low-pass, and broadband a similar amount of times. The presentation order of the faces was randomised. The experimental procedure was identical to that in Experiment 4.

## **Results**

The old/new recognition data was converted into the SDT measure,  $d'$ . The mean  $d'$  recognition accuracy for Experiment 5 is shown in Figure 9. Accuracy was higher for global processors than local processors when faces were learnt broadband or low-pass filtered.

The  $d'$  recognition accuracy was subjected to a 2 by 3 mixed ANOVA with the factors: type of Navon processing (global or local) and type of bandpass filtering of the faces at learning (high-pass, low-pass, or broadband). This revealed a significant main effect of processing type on recognition accuracy,  $F(1, 18) = 8.228$ ,  $MSE = 0.307$ ,  $p < .05$ , partial  $\eta^2 = 0.314$ , whereby global Navon processors had a higher recognition accuracy in the subsequent face recognition test than local Navon processors (mean difference = 0.410). There was also a main effect of type of bandpass filtering of the face,  $F(2, 36) = 4.751$ ,  $MSE = 0.534$ ,  $p < .05$ , partial  $\eta^2 = 0.209$ , that revealed itself through higher recognition accuracy for broadband faces than high-pass filtered faces (mean difference = 0.474,  $p < .05$ ) and low-pass faces

(mean difference = 0.698,  $p < .05$ ). Accuracy was greater for high-pass faces than low-pass faces, though not significantly (mean difference = 0.224,  $p > .12$ ). These main effects were qualified by a significant interaction,  $F(2, 36) = 13.959$ ,  $MSE = 0.534$ ,  $p < .001$ , partial  $\eta^2 = 0.437$ . Simple effects revealed that global processors had a significantly greater recognition accuracy than local processors for broadband faces (mean difference = 1.279,  $p < .05$ ) and for high-pass filtered faces (mean difference = 0.938,  $p < .05$ ), whereas local processors had a significantly greater recognition accuracy than global processors for low-pass filtered faces (mean difference = 0.987,  $p < .05$ ).

*Figure 9 about here*

## **Discussion**

The results from Experiment 5 are broadly consistent with those of Experiment 4. When a high-pass filtered face is learnt, its subsequent recognition is unaffected by global Navon processing, whereas local Navon processing brings its recognition down to near chance levels. Conversely, when a low-pass face is learnt, processing the global figure of a Navon stimulus brings its recognition down to chance levels. The explanation for this is that processing the global figure in a Navon stimulus lowers the discrimination of low spatial frequencies from subsequent perception. As such, a face learnt with only low spatial frequencies becomes virtually unrecognisable because it is now being perceived with only high spatial frequencies available, which had not been encoded.

## **General Discussion**

The five experiments presented here offer a novel explanation for the influence that Navon letter processing can have on subsequent face recognition. The results have demonstrated that it is adaptation to the spatial frequencies within the local features of Navon letters that causes subsequent face recognition performance to be lower than after attending to the global letters. This effect, however, can be changed by changing the visual properties of the Navon letters. The recognition detriment following processing of the local features was removed if the Navon stimuli were blurred

(Experiment 1) or if the contrast of the Navon stimuli was lowered (Experiment 2). Experiments 1 and 2 also demonstrated that there was no recognition advantage for inverted faces following local Navon processing indicating that the effect is not a feature of a shift in processing style from configural to featural. Experiment 3 demonstrated that high contrast high spatial frequency single letters were sufficient to cause a deficit in a subsequent face recognition task. This experiment underlines that size and contrast are important features of the visual stimuli that lead to changes in subsequent face recognition performance.

Experiments 4 and 5 explored the effect of Navon processing on recognition of band-pass filtered faces. Experiment 4 found that faces containing only low spatial frequencies were unaffected by the processing of local features of Navon stimuli. Experiment 5 demonstrated that the processing of Navon stimuli causes a removal of critical spatial frequencies from subsequent perception, causing the detriment in face recognition.

In the introduction, two explanations for why Navon stimuli affect face recognition were presented. The explanation based on transfer-inappropriate processing shift failed to account for the data reported here. Instead, the evidence favours an account based on spatial frequency adaptation to the features of the Navon stimuli being processed. It must be noted that this study does not suggest that the transfer-inappropriate shift explanation of verbal overshadowing is based on low-level perceptual adaptation.

Having suggested that the perceptual explanation of the detriment in face recognition performance following local processing of Navon stimuli, one must consider that the perceptual explanation does not allow for any form of inversion effect. An upright face and an inverted face contain the same spatial frequency components. Nevertheless, inverted faces were less well recognised than upright faces in all conditions in Experiments 1 and 2. This is indicative of the face recognition system involving higher-level visual areas as well as low-level spatial frequency components. The effect Navon stimuli have on face recognition is, thus, unrelated to the inversion effect, suggesting that the mechanisms behind the inversion effect on face recognition and the spatial frequencies involved in face processing are independent of each other to a certain extent (c.f., Rondan & Deruelle, 2004).

If, as posited here, the mechanism for how processing Navon stimuli affects face perception is due to spatial frequency adaptation, then one would expect to see

similar results in an object recognition study. Indeed, Large and McMullen (2006) found that hierarchical stimuli do influence object perception in that local processing primed subordinate level object discriminations. Furthermore, spatial frequency adaptation has been shown to affect the recognition of visual scenes (Webster & Miyahara, 1997). However, Lawson (2007) found no significant effect of processing Navon stimuli on face or object recognition, suggesting a lack of power in her study. Further work needs to be conducted to discover if object perception can be affected by Navon processing in a similar way to face perception. One hypothesis is that the spatial frequencies that are adapted during the Navon processing must be crucial for subsequent object recognition for Navon stimuli to have an effect.

## **Conclusions**

The argument put forward here is that an effect believed to be cognitive in origin turns out to have a perceptual explanation, albeit one that required directed attention to inform the perceptual processes. Perception of the world is the starting point of all cognitive processes. As such, the perceptual explanations should be ruled out before applying high-level cognition explanations. In the present example, perceptual after-effects are able to explain the detrimental effect of processing Navon stimuli on subsequent face recognition, rather than relying on higher-level under-specified cognitive explanations.

The perceptual explanation makes a range of further predictions that can be tested. For example, it should be possible to generate the most effective make-up of the Navon stimuli to influence face recognition. Furthermore, the perceptual explanation can also suggest a localised brain region which may explain this effect. The loci of many visual after-effects are in the visual cortex and in particular V1. Neuronal populations in area V3 respond selectively to certain spatial frequencies (e.g., Derrington & Fuchs, 1981; DeValois, Albrecht, & Thorell, 1982; DeValois & DeValois, 1987, see also David, Hayden, & Gallant, 2006). This suggests that the detrimental effect of processing the local features of a Navon stimulus will be localised in area V3, whereby a lessened response to high-spatial frequencies in faces will be observed.

The effect reported first by Macrae and H. Lewis (2002), whereby processing the local features of a Navon stimulus causes a deficit in subsequent face recognition,

was hypothesised to be due to a transfer-inappropriate shift from global to local processing. The studies reported here indicate that the effect is rather one of perceptual adaptation to high spatial frequency stimuli. This would explain why many researchers fail to replicate the effect when using very subtly different Navon stimuli (e.g., Lawson, 2006; Ryan et al., 2006). This study has thus offered an original, alternative perception-based theoretical framework in understanding the effect processing hierarchical stimuli will have on face recognition.

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## Figures

1. Examples of the Navon letters used in these Experiments: a. An unaltered Navon stimulus (a global R made up of local Ns); b. A blurred Navon letter (a global U made up of local Os); c. A reduced contrast Navon stimuli (a global S made up of local Bs); compared to d. a face (PJH).
2. Predictions made by the cognitive transfer account (left panel) and the perceptual after effect account (right panel) for Experiments 1 and 2.
3. Recognition accuracy ( $d'$ ) split by type of Navon processed and orientation of faces at learning and at test. Error bars represent standard error.
4. Recognition accuracy ( $d'$ ) split by type of Navon processed and orientation of faces at learning and at test. Error bars represent standard error.
5. Predictions made by the cognitive transfer account (left panel) and the perceptual after effect account (right panel) for Experiment 3 and examples of the stimuli used in Experiment 3 from left to right: A small, low contrast letter; A small, high contrast letter; A large, low contrast letter; A large, high contrast letter.
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9. Recognition accuracy ( $d'$ ) split by type of Navon processing undertaken and type of bandpass filtered faces at learning and type of bandpass filtered faces at test for Experiment 5. Error bars represent standard error.