Perceptual Learning in Humans

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Declaration

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree. [1]

This thesis is a result of my own investigations, except where otherwise stated. Other sources are acknowledged by giving explicit references. A bibliography is appended.

I hereby give consent for my thesis, if accepted, to be available for photocopying and for inter-library loan and for the title and summary to be made available to outside organisations.

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[1] It should be noted that Experiments 1 and 2 have already been published as Mundy, Dwyer and Honey, 2006. Experiments 3-7 have been submitted to the Journal of Experimental Psychology: Animal Behavior Processes as: Mundy, Honey and Dwyer, 2006. Experiments 9 and 10C have been submitted to the Quarterly Journal of Experimental Psychology as a part of: Dwyer, Mundy, Vladeanu & Honey, 2006.

Summary of Thesis

Unsupervised exposure to confusable stimuli facilitates later discrimination between them. It is known that the schedule of exposure is critical to this perceptual learning effect, but several issues remain unresolved: I) it is not known whether a mechanism of mutual inhibition, taken by some to underpin perceptual learning in rats, is also evident in humans. II) Although simultaneous presentation of the to-be-discriminated stimuli has been suggested by some to be the most efficient way to promote perceptual learning, the associative mechanisms proposed by others (e.g., that of mutual inhibition) predict the opposite. III) Perceptual learning has been invoked as the process by which a face becomes familiar; but surprisingly, this idea has received little empirical evaluation. The experimental work reported in this thesis addresses these three issues.

Experiments 1 and 2, using flavours as stimuli, reveal that the inhibitory mechanisms that contribute to perceptual learning in rats also contribute to perceptual learning in humans. Experiments 3 and 4 demonstrate a perceptual learning effect using visual stimuli, pictures of human faces and that these effects too, exhibit parallels with studies of perceptual learning with rats. In particular they demonstrate that intermixed exposure results in greater perceptual learning than does blocked exposure. Experiments 5 to 7 indicate that perceptual learning seen following simultaneous exposure is, in turn, superior to intermixed exposure – implicating a process of stimulus comparison. Experiment 8 confirms that this novel effect is also observed with other visual stimuli, chequerboards, while those of Experiments 9 and 10 indicate that the face stimuli used exhibit some of the hallmarks of face processing. These findings establish, along with Experiments 3 to 6, that perceptual learning contributes to the process by which a face becomes familiar.

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Chapter 1

Introduction

Perceptual learning has been defined as "Any relatively permanent and consistent change in the perception of a stimulus array, following practice or experience with this array", (Gibson, 1963, p29). The investigation of how perceptual learning occurs is conducted in a wide range of fields. For example: psychophysics gives us evidence for adaptation in systems responsible for primary perception; neuroscience informs us of mechanisms that allow adaptation and neural plasticity; developmental psychology provides evidence for the changes that occur to our perceptual systems throughout life; and computer science gives us a way to describe functional algorithms and model large neural networks as they adapt and interact. A variety of proposals for specific mechanisms of perceptual learning have been put forward, some based on direct perception of information from the world, others involving influences on early stages of stimulus processing, and further models rely on the introduction of higher-level processes in the form of associations.

In 1890, William James considered this phenomenon of perceptual learning, noting that experts in the tasting and appreciation of wine had a remarkable ability to discriminate between wines that could not be discerned by a novice. James suggested that by attaching a different name to the taste of wines that initially seemed very similar, and hence providing a feedback to the taster, the flavours would be stretched further apart in similarity space, thus becoming more discriminable. Some time later Miller and Dollard (1941) entertained the complimentary suggestion that two stimuli paired with the *same* associate would become less discriminable. This approach to perceptual learning, whilst simple, is echoed in recent discussions of the phenomenon of acquired equivalence and distinctiveness (see for example: Gluck & Myers 1993; Goldstone 1998; Hall 1991; Honey & Ward-Robinson 2002; Lawrence 1949; Mackintosh 1975). However, this form of 'supervised' perceptual learning is not the only method by which stimuli can become more distinctive. Simple exposure to two stimuli is often sufficient to increase their discriminability. Gibson and Walk (1956) hung shapes from the walls in the room which housed the home-cages of their rats. Rats that lived with shapes relevant to the test were better able to distinguish those shapes in a later test than rats that were exposed to shapes which were irrelevant to the test. The opportunity to merely inspect stimuli actually benefited the acquisition of that discrimination. This result is observed without explicit supervised training during the critical exposure stage. This is important since perceptual learning in lifelike situations is often self-regulated and not externally reinforced. There is no feedback available from simple exposure to a stimulus. This perceptual learning effect has been demonstrated on many occasions since, and has been further refined so it is now known that exposure to one stimulus of a similar pair that are later to be discriminated, both stimuli in the pair, or just their common features is enough to improve discrimination over novel stimuli (e.g., Mackintosh, Kaye & Bennett 1991; Bennett, Wills, Wells & Mackintosh 1994).

Further to this, it is not simply the opportunity for exposure to a stimulus that is important for the progression of 'unsupervised' perceptual learning. The nature and quality of that exposure is also important. Honey, Bateson and Horn (1994) discovered that interleaving the presentation of two similar stimuli enhanced their later discrimination more than an equivalent amount of exposure given in blocks, where all trials with one stimulus were presented before all trials of the other. This manipulation of the schedule of exposure created two regimes of presentation containing the same overall amount of 'experience' with each stimulus, but resulted in differential discrimination (see also Dwyer, Hodder & Honey 2004; Honey & Bateson 1996;

Symonds and Hall 1995). Clearly any model of perceptual learning must take into account the fact that the schedule of exposure to a stimulus, or by extension, the nature and quality of that exposure, is critical to the degree of learning that takes place. It has been suggested that pre-exposure to two similar stimuli (i.e., exposure that occurs before a test is initiated that examines the degree of discrimination between them) might affect a relative shift in attention to those features or dimensions that distinguish them (e.g., Gibson 1969) or otherwise reduce the extent to which they activate overlapping representations. (e.g., Gluck & Myers 1993; McLaren & Mackintosh 2000; Saksida 1999; Schyns, Goldstone & Thibaut 1998).

1.1 *Rationale*

The rationale for this thesis will be separated into three major, yet related, themes. The first theme will consider how applicable animal models of perceptual learning are to humans. Many previous experiments involving the exploration of unsupervised perceptual learning have involved the use of animals (e.g., Gibson & Walk 1956; Honey et al., 1994), and thus many of the mechanisms proposed to support perceptual learning are based on the observations of animals. However, there has also been evidence to suggest that the mechanisms identified for perceptual learning in animals are also used by humans (see Dwyer, Hodder & Honey 2004). This suggests that the comparison of animal and human data in the study of perceptual learning might reveal interesting and useful parallels, not least demonstrating that perceptual learning is a remarkably universal process. One particular mechanism, that of mutual inhibition, has been shown in rats (see Bennett, Scahill, Griffiths & Mackintosh 1999; Dwyer, Bennett & Mackintosh 2001), but no evidence exists that humans also use this method of perceptual learning. It is clearly important to ascertain whether or not humans and other animals share a common mechanism(s) in this respect.

The second theme will be concerned with assessing the specific mechanisms that underpin perceptual learning, with particular emphasis on the possibility that more than one mechanism may be required. There have been several authors that have suggested perceptual learning is supported by multiple mechanisms (Dwyer et al., 2004; Goldstone 1998; Hall 2003; Honey et al., 1994), and there are of course several mechanisms that have been proposed as candidates (e.g., Gibson 1969; Symonds & Hall 1995; McLaren & Mackintosh 2000, 2002). One particular area that requires empirical analysis is the outcome of simultaneous exposure to stimuli. The main competing theories of perceptual learning have divergent predictions over the outcome of simultaneous exposure.

The final theme of the Thesis will centre on the exploration of perceptual learning in a specific instance: human faces. This form of learning has been implicated in face processing (see e.g., Bruce & Burton 2002), but has yet to receive any detailed empirical analysis in terms of unsupervised exposure. Human faces provide both a convenient and flexible stimulus with which to explore perceptual learning in general, and an opportunity to give the study of face familiarity a mechanism on which to work. This thesis will compare perceptual learning effects with human faces and other visual stimuli. The following sections of introduction will review each of the main theories of perceptual learning in turn, assess their relevance to the main themes I have identified, and explore the relationship between perceptual learning and the face processing literatures.

1.2 *Gibson's theory of Perceptual Learning*

First presented, in 1955 (Gibson & Gibson, 1955) the idea of 'specificity theory' was later updated by Gibson (1969). Eleanor Gibson defined perceptual learning as an increase in the ability of a subject to get information from its environment, as a result of practise with the stimulation provided by the environment. This change is proposed to be brought about simply by the observation of the environment itself. The processes that gather information from the environment are tailored to the organism's use of that information as it perceives and interacts with its surroundings. Gibson states that there are aspects of target stimuli which are not initially differentiated from the mass of information a subject receives from its environment. However, given the appropriate conditions of exposure and practise, these aspects may become differentiated. As a consequence, the resulting perceptions become more specific to the stimulation providing them. In other words, the perceptions are activated by a smaller subset of similar confusable stimuli, and thus better represent the target. This provides an organism with a change in available responses. A change in response is not an acquisition or substitution of a new response to stimulation that was previously responded to in an alternative manner. It is behaviour that is manifest in response to a variable of stimulation not previously responded to. Gibson therefore describes perceptual learning as an increase in specificity, where properties, patterns and distinctive features of a stimulus are learned.

Gibson and Gibson (1955) included an experiment involving the discrimination of 'scribbles'. Participants were shown a prototype stimulus and subsequently asked to identify the other items in the sequence of scribbles that were identical to the prototype, using a same/different response. The number of errors made by participants was dependant on the number of stimulus variables by which the item differed from the prototype. If the trial item only differed on one dimension/feature the errors were greater than if it differed on two. This suggests that the identification of critical features is central to the process of discrimination learning. Specificity, or correct identification of prototypes, increased with repeated practise so that participants were able to respond to stimuli that were previously undistinguishable, simply because of the practise itself.

Gibson notes that the response 'same' (indicating that a trial item was the same as the prototype, and thus a correct target) was applied throughout, so that a subject did not *change* their response to a target stimulus, only learned to apply it to an increasingly specific set of stimuli.

Another piece of evidence that Gibson cites is the finding of Lawrence (1952) who trained rats to discriminate between two shades of grey. When the animals were first trained on a coarse discrimination and then gradually transferred to discriminations involving only subtle differences in greyscale they increased in correct selections far quicker than rats trained on the more difficult task from the outset. Gibson suggests that this was due to the fact that rats exposed to the easier discrimination were better able to identify the relevant stimulus dimension (brightness), and hence transfer this selection to the tasks that followed. However, this effect of transfer along a continuum can be explained from an associative perspective (see McLaren, Kaye & Mackintosh, 1989).

Gibson makes several predictions about what such a method of learning distinctive features should mean for discrimination (i.e., when a participant is exposed to a pair of similar stimuli, and is required to consistently choose the correct one without external corrective feedback). First of all discrimination should be best when feature differences between pairs are at a maximum, and poorest when they are minimal. This suggestion is supported by Gibson's finding using 'scribble' stimuli, which are better discriminated when differing along more than one dimension (Gibson & Gibson 1955). Secondly, discrimination should be increased when distinctive features are enhanced in a stimulus display. Presumably, this simply aids the process of abstracting features from a stimulus that are diagnostic of its identity (e.g., Gagné & Gibson 1944). Gibson (1969) uses the example of caricatures to illustrate this point, with many findings suggesting that images of this nature are often as good as (and sometimes better than) photographs in identifying stimuli (e.g., Ryan & Schwartz

1956). The enhancement of distinctive features is also not necessarily dependant on their exaggeration, but can also be achieved through eliminating non-distinctive features. It is suggested a participant can learn to ignore irrelevant elements of a stimulus array (e.g., Gollin 1960).

Gibson (1969) suggests that if two stimuli (AX and BX) are exposed in such a way as to promote their comparison, a process of stimulus differentiation operates that increases attention to their unique features (A and B) relative to their common features (X). This suggestion clearly implies that the schedule of exposure, i.e., the nature of comparison afforded to the stimuli, is critical to the quality of learning that is achieved. Gibson suggests that the most effective way in which stimuli can become differentiated is when an organism has the chance to actively compare one with another, with the most effective comparison between two stimuli taking place when they are presented simultaneously. This an interesting suggestion not least because it does not follow from an associative analysis (see below) and yet there is no empirical work that has addressed this issue in the context of the effects of unsupervised exposure to two stimuli. One aim of the empirical work presented in this thesis (Chapter 3) is to examine this suggestion.

Gibson (1969) offers three possible mechanisms that support this kind of perceptual learning. The process by which a critical dimension for discrimination in a set of stimuli is discovered is proposed to be abstraction. Abstraction occurs when an invariant relation is discovered over a number of varying objects or events. Not necessarily a conscious search, the relation relies on the extraction of cases that provide a contrast. The second mechanism proposed is that which 'filters' out the irrelevant randomly varying stimulus elements. This process works in harmony with the action of abstraction. Gibson suggests that the filtering action is shown in (among others) experiments where embedded figures are successfully identified with practise, that exposure appears to lower the threshold for perceiving the stimulus contours, despite the camouflaging irrelevant lines (e.g., Francès 1963, cited in Gibson 1969; see also Broadbent, 1958). A final mechanism which is thought to mediate perceptual learning is the action of focal attention. In harmony with the central actions of abstraction and filtration, exploratory activity of the senses is suggested to direct focal attention. Clearly these actions are needed for selective perception – e.g., direction of gaze towards a unique stimulus element. An organism will use selective attention to expose stimuli receptors to 'chosen aspects of potential stimulation'. Practise in attentively exploring stimulus arrays is thought to facilitate the discovery of critical properties. This is an active process, adaptively selecting or rejecting areas of interest, what is salient to the organism from the mass of information available. Exploration is directed, and will become increasingly more directed with practise. This mechanism of perceptual learning suggests that it is possible to *learn* to learn perceptually – a possibility that is relevant to the discussion of some of the results presented in Chapter 4

Gibson (1969) suggests that perceptual learning is a result of learning to extract information that is already available, but not already detected and utilised. She suggests that what is learned by an organism are distinctive features, and common elements, which are not associated with any outcome (since there is no outcome *per se* when an organism is simply exploring a stimulus) but rather filtered and abstracted from the array via a process of active search. This search is proposed to be motivated by the task and 'intrinsic cognitive motives' – such as the need for food or relevant survival information from the environment. The eventual presence or absence of food might be considered an 'outcome', but Gibson suggests that the search for distinctive features is ended, not by external rewards and punishments, (producing differential reinforcement as the enrichment association theorists suggested at the time, e.g., Bruner, 1957), but by the 'internal reduction of uncertainty'. Thus, the products of a search reduce the information to be processed in an adaptive, self-regulated way. So this form of 'unsupervised' perceptual learning is not dependant on the correction of erroneous responses, but on the discovery of distinctive features that allow an organism to better interact with its environment in the future.

1.3 *Alternative interpretations of perceptual learning.*

In a recent review of perceptual learning Goldstone (1998) considered a number of mechanisms to be responsible for the phenomenon of perceptual learning including attentional weighting, differentiation, and unitisation, that will be reviewed below. Although Goldstone's more mechanistic approach diverges from the ecological approach advocated by Gibson (1969), he notes, seemingly in agreement with Gibson, that there is a clear distinction between training mechanisms that require feedback of information to the organism (supervised learning), and mechanisms that use 'statistical structure inherent in the environmentally supplied stimuli' (unsupervised learning; Goldstone, 1998 pg 588). Goldstone also refers to the existence of peripheral, specific adaptations, and their distinction from general, strategic processes, and perceptual learning mechanisms that are quick and others that take time to progress and distinguishes between what he terms 'perceptual learning' and 'higher-level cognitive learning' (or learning by association). Goldstone's perceptual learning mechanisms focus on the early stages of information processing, where adjustments are made to the representation of the stimulus itself. Goldstone also notes that perceptual learning effects can be generated by higher-level (e.g., associative) processes. This distinction raises the possibility that in humans different assays of perceptual learning, for example generalisation tests compared to same/different judgements, could produce divergent results and will be considered in Chapters 2 and 4.

1.3.1 Attentional weighting

Perception can be adapted to tasks by increasing attention to perceptual features or dimensions that are important, along with decreasing attention to irrelevant dimensions. As early as 1949, Lawrence describes examples of stimulus dimensions 'acquiring distinctiveness' when they predict reward. Nostofsky (1986) notes that during categorisation, shifts are seen towards the dimension useful to the task – 'stretching' the relevant dimension, and de-emphasising features that were previously salient, but not important for categorisation. Irrelevant dimensions draw less attention (becoming less distinguishable from one another) and different values on the relevant dimension become less distinct. Goldstone (1998) suggests that the shifts in attention might simply reflect a strategic choice rather than a shift in perception *per se*, but the outcome of priming tasks suggest that the mechanism cannot be completely voluntary: Attentional highlighting of information can occur to the detriment of an observer. For instance, when a stimulus is consistently presented as a target in a detection task, and subsequently becomes a distractor, it still automatically acquires attention (e.g., Schiffrin & Schneider 1977). This effect can last for many hours, suggesting that a relatively permanent change has taken place.

Attentional weighting as a mechanism for perceptual learning is implicated in the phenomenon of categorical perception. When stimuli are sourced from different categories they are easier to discriminate than stimuli from the same category. There are many examples of categorical perception, all containing the central effect of sensitisation to a categorical boundary following training with the relevant stimuli. For example Beale and Keil, (1995) show that participants are better able to categorise two familiar faces as belonging to either one individual or the other (when viewing individual stimuli from a continuous morph between the two) as they are more sensitive to differences at the half-way point between the faces. Goldstone (1994, 1995), using artificial shape stimuli varying, for example in greyscale saturation, has provided evidence for three influences of categories on perception: i) Dimensions relevant to the category are sensitised. ii) Irrelevant variation is deemphasised. iii) The relevant dimensions are selectively sensitised at the category boundary – discrimination between stimuli was elevated around the boundary, perceptually 'widening' the boundary. It is interesting to note that an idea of shifting attention, albeit in a rather less defined manner, was one that Gibson (1969) adopted as she described the attentional 'filter' responsible for reducing the perceptual emphasis on irrelevant randomly varying stimulus elements, working alongside a more peripheral filter which allows an organism to randomly sample its environment, selecting areas of interest and importance. [2] I will have cause to return to this form of analysis in considering the results presented in Chapter 4.

1.3.2 Differentiation

In interpreting Gibson and Walk's (1956) demonstration that pre-exposure facilitated discrimination, Gibson (1963, 1969) suggested that a process of differentiation had taken place whereby stimuli that were initially perceived as similar became perceived as increasingly different. Several neural mechanisms have been suggested for simple stimulus or psychophysical differentiation. One example relies on the surprising lack of transfer between training on vernier acuity between horizontal and

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[2] Although the theories of Gibson and of Goldstone are from very different philosophical perspectives, making this comparison seem rather superficial, the two viewpoints are not necessarily incompatible. Whilst the realist viewpoint of Gibson denies that 'cognition' and 'representation' exist within the brain, biological mechanisms, of the kind described by Goldstone seem well placed to contribute to the processes that she describes. It would seem likely that had Gibson been minded to talk in these terms, these 'early' perceptual processes could have been implicated in her description of perceptual learning.

vertical lines (see Poggio, Fahle & Edelman 1992). On the basis of observations of this sort, Karni and Sagi (1991) argue for an early cortical locus of the effects of training because cells involved in early visual processing exhibit such specificity. The firing of cells that correlate with the discrimination becomes more influential over time, so the mechanism for differentiation here is the selective emphasis of the relevant receptive neurons (Poggio et al., 1992). A second method of differentiation involves the increased representation of receptive cells that permit discrimination between stimuli. Recanzone, Merzenich and Jenkins (1992) show that monkeys trained to discriminate between tones develop larger cortical representations of tones that they are exposed to than control animals. A third mechanism involves the 'tuning' of critical receptors. Large receptive fields become increasingly more responsive to a limited set of stimuli after training. Saarinen and Levi (1995) report evidence which suggests that training on a vernier discrimination task tunes receptors (or narrows their receptive field) to diagnostic orientations. Luce, Green and Weber (1976) suggest that a 'roving' attentional band can be placed selectively on the critical regions of a perceptual dimension, and that signals within the attentional band are enhanced above those that fall outside it. These factors differentiate stimuli by 'warping' regions of stimulus space. All three of these mechanisms could be considered as ways to implement the processes that Gibson (1969) describes as abstraction and filtering of stimuli.

Discriminations involving more complex stimuli have also shed light on the mechanisms of differentiation. Mackintosh (1974) notes that initial simple discriminations along a particular dimension aid subsequent learning of more difficult discriminations along the same dimension, indicating that the initial easy discrimination allows a subject to attend to the relevant dimension. This is shown by transfer along a continuum, or the 'easy to hard' effect, along with the phenomenon of overtraining reversal (e.g., Mackintosh, 1969). Once a relevant element or dimension has been extracted, attention can be allocated to this, allowing transfer to similar, yet more difficult discriminations and more rapid reversal learning.

Faces are of particular interest in complex discriminations as they represent stimuli that vary along many different dimensions. The 'own-race' effect where faces belonging to a participant's own race are easier to discriminate than faces from another race (e.g., see Shapiro & Penrod, 1986), can be considered as an example of familiar objects undergoing differentiation. However, other-race faces are easier to categorise and Goldstone (1996) suggests this may be because differentiation relies on the development of features that identify less common objects from familiar objects. This is also in accordance with suggestions made by Gibson involving familiarity with stimulus features. She suggested that new stimuli belonging to a class with distinctive features should be more easily distinguished than an equivalent set in a novel class, but discrimination is increased when distinctive features are enhanced in a stimulus array. This will occur due to the identification of features that define the 'less-common' group. So whilst own-race faces belong to a class that has developed distinctive features within itself, and will therefore contain examples that can be distinguished within it, other-race faces as a group, will naturally contain features that are distinctive from own-race faces and hence foster easier categorisation. The contribution of perceptual learning to the own-race effect will be considered in more detail later on. However, differentiation clearly also occurs within categories. For instance, experts will categorise objects at a specific subordinate level far quicker than novices, but only within their domain of expertise (e.g., see Tanaka & Taylor's (1991) study of speeded classification by dog and bird experts, see also McLaren, 1997). These findings indicate that experience builds upon basic broad levels of category by narrowing them into differentiated sub-categories. As experience with a category or group of stimuli increases, so does the subject's power to discriminate members of that category or group. For example, O'Toole, Peterson and Deffenbacher (1996) find that Caucasians and Japanese are faster at classifying faces of their own race into 'male' and 'female' categories than faces of the other race.

1.3.3 Unitisation

Goldstone (1998) refers to unitisation as the construction of single functional units that are triggered by a complex configuration (for a related use of the term see McLaren et al., 1989; see also Czerwinski, Lightfoot, and Shiffrin, 1992, with respect to the related idea of 'chunking'). Possession of a unitised representation means that activation of any subset of the pattern will activate the unitised representation, so a task that previously required the detection and use of several parts, via unitisation, can be performed on the basis of the detection of only one. The fact that real words are processed more efficiently than non-words has been taken to be indicative of a process of unitisation (e.g., O'Hara 1980). Repeatedly presenting non-words to participants has the effect of removing the disadvantage over real-words, since participants can develop single, unitised codes for them as well (Salasoo, Shiffrin & Feustel 1985). When a well known face (or indeed many well-learned or highly practised visual stimuli) is inverted, the time for it to be recognised is disproportionately increased (Diamond & Carey, 1986; Tanaka & Gauthier, 1997; see Valentine, 1988 for a review). Such inversion effects have also been cited as evidence for the formation of a unitised holistic or configural representation of the face, which prevents or supersedes recognition at a featural level (e.g., Farah, 1992). This configural representation is disrupted more by inversion than a featural representation, explaining why other objects do not suffer the inversion effect to a large degree. This inversion effect can be replicated in a laboratory with initially novel stimuli, which are shown to participants over a prolonged period (Gauthier & Tarr 1997). Simply, repeated exposure to any object will lead to the development of a configural representation which has the action of combining all of its constituent parts into a single (viewpoint specific) functional unit. Later discussion will focus in more detail on the inversion effect, and the action of featural and configural processing on face perception (see Section 1.8).

It should be recognised that unitisation could produce results opposed to those produced by differentiation. Goldstone (1998) suggests that the product of this opposition will depend both on the nature of the task and stimulus. On one hand, objects will undergo differentiation when their component parts reflect 'independent sources of variation' (pg 604), or are differentially relevant to discrimination. On the other hand, parts that co-occur frequently will undergo unitisation since they will more often than not require the same response. Given appropriate feedback, the processes of unitisation and differentiation can compliment each other to produce representations of stimuli that are appropriately sized for the task that is required of them.

1.4 *Differentiation and unitisation and the effect of schedule of exposure.*

Mentioned above is the critical rider that any theory of perceptual learning must account for the fact that schedule of exposure to stimuli is critical. The finding that discrimination between two confusable stimuli following an intermixed schedule of exposure is superior to that following a blocked schedule is now well established within the animal (e.g., Honey et al., 1994, Symonds & Hall 1995), and human learning literatures (e.g., Dwyer et al., 2004; Graham, 1999). For example, Dwyer et al. (2004) gave one group of human participants an alternating presentation of two similar compound flavours (Saline-Lemon and Sucrose-Lemon), while a second group received a blocked presentation. During this time, the participants were asked to rate the pleasantness of the flavours. Following this, both groups were given presentations of one of the flavours tainted with a foul-tasting substance. Finally, they were tested for their pleasantness rating of the compound flavour which was not tainted previously. Participants in the blocked group rated that flavour as significantly more unpleasant during the test compared to during pre-exposure than participants in the alternating group did. It is presumed that those in the alternating group suffered less generalisation of aversion from the tainted flavour as they had learned more about the unique properties of both flavours during pre-exposure (and were thus more able to discriminate them) than had the participants in the blocked group.

Aside from the contributions of associative learning, which are to be considered in detail shortly, the theories of differentiation and unitisation can also be invoked as models for the effect of schedule. When two similar stimuli are presented to a subject so that they are alternating, the processes that both Gibson (1955, 1969) and Goldstone (1998) consider as critical to perceptual learning can take place. Alternation allows the subject an opportunity to compare the stimuli, and contrast their features. Gibson would suggest that this allows non-distinctive or common/invariant features to be abstracted from the array and 'filtered' out to be ignored, leaving the unique and diagnostic features to be extracted, enhanced and available to attention.

The better specified theory of differentiation in early perception (see Goldstone 1998) would suggest that as cells in receptive fields relating to the presented stimulus are exposed to that stimulus, they become adapted. Cells that are diagnostic of a change in stimulus, in other words, those that change in activity when for example the first stimulus switches for the second, clearly code for elements that are unique to that stimulus. These cells become selectively emphasised (e.g., Poggio et al., 1992). A large receptive field, which for the most part will have been active for both stimuli, will become 'tuned' through these critical receptors, so that the field will become increasingly responsive to the individual stimuli. The repeated presentation of common elements in the stimuli will presumably result in fatigue of cells that code for these elements, whereas receptors responding to unique features have time to recover between presentations. This means that areas of the receptive field containing receptors coding for unique features will automatically be enhanced in perception over those that are common to both stimuli and thus fatigued. This may result in the selective emphasis of those cells in later encounters with the stimulus through the strengthening of their interconnection – cells that 'fire together, wire together'. This implies that those cells which are fatigued will not be included in the general enhancement of these connections brought about by repeated exposure (cf. Poggio et al., 1992) or the number of these cells may increase to create a larger cortical representation of the unique feature (cf. Recanzone et al., 1992). However, if the interval between presentations is sufficiently long, then cells representing both common and unique elements should have the opportunity to recover. This creates a problem for the analysis provided above, as many experiments involving the exploration of perceptual learning are performed over intervals spanning a period of several hours, if not days (e.g., Symonds & Hall, 1995), indicating that, at least in these cases, some longer-term process must occur.

During a blocked schedule Gibson might predict that neither the process of abstraction or guided peripheral attention can work properly. Since there is little opportunity for comparison between the stimuli, the chance of abstracting an invariant feature is rather high – the whole stimulus is in this case invariant. Guided exploratory activity through peripheral attention will also reveal no useful 'aspects of potential stimulation' (Gibson 1969, pg 63). Differentiation theory would predict that a blocked schedule creates a situation where all cells in a receptive field evoked by a stimulus become fatigued. This leaves little opportunity for the cells coding for unique elements within the field to become more influential. Unitisation may also take place here, effectively 'chunking' the stimuli together into one representation (although it is equally possible that chunking during blocked exposure creates a chunk for each stimulus, and that it is the relative predominance of common features that allows them to be compounded). If there is no variance detected in the presentation, then it is plausible to suppose that the two stimuli will become identified as one stimulus. This would in fact hinder later discrimination of the two stimuli as they could become linked to the same 'single-unit', so presentation of one of the stimuli will trigger the activity relating to the presentation of both. During an alternating schedule unitisation might act to further *enhance* the discrimination, since the activation patterns relating to the complex stimuli (which have been 'tuned' via differentiation) will eventually become linked to separate 'single-units', plausibly allowing the faster and more accurate detection and discrimination of the stimuli in question.

The most effective way, that is intrinsic in Gibson's predictions, for two stimuli to be discriminated successfully, is by arranging for maximal opportunity for comparison. This is clearly achieved by presenting both stimuli together. Gibson's exploratory attention process will have the greatest chance in this situation. As both stimuli are available to sample at once the subject can both pace and direct for itself, enhancing the action of the abstraction and filtration processes by allowing the opportunity for greater choice in aspects of potential stimulation. The two stimuli can be directly compared. Assuming that a process of roving attention is also compatible with the models of differentiation and unitisation this will allow simultaneous presentation of two stimuli to again enhance the mechanisms behind them. The unhindered and self paced shifting of gaze between the two stimuli should serve to speed up the process by which both invariant features and unique elements are detected. However, for this to fit with the adaptation analysis presented earlier, one would have to assume that the pace of sampling is in tune with the refactory period of cells in the receptive field. If the sampling of each stimulus is too fast, then cells that represent unique features will not have time to recover between samplings.

1.5 *Associative models of Perceptual learning.*

The process of differentiation and that of building associations between stimuli are clearly linked (Hall, 1991). The text above considers perceptual learning as a result of both a very simple and direct perception discovering unique features, and that of an adjustment to the representation of a stimulus within the early phases of perception. The mechanisms of perceptual learning (attention weighting, differentiation and unitisation) are modelled on processes that occur early on in perceptual processing. The ideas behind unitisation and differentiation (either Gibson's (1955, 1969) specificity theory based on comparison, or perceptual differentiation of the kind described by Goldstone, 1998) in particular require that, on the one hand, stimuli can be broken down into component parts, in order to identify features that are diagnostic and features that are common, and on the other hand, that components, or indeed whole stimuli which are initially separate but appear to co-occur, become combined into one representation.

The loci of the effects at the intercellular level can be seen in areas of the brain that are primarily responsible for perception (e.g., primary visual areas – see Saarinen & Levi 1995), but this does not seem to account for the fact that adaptation at one point can influence attention at another. For example, cellular fatigue is fleeting and cannot alone account for the effects of perceptual learning seen over presentations that span days, and retention periods that last for weeks. The requirement for more permanent relations to form between representations of stimuli (in particular, complex stimuli) and within the constituent parts of the stimuli themselves is quite clear, so that the effect of those mechanisms which allow differentiation and discrimination can be utilised across disparate presentations and future experience.

Associative learning is based on the idea that when two stimuli occur in a predictable relationship a bond is formed and strengthened between them so that the presentation of one activates a representation of the other (and can evoke behaviour associated with it). The degree of association produced by pairing two stimuli is thought to be a direct function of the activity in the representations (set of elements) belonging to each, that is a reflection of the intensity of the stimuli (Wagner, 1981). Normally the elements of non-present stimuli are in an inactive state, but they may be promoted into one of two states of activation, A1 and A2. An A1 state can be likened to the stimulus being at the focus of attention. The only route by which elements in a node may enter the A1 state is by presenting the stimulus itself, but there are two routes into the A2 state. One route is through decay from A1 (which happens over time), and the other depends on previously formed associations. For example, if a CS has been paired with a US, subsequent presentations of the CS will excite US elements directly to the A2 state. Once elements are in the A2 state they can only move to the inactive state, even if the stimulus to which they are related should be presented. Elements that are simultaneously in the A1 state form bidirectional excitatory associations and elements in the A1 state form inhibitory associations to elements that are simultaneously in the A2 state. To apply Wagner's theory to the case that is critical to this thesis (i.e., exposure to two similar stimuli, AX and BX) is simple. The presentation of a compound (e.g., AX) will allow the formation of within-compound excitatory links between its components (A and X). When a second compound (BX) is presented then two things will occur: an association will form between B and X, and the previously formed association between X and A will activate A into the A2 state. The ability of the exposed stimulus (BX) to activate an A2 representation of the non-exposed stimulus (A) is crucial to several associative theories of perceptual learning.

Following the tradition of many associative theories McLaren and Mackintosh (2000, 2002) combine associative learning algorithms with elemental representations. It is clear that repeated exposure to similar stimuli, in the absence of feedback, instruction or reinforcement, facilitates subsequent discrimination between them. The authors resist the viewpoint of Hall (e.g., 1991) and others (see previous section) that this phenomenon of perceptual learning needs to encompass non-associative mechanisms, instead maintaining that an associative, elemental approach is sufficient to provide a detailed explanation.

The elemental model of McLaren and Mackintosh (2000; developed from McLaren, Kaye and Mackintosh, 1989) employs real-time learning, weight decay and salience modulation, supervised by an error-correcting learning rule. A stimulus is conceptualised as a set of elements, each element being a primitive 'feature' of the stimulus. A stimulus representation consists of a pattern of graded activation distributed over a set of units, corresponding to the elements of the stimulus. Each stimulus will consist of a partially overlapping set of elements, with the degree of similarity between stimuli corresponding to the proportion of elements common to each (McLaren & Mackintosh 2000). A critical factor in the elemental model is the assumption that not all elements of a given stimulus will be sampled at any one time. Thus, not all units will be active on an individual trial. Given that simultaneously active units will come to associate with one another, as trials progress the number of elements sampled will increase and in turn an improvement in recognition of the stimulus will be seen. So initial variable sampling of elements will become reduced as the associative connections between elements sampled will arrange for the situation where any subset of sampled elements will activate the remainder. However, a consequence of this is that external activation is reduced, so that on subsequent occasions the stimulus attracts less overall attention.

A later development of the elemental model was designed to accommodate dimensions of features (McLaren & Mackintosh, 2002). Each representational unit, rather than having a direct or one-to-one correspondence to a stimulus or element, has a 'tuning curve' which responds most strongly to one particular value along a dimension and less strongly to neighbouring values. This means as stimuli vary along a certain dimension they will be represented by different sets of units that correspond to different values of that dimension. The coding of placement on the dimension will therefore not only rely on the intensity of activation of units, but also the pattern and activation of neighbouring units.

McLaren and Mackintosh apply their model to various contributions to perceptual learning, the first of which is latent inhibition (for reviews see Hall 1991, Lubow 1989). The simplest application of this idea is the case when perceptual learning is observed following exposure to a single stimulus (BX) before training (with AX). Since both stimuli contain a common feature (X), without pre-exposure it would be expected that aversion to AX would generalise to BX via their mutual association with X. However, since BX has been pre-exposed the features of this stimulus will have undergone habituation, they will be reduced in salience. Therefore, when sampling AX during conditioning, the X element will be less salient, allowing the unique element A to overshadow it. This means that A will acquire most of the associative strength to the US, and leave little to accrue to X and hence generalise to BX. When subjects are pre-exposed to both compounds (AX and BX) latent inhibition still contributes to discrimination as X elements are sampled twice as often as A or B elements and therefore the salience of X will have been reduced more than that of A or B.

McLaren and Mackintosh (2000) also describe a process of unitisation whereby stimulus elements presented at the same time come to activate each other so that presentation of a subset of the elements will result in the activation of the entire pattern of stimulation. When two complex stimuli are similar (that is sharing more than half of their elements) it is highly probable that their unique features will be sampled less often than their common features. As associations form between active elements, this means that X elements will from a unitised representation and will lose salience far quicker than A or B elements. On subsequent presentations of the compound stimulus the unique elements are now more likely to form associations with one another (e.g., A'-A'', B'-B'') than with X. In this case, unitisation will produce separate representations of A and B rather than compound representations of AX and BX, between which there would be more generalisation, which would have happened had the exposure been only to AX or BX.

Neither process of unitisation and latent inhibition can provide an obvious account of why the schedule of exposure should profoundly affect perceptual learning. For example, during intermixed and blocked schedules the same amount of exposure is given to the common and unique elements so there is no basis for difference in latent inhibition to influence perceptual learning. McLaren and Mackintosh (2000) suggest that after relatively prolonged exposure inhibitory associations contribute to perceptual learning. The excitatory associations between A-X and B-X result in the situation where, on an AX trial, the presence of X activates a representation of B. The B element is absent on this AX trial, where the activation of its representational units predicts it to be present. This situation means that an inhibitory association will form between B and A elements. The formation of these links is predicted by any associative theory of inhibition, for example, in Wagner's (1981) terms AX is in the A1 state, whilst exciting B into the A2 state. According to Wagner's learning rules, this situation results in the formation of an inhibitory link from A to B, to inhibit B. On BX trials, the complimentary state will operate, resulting in mutually inhibitory links between A and B. On future AX trials the active A elements will now inhibit activation of the B elements that would otherwise be provoked by X (and *vice versa*). If AX is now conditioned and if BX is then tested, the presence of B in the compound will actively inhibit the activation of A by X, and hence also any behaviour relating to the conditioning of A. If AX and BX are presented in separate blocks then there is less opportunity for inhibition to form. During the first block, for example when AX is presented, there is no chance that B can be retrieved into the A2 state as it has yet to be encountered. During the following BX block, A will be retrieved into the A2 state, due to the association with X, but the repeated presentation of BX alone will assure that it will be less so than in the intermixed case.

Evidence for the action of inhibitory links in perceptual learning is provided by experiments that modify the nature of alternation between AX and BX (Bennett, Scahill, Griffiths and Mackintosh, 1999). If subjects receive consistent presentations of AX before BX an inhibitory association should form from B to A, since A is in the A2 state whilst B is in the A1 state. If subjects receive consistent presentations of BX before AX the inhibition will be from A to B. Bennett et al. (1999) gave rats either forward pairings of AX and BX (i.e., AX→BX) or backward pairings (i.e., BX→AX). Following these two schedules of exposure, an aversion was then established to AX by pairing it with lithium chloride. There was greater generalisation of aversion from AX to BX in group backward than in group forward. This is consistent with the idea that inhibition from B to A results in decreased generalisation because BX can now inhibit the activation of A at test. Direct demonstrations involving conventional assessments of inhibition in the form of summation and retardation tests provide direct support for the suggestion that inhibition forms during alternating exposure and importantly that this inhibition is dependent on order of presentation (Dwyer, Bennett & Mackintosh 2001; Dwyer & Mackintosh 2002; for converging support of the contribution of inhibition to perceptual learning see Mackintosh et al., 1991).

Although there is good evidence that inhibition contributes to perceptual learning from experiments using flavours as stimuli and rats as subjects, there are currently few grounds for supposing that this contribution is a general one. Specifically, there is no direct evidence that the formation of inhibitory links play any role in human perceptual learning, leaving an important parallel between animal and human research untested. For example, although there is some evidence to suggest that human perceptual learning is subject to the same schedule effects as perceptual learning in other animals (e.g., Dwyer et al., 2004), there is no evidence to confirm that inhibitory links underpin this effect. A recurring theme of the experimental work presented in this thesis is to establish the role of inhibitory processes in human perceptual learning.

1.6 *Simultaneous presentation of stimuli – an associative problem*

Alternation is not, according to Gibson (1969), the most effective means of generating differentiation. She supposed that simultaneous presentation of stimuli that are to be later discriminated should produce the greatest perceptual learning. This idea does not sit well with any theory of perceptual learning based on associative principles. When two stimuli are presented together, or in close temporal proximity, standard associative principles predict that the two should become associated, so that presentation of one will activate the representation of the other and thus elicit behaviour associated with the other. Bennett and Mackintosh (1999) showed that whilst perceptual learning was increased as the interval between presentation of two similar flavours given to rats was decreased, when the interval between presentation was decreased to zero seconds (i.e., not exactly simultaneous presentation, but there was no break between presentations) generalisation between the flavours was increased (see also Alonso & Hall 1999; Honey & Bateson, 1996).

In contrast, there are also data which suggest that performance on some visual discrimination tasks is better if the stimuli are presented side by side (simultaneously) on the same trial than if they are presented on separate trials (e.g., MacCaslin, 1954; Saldhana & Bitterman, 1951). Saldhana and Bitterman (1951) used two pairs of simple, yet confusable picture-card stimuli. One pair differed only in greyscale – one card was grey, the other was a darker shade, the other pair were line-gratings – differing only in the density of the lines. One card in each pair was chosen to be reinforced. They found that rats were able to learn a discrimination involving congruent, simultaneous pairings of the stimuli (array 1 - grey+, dark grey; array 2 - stripe1, stripe2+ [+ indicates reinforcement]). A second group of rats were unable to learn a discrimination involving incongruent pairings of stimuli (array 1 - grey+, stripe1; array 2 - stripe2+, dark grey). Importantly, rats trained on the first discrimination were able to solve the second discrimination unlike those trained on the discrimination from the start of the experiment. Despite being seen during learning, rather than during unsupervised exposure, such effects seem to fit with a non-associative Gibsonian account of perceptual learning and discrimination. However, Wills and Mackintosh (1999) demonstrated that the advantage produced by simultaneous presentation *did not transfer* to tests using alternating presentation. They argued this was because simultaneous presentation allowed for the presence of a simple contrast cue, which aided discrimination in this mode, but would not transfer to other tests. They interpreted this result to mean that the advantage produced by simultaneous presentation in these experiments is unlikely to form the basis for long-term perceptual learning. For this reason the animal studies have been questioned as conclusive evidence for comparison processes contributing to perceptual learning (McLaren & Mackintosh, 2000). Further empirical work is required to satisfactorily ascertain whether perceptual learning, for humans in particular, results from a mechanism of comparison during simultaneous exposure. This is critical given that Gibson (1969) specifically states that simultaneous exposure should afford the greatest benefit to discrimination, indicating that non-associative perceptual learning may also be required.

1.7 *Neo-Gibsonian models of Perceptual Learning*

Hall (1991) and colleagues (e.g., Symonds & Hall 1995, Mondrágon & Hall 2002) provide an alternative to the associative account of perceptual learning. Symonds and Hall (1995) reprised Gibson's (1969) suggestion that the opportunity to compare and contrast two stimuli was crucial to perceptual learning. This comparison allows for a process of perceptual differentiation whereby attention is attracted to the unique, and thus differentiating, features of the stimuli at the expense of the common features that do not differentiate them. In other words, this perceptual differentiation would produce an increase in the perceptual effectiveness of the unique features and reduction in the effectiveness of the features common to the two stimuli – a process they called 'Salience Modulation'. So, for example, during alternating pre-exposure to AX and BX, A and B will become relatively more 'perceptually effective' than X. Thus, an aversion subsequently conditioned to AX will no longer generalise strongly to BX, since any generalisation relies upon the associative strength of X, and following pre-exposure, A will gain more associative strength than X. Although adding little to Gibson's (1969) original account, Symonds and Hall (1995) made explicit the implications of changes in the perceptual effectiveness of the features of compound stimuli for learning about those features themselves. For example, if alternating exposure facilitated comparison this should increase the perceptual effectiveness of the unique features and thus these features should be more readily involved in learning when presented on their own. Mondragón and Hall (2002, see also Blair & Hall 2003; Blair, Wilkinson & Hall 2004) show direct evidence in support of this analysis. Conditioning to X was more effective following blocked exposure to AX and BX than after intermixed exposure. In contrast, conditioning with A was more effective after intermixed than after blocked exposure. However, Bennett and Mackintosh (1999) found no difference in learning to common elements following alternating or blocked regimes, and concluded that it is the unique elements alone that are critical to perceptual learning. However, the contrast here could simply be due to the relative sensitivity of the tests used to ascertain the associative strength of X.

Hall and colleagues reject the possibility that the differential conditioning of common and unique elements can be fully accounted for by the phenomenon of latent inhibition. In a within-subjects version of a pre-exposure schedule experiment, Blair and Hall (2003, see also Blair et al., 2004) showed that following intermixed exposure to AX and BX, and blocked exposure to CX, an aversion conditioned to X generalised less to BX than to CX. The authors argue that latent inhibition cannot be a factor in this case as each subject has an equivalent experience of the X element. The associative strength of X should therefore be the same regardless of its existence in a (previously blocked) CX test or an (intermixed) BX test. Blair and Hall (2003) suppose that it must that B has greater 'perceptual effectiveness' than C and this allows it to interfere with performance to X to a greater extent. Blair and Hall (2003) supposed that presenting AX and BX in alternation might attenuate or reverse the process of reduction in salience to A and B resulting from repeated presentation (which was not the case for the blocked CX), leaving B relatively more salient than C.

Hall (2003) proposed a learning process that might underpin changes in stimulus salience. Hall (2003) suggests that associative activation of a stimulus into A2 (cf. Wagner, 1981) in its absence raises salience, or at least restores lost salience. This means that during intermixed exposure elements A and B will recover from habituation, and consequently will become more 'perceptually effective' than X. During blocked exposure the unique elements of the stimuli will have less opportunity to become active in their absence and thus their salience will not be maintained. It is worth noting here that the elemental model of McLaren and Mackintosh (2000) can in fact account for 'salience modulation', by modulating the activity of a unit depending on how well it is predicted by the pattern of stimulation with which it occurs. Again, A and B will be less predicted by X over the course of intermixed exposure than over blocked exposure.

Another development of Gibson's ideas is presented by Saksida (1999) who implemented a form of the non-associative differentiation account in a connectionist model of perceptual learning by further refining the competitive-learning approach given by Rumelhart and Zipser (1986). The model consists of a first layer representing the pattern of stimulus input which passes input to a second competitive layer which in turn is connected to outcome units. The latter part of the model operates on a relatively standard delta-rule whereby the strength of the association between an active element in the competitive layer and the outcome is changed in proportion to the difference between the actual and predicted outcomes. Perceptual learning is accounted for by the connections between the input and competitive layers. Briefly, the units in the competitive layer compete to code the pattern of activation from the input layer: the most active element and its near neighbours in the second layer strengthen their connections with the input layer so that they will be more easily activated when that input pattern reoccurs. Exposure to two similar stimuli will initially recruit overlapping units in the competitive layer which will result in little overall change in the links between these units and the input layer as their connections to the relevant patterns of activation will alternatively be weakened and strengthened. At the same time, units which are activated only by one or other of the stimuli will progressively strengthen their connections with the relevant input pattern thus pulling apart the wining units in the competitive layer which code for the two patterns of input. Thus, pre-exposure enhances discriminability by increasing the distance between the units coding for the exposed stimuli in the topologically organised competitive layer. Simulations of the model show that this process will occur most readily when two stimuli are presented in alternation and thus the model explicitly predicts that alternating pre-exposure will produce better perceptual learning than blocked pre-exposure.

Gibson (1969) suggests that it is simultaneous exposure that affords the greatest opportunity for comparison between two stimuli, an idea that explicitly contradicts associative accounts of perceptual learning. The structure of Saksida's (1999) model requires that in order to account for the advantage of simultaneous presentation it would have to be treated as *rapidly alternating* presentations of the two stimuli (see Bennett and Mackintosh, 1999, who also likened rapid alternation to simultaneous exposure). This would presumably correspond to the situation where a subject fixated first on one and then the other stimulus. However, while this model might be able to account for an advantage of simultaneous exposure, McLaren and Mackintosh (2000) make a convincing case that it cannot explain other findings in the perceptual learning literature. For example, McLaren (1997) and Wills and McLaren (1998) have shown that pre-exposure will only facilitate the discrimination of exemplars within a category if the category has a prototypical structure. Whereas Saksida's account simply requires that stimuli are similar to one another. There is also no explicit mechanism for inhibition *between* features of a configuration, so Saksida's model does not explicitly account for the situation where alternating exposure to AX and BX will produce mutual inhibition between A and B. This is because the delta rule only applies to the competitive layer to outcome links, not the input layer to competitive layer links. Furthermore, rapid alternation should produce excitatory associations, so even if the representations of AX and BX are drawn apart in the competitive layer they should nevertheless come to predict one another, or perhaps produce a single unified representation of the compound stimulus, thus driving increased generalisation. In Chapter 3 of this thesis the effects of simultaneous exposure on perceptual learning are examined in detail.

1.8 *Face Perception*

Our ability to process faces is clearly crucial for many aspects of human interaction. We are able to differentiate between people we have encountered before, and identify others with whom we have had no previous contact. Whilst a great deal is known about how faces are processed, whether familiar to us or newly encountered, there is little evidence in the field concerning the mechanism by which faces progress from being unfamiliar to easily recognised. In spite of a lack of learning mechanism, many differences between the processing of face and non-face objects have been noted, along with further processing differences between familiar and unfamiliar faces. Perceptual learning has often been implicated in the process by which faces become familiar (e.g., Bruce & Burton 2002).

One area of particular interest lies in the differences between the processing of familiar and unfamiliar faces, especially because the recognition and perception of familiar faces seems to be somewhat superior. For example, it is easier to detect a difference between two pictures when familiar faces are used compared to when the faces are novel (e.g., Buttle & Raymond, 2003). Recognition memory for familiar faces is also superior to unfamiliar faces when poor quality images are used (e.g., Burton, Wilson, Cowan, & Bruce, 1999). Changes in viewpoint or expression have less impact on the recognition of familiar faces than they do for faces that are novel (e.g., Bruce, 1982). There are of course also many similarities in the processing of familiar and unfamiliar faces: for example, the processing of both familiar (e.g., Young, Hellawell, & Hay, 1987) and previously unfamiliar faces (e.g., Rhodes, Brake, & Atkinson, 1993) are disturbed by inversion, implying that both are underpinned by relational or configural representations. Moreover, both familiar (Beale & Keil, 1995) and unfamiliar (Levin & Beale, 2000) faces show categorical perception effects. Despite such similarities, superior recognition with familiar faces suggests that the recognition of familiar and unfamiliar faces might rely on different processes. Indeed, models of face processing tend to make a distinction between familiar and unfamiliar face perception (e.g., Burton, Bruce, & Hancock, 1999; Hancock, Bruce, & Burton, 1998). However, it is not simply that recognition is superior in familiar faces; there is evidence for at least one qualitative difference in the processing of familiar and unfamiliar faces.

Ellis, Shepherd, and Davies (1979) found that the internal features of the face (e.g., eyes or mouth) were relatively more useful than the external features (e.g., hair or face outline) in the recognition of familiar as opposed to unfamiliar faces. Similar results have been found in a matching task (Young, Hay, McWeeny, Flude, & Ellis, 1985). However, while we know that there are both quantitative and qualitative differences between the processing of familiar and unfamiliar faces remarkably little is known about the processes by which a new face becomes familiar. Nevertheless, some process of perceptual learning is consistently identified as being central to this change (e.g., Bruce & Burton, 2002; O'Toole, Abdi, Deffenbacher, & Valentin, 1995; Valentine, Chiroro, & Dixon, 1995).

1.8.1 *Do faces represent a unique class of stimuli?*

There have been a number of previous experiments within the field of learning theory that have used morphed faces. The outcome of these experiments has produced learning effects that have been seen with non-face stimuli. Transfer along a continuum and transfer after outcome reversal (Suret & McLaren, 2003; see also Goldstone, Steyvers, & Rogosky, 2003) are two such examples. There are those who consider the processing of faces to be special, perhaps based on a unique face-specific system or systems, located in anatomically distinct regions of the brain (e.g., Farah, Wilson, Drain & Tanaka, 1998; Kanwisher, 2000, and Moscovitch, Winocur & Behrmann, 1997). There is of course argument to the contrary, suggesting that it is the vast experience we have in face recognition that allows us to make such fine discriminations, and that experience with any object category can show face-like (holistic) processing and give similar results (e.g., Tanaka & Gauthier, 1997).

Innateness is one reason face processing has been considered to be special. Many studies have found evidence that neonates are more tuned to face-like stimuli than other stimuli, and have taken this to support the argument that face processing may be innate. For example, Easterbrook, Kisilevsky, Hains and Muir (1999) show that within 30 minutes of birth neonates track moving faces longer than patterns of comparable complexity, indicating that newborns may have a predisposition to view faces. Within just a few days, infants can distinguish their mother's face from that of a stranger (Bushnell, Sai, & Mullin, 1989). However, this does not seem to require that face processing is innate at this point *per se*, as the newborn may simply have had more experience with the mother's face. Furthermore, this effect is based solely on the external features of the mother's face, whereas the Easterbrook et al., (1999) study might suggest it is internal features that capture an infant's attention. For a newborn, however, visual acuity would limit specific recognition to large features found externally, attenuating their ability to perform adult-like face perception. Nonetheless, newborn babies less than 3 days old appear to be able to judge attractiveness based upon the internal features of a face, and their sensitivity to this is restricted to the upright orientation (Slater, Bremner, Johnson, Hayes & Brown 2000), implying to some that these facets of face processing are innate. This pattern of preference for conspecifics at birth is found in other species, such as chicks and ducklings. However, developmental studies have shown that adult-level face recognition and discrimination can take many years to mature (e.g., Carey 1992). This could mean that the mechanism for identification of faces, and learning discrimination at a facial level is in fact an 'expert' system (i.e., not necessarily innate) and it is only a face detection system that is genetically hard-wired (and therefore responsible for the many phenomena of face perception seen in neonates).

Heyes (2003; see also Morton & Johnson, 1991; De Gelder & Rouw, 2001) proposes a two-system approach with respect to the evolution of face processing mechanisms. She suggests that natural selection shapes non-cognitive processes which in turn influence the supply of input to recognition systems. Evidence suggests that neonatal face preference is mediated by different subcortical structures than adult-level face-recognition (Atkinson, 1984). Preference for three high-contrast blobs arranged in a triangle declines sharply 4-6 weeks after birth (Johnson, 1999). This initial bias toward face-like arrays is assumed to be a product of natural selection, which in turn biases input to relatively domain general recognition mechanisms. These systems then acquire distinctive properties through extensive experience with faces. Findings that show faces are processed in the same regions of brain as, for example, houses and chairs (Ishai, Ungerleider, Martin, Maisog, & Haxby, 1997) imply that 'expertise' is a product of development through exposure. On this view, our impressive ability to recognise faces is simply a product of greater exposure, initially ensured by a biasing non-cognitive system. However, suggesting that a system is not genetically based, and is formed by learning only on the basis that it requires repeated environmental stimulation, is considered by some as a weak argument, as many hardwired genetic systems are triggered in this way (Liu & Chaudhuri, 2003).

The supposed special status of face recognition has also been supported by behavioural data recorded from adults, for example, from the finding that inverted faces are disproportionately more difficult to recognise than inverted objects (for a review, see Valentine, 1988). Several researchers have suggested that it is the tendency for us to process faces in a 'holistic' or configural manner that contributes to the inversion effect. It is proposed that we rely on more global/configural relationships (with faces) than featural information (with other objects) because global relationships are more disturbed by inversion (e.g., Bartlett & Searcy, 1993, 1996; Robbins & McKone, 2003). Although other stimuli may be represented configurally, it seems plausible to suppose that faces represent a class of stimuli in which configural processing is particularly important; so much so that faces may represent a unique class of objects that require qualitatively different mechanisms and dedicated neural substrates (e.g., Yin 1969, but see above e.g., Ishai et al., 1997). It should be noted that inversion effects have been observed with people who are experts with stimuli other than human faces (e.g., dogs, Diamond & Carey, 1986; cars, Bauml, Schnelzer & Zimmer, 1997), suggesting that configural processing could stem from expertise rather than a face-specific processing. Diamond and Carey (1986) suggest that expertise (i.e., discrimination that is acquired over many years of development and experience) is required for recognising all stimuli that are structurally similar (i.e., based on a prototypical structure). It is widely accepted that fine discrimination among structurally similar stimuli requires configural or holistic processing – a skill that involves encoding of spatial relations between (facial) features or relatively fewer part decompositions (e.g., Farah et al., 1998; Rhodes 1998). It can be argued therefore that since faces require configural or holistic processing (as shown by the inversion effect), that face perception cannot be special. Configural processing for any type of object requires experience, thus face perception is equivalent to processing other homogenous stimuli as it requires the same amount of training to achieve the expert level of performance (see Tanaka & Gauthier 1997; but see Gauthier, Tarr, Anderson, Skudlarski & Gore 1999, suggesting that expertise can be acquired over a matter of days). However, instead of assuming that discrimination and recognition of complex objects is governed by a domain-general system, one can of course argue that we can possess more than one domain-specific recognition system – and each is tuned by expertise (see Kanwisher, 2000 for a more detailed discussion).

Much of the empirical work presented in this thesis uses pictures of human faces as stimuli. Some of this work was intended to examine whether some of the features of perceptual learning can be observed with face stimuli. As already mentioned, I will also examine the effects of the nature of exposure (simultaneous versus alternating) on perceptual learning, in the first instance, using pictures of faces of stimuli. If this examination reveals novel effects, it will then be important to examine whether or not these effects are specific to the use of pictures of faces as stimuli. Finally it will be important to examine whether the face stimuli used are processed as faces (e.g., are subject to inversion effects).

1.8.2 *Exposure to a face changes the way it is processed.*

The issue of configural and featural processing also arises in literature regarding the processing of familiar and unfamiliar faces. The type of information used in perceiving a familiar face is different from that used to discriminate unfamiliar faces. Using famous faces which were presumably very familiar to the participant, Ellis et al., (1979) note that their subjects were more accurate in identifying the stimuli when internal features (e.g., eyes and mouth) were used instead of external features (e.g., hair and jaw-line). In addition, Bruce, Henderson, Greenwood, Hancock, Burton and Miller (1999) show that participants use external features to identify and match unfamiliar faces with greater success than internal features. Although other authors note little difference between the use of internal and external features in unfamiliar faces, all see an increase in the accuracy of judgements made to internal features with familiar faces (Young et al., 1985; Ellis & Shepherd, 1987, cited in Ellis & Shepherd, 1992).

Recently O'Donnell and Bruce (2001) have shown a shift from external to internal features, with increasing familiarity with the target face. Familiarity produced by experimental exposure resulted in selective enhancement of performance when pairs of faces differed in the characteristics of the eyes alone. This suggests that there is a shift in the use of external to internal features over the course of experimental exposure. Consistent with this suggestion, Haig (1985, 1986) has shown detection to changes in the mouth is more accurate with familiar than unfamiliar faces. O'Donnell and Bruce (2001) altered the spatial relationship between the target's eyes, which improved detection of differences in familiarised faces, possibly due to the disruption of the internal configuration of the face, whereas changes in the features of the eyes themselves were equally well detected in familiar and unfamiliar faces. The more general conclusion that familiar and unfamiliar face processing are underpinned by different mechanisms is supported by neuropsychological investigations.

Young, Newcombe, De Haan, Small, and Hay (1993) describe a series of experiments with patients who had suffered unilateral brain injuries which affected posterior areas of the left or right cerebral hemisphere. Whilst all patients showed a deficit in the processing of facial expressions, there was evidence that suggested a dissociation between familiar face recognition and unfamiliar face matching: some patients were more impaired with recognising familiar faces than they were with matching pictures of unfamiliar faces (and some patients showed the opposite deficit) – indicating that familiar face processing was not completely co-dependant with the processing of unfamiliar faces. Nevertheless, the authors make it clear that these two processes (familiar face recognition and unfamiliar face matching) are not entirely independent either, so a strong claim about the degree of overlap between familiar versus unfamiliar processing cannot be made on the basis of this data.

1.8.3 *From novel to familiar*

The above findings suggest that simple exposure to a face somehow changes the way in which it is processed, whether that be due to attention shifting from external to internal features or from featural representation to configural representation. Exemplar-based models of face processing like that of Valentine (1991) suggest that face representations are held within a Euclidean space. The identity of one face is calculated as a vector distance from that of others in the multi-dimensional space, such that typical/confusable faces or faces that are members of the same category tend to group closer together and hence are harder to discriminate than distinctive faces. However, Valentine (1991) does not propose a mechanism to move faces from typical to distinctive (i.e., to warp the dimension of distribution) since, after learning, the face itself has not been changed (it has not become more physically distinctive); that is, this model incorporates no process of perceptual learning. Lewis (2004) adds a dimension of familiarity to the representation of each individual face within the Euclidean space. This means that the location of an individual within the face space does not change with familiarity but the strength of the representation increases. The dimension of familiarity itself is a simple all-or-nothing code, so that a face is either unknown or it is familiar, which does not reflect the process of how a face becomes familiar *per se*. Nor does this modification of the face-space model account for the increasing contribution of internal features to the representation of a face as it becomes familiar. While Lewis (2004) shows how familiarity might be described in a face-space model, he does not account for the process by which familiarity is acquired.

Despite the fact that little is known about exactly how the representation of a face changes from being unfamiliar to becoming familiar (c.f. Bonner et al., 2003), some authors have invoked an unspecified process of perceptual learning in explaining certain phenomena. For example, Bruce and Burton (2002) suggest that perceptual learning could contribute to the fact that faces from one's own race are more readily distinguished than faces from other races, on the grounds that our ability to differentiate between own-race faces is dependent on our greater experience with them. Whilst it is yet to be tested empirically, a process of perceptual learning may well contribute to the acquisition of familiarity with faces, and is clearly consistent with the idea that the discriminability of faces changes with experience (see Valentine et al., 1995; Buttle & Raymond, 2003). However, the own-race bias need not reflect any face-specific increase in discriminability, but instead might reflect a more general strategic influence on the processing of own-race faces as a group that transfers to novel own-race faces. This strategic effect might therefore be a product of simple and protracted (supervised or unsupervised) exposure to own-race faces or the lack of exposure to other-race faces (e.g., Levin 2000).

A Gibsonian analysis of perceptual learning seems to sit well with the fact that different features underpin the identification of familiar and unfamiliar faces. For example, recent studies have shown that a limited amount of exposure to previously novel faces can produce a shift towards the dominance of (or in attention to) internal features (Bonner et al., 2003; O'Donnell & Bruce, 2001). In addition, one of the simplest markers of perceptual learning is that confusable stimuli become increasingly easy to distinguish with experience. Stevenage (1998, see also Robbins & McKone, 2003) shows that with training to categorical perception of twins, same-twin pairs come to look significantly more similar and different-twin pairs come to look more different, due to perceptual warping of category boundaries. This experiment involved giving participants feedback as to which twin was which, making their exposure 'supervised'. Nevertheless, these experiments confirm the quantitative advantage for familiar stimuli and demonstrate that at least one qualitative difference in processing can be acquired over a time period that is short relative to the usual lifetime exposure to familiar faces.[3]

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[3] It is worth noting that the recognition of unfamiliar faces has been claimed to be image-specific. Changes in viewpoint or expression have a larger detrimental effect on the memory for unfamiliar faces than for familiar ones (e.g. Bruce, 1982; Roberts & Bruce, 1989). The improvement in

However, these studies only examined whether a change has occurred as a result of exposure or what has been changed by that exposure, not how that change has been brought about. In other words they have examined the products rather than the processes of perceptual learning.

1.8.4 *Models of face learning*

One way in which the process of perceptual learning has been envisaged within the face processing literature is via the application of a principal component analysis (PCA, e.g., Burton et al., 1999a; Furl, Phillips, & O'Toole, 2002; O'Toole et al., 1995). PCA is a statistical procedure for producing an efficient representation of a set of correlated variables in terms of a number of factors or principal components (PCs). Any particular case in the original data can be described as a weighted sum of these PCs. One feature of this approach is that the factors extracted depend entirely on the statistical structure of the faces used to train the system and so the extraction of factors is seen as a perceptual learning process whereby the features used by the system are developed by contact with the faces themselves. Principal component analyses are generally presented as static models (see Burton et al., 1999a for a discussion of this issue): a set of faces is presented to the system, factors are extracted, and these factors used to represent the original data (and other examples of the same form). However, there is clear evidence that the perception or representation of a face can change as it becomes more familiar (i.e., as the face has been experienced on more occasions). This suggests that, in addition to the extraction of general factors on which faces may be represented, models of face processing need to include a *dynamic* learning component

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discrimination between photographs of identical twins produced by exposure does in fact transfer to novel test stimuli (Stevenage, 1998; see also Robbins & McKone, 2003) so some aspects of face processing (and perhaps therefore perceptual learning) must be image-independent.

in order to explain the process by which a face becomes familiar. Interestingly, some recent models (e.g., Moghaddam & Pentland, 1998; Zhao, Krishnaswamy, Chellappa, Swets, & Weng, 1998) have added a second stage to the PCA based feature extraction where the PCA derived space is warped to improve the discrimination between individuals represented. This class of models has recently been shown to give a better account of the own-race/other-race effect than static PCA models (Furl et al., 2002). The improvement in representation highlights the fact that simply extracting the relevant dimensions on which face stimuli vary might not be a complete description of perceptual learning and that modifications in the weights given to these factors might also play an important role.

One simple model of face learning was presented by Burton (1994) as an addition to the interactive activation and competition model of face recognition. The model assumes faces to be represented as a combination of 12 different parameters, each of which can take on a number of different values. While this is a deliberate simplification of the representational processes involved in face processing, a more recent discussion (Burton et al., 1999a) argued that a more realistic representation based on PCA extracted factors should not change the basic working of the model. These input factors are fully connected to a number of face recognition units (FRUs) and the weights of these connections are initially set randomly. The FRUs themselves have mutually inhibitory links. Using a Hebbian process the model can learn to link a particular pattern of input to a particular FRU and thus learn to "recognise" a new face. This model seems much like the process of unitisation described in the model of Grossberg (1984, 1991) where a diffuse pattern of activation relating to many perceptual features becomes linked together, and to a 'single-unit' deeper in the network. Reactivation of this single unit is all that is required to reactivate the whole original representation. For Burton's model, in order to learn multiple faces, each had to be presented repeatedly so that it was learnt well before the learning of the next face. Burton (1994) noted that this feature of the model was essentially arbitrary. However, it should be remembered that blocked presentation of stimuli is not the most effective method of fostering perceptual learning.

This review shows that current analysis of face processing lacks a mechanism that can account for the schedule effects previously seen with perceptual learning with other stimuli in humans (e.g., Dwyer et al., 2004) and in other species (e.g., Symonds & Hall, 1995). There are a variety of well specified associative and non-associative accounts of perceptual learning that could apply to face processing (e.g., Gibson, 1969; Hall, 2001; McLaren et al., 1989). However, without an empirical demonstration that schedule effects actually occur in human face learning there is no good reason to suppose that these models are applicable to face processing. The results presented in Chapters 3 and 4 will be directly relevant to this issue.

1.9 *Summary – Unanswered Questions*

Fundamental questions remain both within the realm of perceptual learning itself, and in the analysis of perceptual learning in the context of face processing. Three main areas that I have identified as requiring further empirical work are as follows: the contribution of inhibitory associations to perceptual learning in humans (Chapter 2); the role of stimulus comparison in perceptual learning (Chapter 3); and the contribution of perceptual learning to face processing (Chapters 3 and 4).

Chapter 2

Abstract

Chapter 2 reports two experiments that examine perceptual learning in humans. In Experiment 1, participants received intermixed exposure to two similar compounds (AX, BX, AX, BX…) and blocked exposure to a second pair of similar compounds (CY, CY… DY, DY…). Aversions established to AX and CY generalized less to BX than to DY. This confirms that intermixed exposure results in greater perceptual learning in humans and establishes the sensitivity of the within-subjects procedure. In Experiment 2, one pair of compounds was presented in a forward order (i.e., AX→BX) whereas the second pair of compounds was presented in a backward order (i.e., DY→CY). Aversions established to AX and CY generalized less to BX than DY. These results indicate that inhibitory associations contribute to perceptual learning in humans and thereby establish a fundamental similarity between the mechanisms that underlie perceptual learning in humans and rats.

2.1 *Introduction*

Gibson (1969) suggested that when two stimuli (AX and BX) are exposed in such a way as to allow their comparison, a process of *stimulus differentiation* operates that increases attention to their unique features (A and B) relative to their common features (X). This suggestion is consistent with the finding that intermixed exposure, that should provide an opportunity for stimulus comparison, is a more effective means of generating a perceptual learning effect than is blocked exposure, which should provide little scope for stimulus comparison (see also, Blair & Hall, 2003; Hall, 2003; Honey et al., 1994). Others have offered an associative explanation for perceptual learning that can also provide an account of the scheduling effect, based on inhibitory links (McLaren, Kaye & Mackintosh, 1989; McLaren & Mackintosh, 2000; 2002).

According to associative principles (e.g., Wagner, 1981) and findings from Pavlovian conditioning procedures (see Ewing, Larew, & Wagner, 1985; Maier, Rapaport, & Wheatley, 1976) forward pairings of AX and BX (i.e., AX→BX) should be a more effective means of generating an inhibitory association from B to A than should backward pairings (i.e., BX→AX) that should result in an inhibitory association from A to B. The prediction of the associative account, derived in Section 1.5, is that forward pairings should produce a more marked perceptual learning effect than backward pairings. However, according to the Gibsonian analysis both forward and backward pairings should provide equivalent opportunities for stimulus comparison and, therefore, for stimulus differentiation (see also, Hall, 2003). The limited amount of research that has been conducted on this issue (see Bennett et al., 1999; see also Dwyer & Mackintosh, 2002) favours the associative account: At least in flavour aversion procedures in rats there was greater evidence for perceptual learning following forward than backward exposure.

The general aim of the experiments reported in Chapter 2 was to assess whether evidence taken to support the contribution of inhibitory associations to perceptual learning in rats can also be observed in humans. Experiment 1 is an attempt to provide a within-participants demonstration advantage of intermixed exposure and Experiment 2 assesses whether an order effect of the form reported by Bennett et al. (1999) can be demonstrated in humans. If these experiments are successful then they would begin to represent a secure basis for the suggestion that inhibitory associations contribute to perceptual learning in general.

2.2 *Experiment 1*

The design of Experiment 1 is shown in Table 1. Participants received exposure to compound stimuli from two modalities, flavour and odour, prior to receiving aversive conditioning trials with two of the compounds and then a series of test trials. Pairs of compounds constructed from components from one modality (e.g., odours) were exposed in an intermixed fashion (AX, BX, BX, AX) and pairs of compounds from the other modality were exposed in blocks (CY, CY... DY, DY...). Participants then received conditioning trials in which separate presentations of AX and CY were paired with the presentation of the bitter substance Bitrex™. Following these conditioning trials participants received presentations of all four compounds (AX and BX; CY and DY). In each stage of the experiment participants were required to rate the pleasantness of the compound that they were sampling (and to make a judgement of whether or not that compound was the same as the previous compound). Experiment 1 should allow us to replicate the effect of schedule of pre-exposure on perceptual learning using a within-participants procedure: in the present case, such an effect would be evident if participants rated DY as being less pleasant than BX. The use of this within-participants procedure is important. In the sole previous demonstration of a schedule of pre-exposure effect in humans (Dwyer et al., 2004) and many of those in animals (but see Blair & Hall, 2003), between-participants procedures have been used. Under such circumstances the observed differences in generalisation that followed the two pre-exposure schedules might have reflected a difference not in perceptual learning (that should be stimulus specific) but rather in some more general process of arousal. It is plausible to suppose that the two schedules of pre-exposure maintain different levels of alertness or arousal and that, should such a difference be sustained during conditioning and the generalisation test, it could affect the observed pattern of test results.

Table 1

Experimental design used in Experiment 1

Condition	Pre-exposure	Conditioning	Test
Intermixed	AX, BX,...AX, BX,...	AX→Bitrex	AX, BX
Blocked	CY, CY,... DY, DY,...	CY→Bitrex	CY, DY

Method

Participants and Stimuli

A total of 32 undergraduate students were recruited through the participant panel in the School of Psychology at Cardiff University, and gained course credit for taking part. Of these participants, twenty one were female and eleven were male, ages ranging from 18 to 26.

The compound flavour stimuli, sucrose-lemon and saline-lemon, were made from 0.1% w/v saline, 1.0% w/v sucrose and 3.5% Jif™ Lemon Juice (Colman's, Norwich, United Kingdom). The compound odour stimuli (raspberry-lemon and strawberry-lemon) were made from three kinds of scented pads supplied by Dale Air (Lytham, United Kingdom), listed in their catalogue as: Lemon-Wild (218), Raspberry (CARV) and Strawberry (RA123). The bitter substance added to induce aversion was 0.1ppm Bitrex™ (Macfarlan Smith Ltd, Edinburgh, United Kingdom). This substance is normally used to denature household chemicals to reduce the likelihood of accidental consumption, and whilst tasting exceptionally unpleasant, is not harmful.

The stimuli were presented at room temperature in special containers, constructed from standard 23cl (8oz) canteen-style disposable polythene cups, and a fixed plastic lid which contained a 2-cm recess and a drinking aperture. Flavour stimuli consisted of 5-ml samples placed in the base of the cup and odour stimuli consisted of scent pads that were placed adjacent to one another inside the recess of the lid. During the flavour trials, the cup contained 5-ml samples of the compound flavours (that were mixed with Bitrex™ during the conditioning trials) and the lid did not contain any odour. During odour presentations, the cup contained 5-ml of plain water, except during conditioning, where this was replaced with 5-ml of Bitrex™. However, the participants were not informed about whether the cups, placed in a line on a table in front of them, contained a flavour or an odour. Plain water was continuously available in a separate polythene cup.

General procedure and instructions

On each trial, participants were required to sample the contents of a cup and to both rate their pleasantness and judge whether or not the current sample was the same as that presented on the previous trial. The written instructions given to the participants are shown below:

> *You will be sampling a series of odours and solutions, many of which will be quite similar to each other. Some of them may be unpleasant, but none is harmful. On each presentation, swirl the solution around your mouth whilst inhaling the odour, and then swallow. Once you have done this, please rate how pleasant you found the taste of the solution and the smell of the odour (individually) on a scale from -100 to +100. Zero is neutral, negative numbers are unpleasant and positive numbers are pleasant.*
>
> *Once you have done this, please indicate if you think that the current solution was the same as, or different to the one you tasted immediately before. Please also indicate if you think that the current odour was the same as, or different to the one presented immediately before.*
>
> *One of the aims of this study is to investigate whether people change their evaluation of a flavour or odour over a limited number of repeated exposures. So, there is no reason to automatically give the same or a similar 'pleasantness' rating to a solution or odour that you have encountered before. Consider each individually. (Of course, if you find two exposures similarly pleasant, then give them a similar rating).*
>
> *To avoid the presentations interfering with each other, please take a sip of water, and a deep breath between each presentation.*

Once the experimenter had ensured the participants had understood these instructions the experiment began with a sip of water. The sampling of the contents of each cup was followed by a deep breath and a sip of plain water. Then, the pleasantness of both the flavour and odour were rated by giving the experimenter a number on a scale of -100 to +100, and same/different judgements were performed. Once the same/different judgement had been made the next trial began. Each trial lasted approximately 15 sec. No feedback was given by the experimenter at any time.

Pre-exposure, conditioning and test

The Experiment was split into three stages: pre-exposure, conditioning and test. However, the stimulus presentations from each stage consisted of a continuous sequence.

Pre-exposure: Participants received 6 exposures to each of the compound stimuli (AX, BX, CY and DY). These exposures were arranged as 12 pairs: 6 intermixed (3 AX, BX and three BX, AX) and 6 blocked (3 CY, CY and 3 DY, DY). The identities of AX/BX and CY/DY were counterbalanced so that half of the participants received intermixed trials with flavours and blocked trials with odours, and the remainder received the reverse arrangement. Intermixed pairs were either presented at positions 1, 3, 5, 7, 9, and 11 within the sequence and blocked pairs at positions 2, 4, 6, 8, 10, and 12, or *vice versa*. Within the subgroups created by counterbalancing the sequence, half of the participants received blocked trials for CY, at positions 2, 4, and 6 (or 1, 3, and 5) before blocked trials with DY at positions 8, 10 and 12 (or 7, 9, and 11), and the other half received the opposite sequence (pairs of DY preceding those of CY). Half of the subgroups created by the preceding counterbalancing operations received initial intermixed trials where AX was presented before BX at position 1 (or 2), and BX before AX at position 3 (or 4) etc., continuing in double alternation, and half received the reverse patterning of intermixed pairs. There were, therefore, 16 pre-exposure sequences.

Conditioning: The participants then received five separate presentations of AX and CY that were adulterated with Bitrex™ and presented in a pseudo-random order with the constraint that there were no more than two trials of the same type in succession and that for half of the participants the sequence began with AX and for the remainder it began with CY.

Test: Each participants received two test sequences that contained two occasions on which the judgement 'same' was correct and two on which 'different' was correct. The sequences were AX, BX, BX, AX, AX (sequence 1; or BX, AX, AX, BX, BX, sequence 2) and CY, DY, DY, CY, CY (sequence 3; or DY, CY, CY, DY, DY, sequence 4). Half of the participants received sequences 1 and 3 and the remainder received sequences 2 and 4. For half of the participants in each of these subgroups the AX/BX sequence was presented first and the CY/DY sequence second and for the remaining participants this arrangement was reversed.

Data Analysis

The absolute levels of the pleasantness ratings for all compounds varied greatly between participants during the test. Therefore we expressed these ratings as a difference score from those made for the corresponding compound given during pre-exposure. Same/different judgements were collected throughout the pre-exposure trial sequence and a percentage correct score was calculated to determine their accuracy. In Experiment 1, during pre-exposure these percentage correct scores will be compromised by the nature of the two pre-exposure sequences: the correct response for the first and second member of Intermixed pairs is always 'different' whereas the correct response to the second member of Block pairs is always 'same'. However, as indicated above, the nature of the test sequences meant that they were not compromised in this way. A significance level of $p<.05$ was adopted throughout this thesis. In addition, where F values are greater than 1 but the test proves insignificant, an exact p value is given in assurance of the null result.

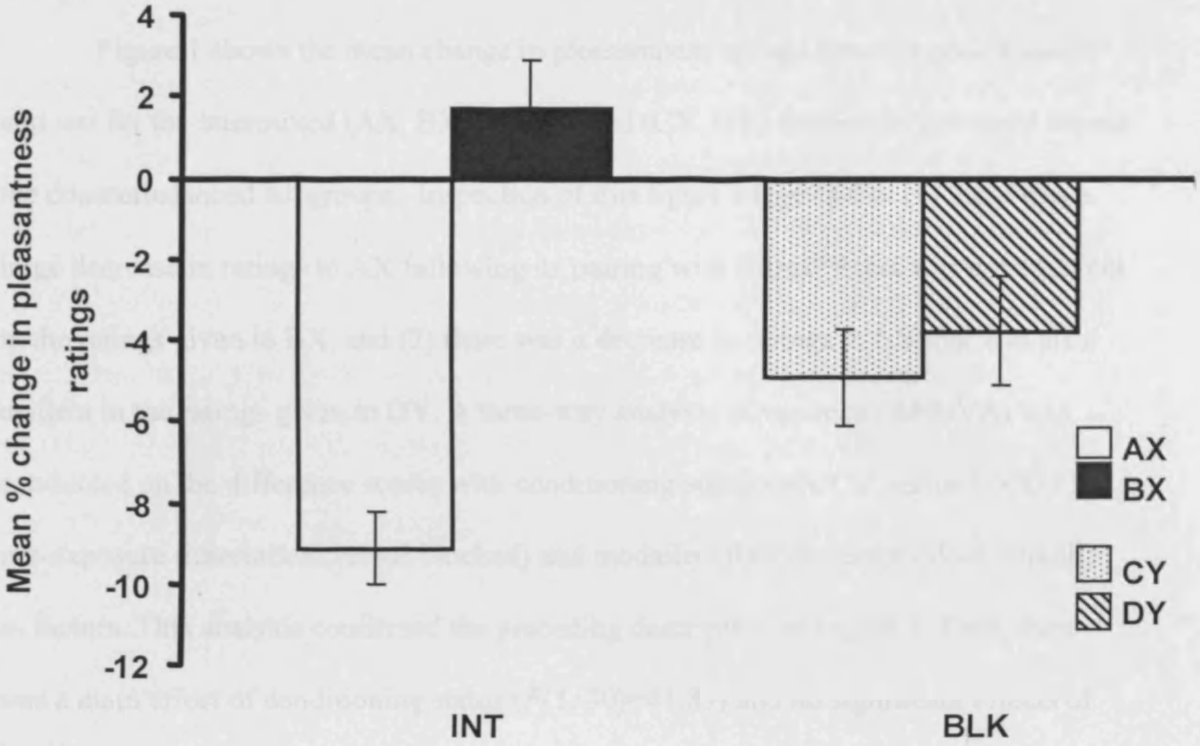


Figure 1. INT and BLK refer to within-subjects conditions of intermixed and blocked exposure to pairs of compound flavours and odours (collapsed). The scale refers to mean changes (pre-exposure → test) in pleasantness ratings, for conditioned compounds AX and CY and unconditioned compounds BX and DY (± Standard Error of the Mean - SEM).

Results

Figure 1 shows the mean change in pleasantness ratings between pre-exposure and test for the intermixed (AX, BX) and blocked (CY, DY) conditions collapsed across the counterbalanced subgroups. Inspection of this figure suggests that (1) there was a large decrease in ratings to AX following its pairing with Bitrex™ that was not apparent in the ratings given to BX, and (2) there was a decrease in ratings to CY that was also evident in the ratings given to DY. A three-way analysis of variance (ANOVA) was conducted on the difference scores with conditioning status (AX/CY versus BX/DY), pre-exposure (intermixed versus blocked) and modality (flavour versus odour stimuli) as factors. This analysis confirmed the preceding description of Figure 1. Thus, there was a main effect of conditioning status ($F(1, 30)=41.85$) and no significant effects of pre-exposure or modality (Fs<1). There was, however, an interaction between conditioning status and pre-exposure ($F(1, 30)=22.67$) that was not accompanied by any other significant interactions (Fs<1). Analysis of simple main effects revealed that that the scores for AX and BX differed ($F(1, 30)=62.31$), but those for CY or DY did not ($F(1, 30)=1.27$, $p=0.269$). There was also a significant difference between the scores for BX and DY ($F(1, 30)=12.62$) and AX and CY ($F(1, 30)=4.20$). A parallel analysis conducted on the baseline scores (*M*s: AX=10.25, BX=9.56, CY=9.95 and DY=10.43) used to calculate the change in pleasantness ratings revealed no significant effects of conditioning status, pre-exposure and modality (maximum $F(1, 30)=1.08$, $p=0.307$).

The mean percentages correct for the same/different judgements during pre-exposure and test for the intermixed condition were 51.56% and 56.25%, respectively, and for the blocked condition were 46.88% and 48.44%, respectively. Separate ANOVAs conducted on the pre-exposure and test results confirmed that there were no significant effects of stimulus modality or pre-exposure type and no interaction between these factors (largest $F(1, 30)=1.24$, $p=0.274$).

2.3 *Experiment 2*

In Experiment 2, using a similar procedure to the first Experiment, the pairs of compounds from two modalities were presented in two consistent sequences in which AX consistently preceded BX (AX→BX) and DY consistently preceded CY (DY→CY). By arranging for each pair to be constructed from a different modality (e.g., AX/BX flavour, CY/DY odour) and interleaving the two types of trials it was possible to examine order of exposure within-participants. As in Experiment 1, after this pre-exposure stage, AX and CY were paired with Bitrex™ and then generalisation to BX and DY were assessed. The design of Experiment 2 is shown in Table 2.

Table 2

Experimental design used in Experiment 2

Condition	Pre-exposure	Conditioning	Test
Forward	AX→ BX,...AX→ BX,...	AX→Bitrex	AX, BX
Backward	DY→ CY,... DY→ CY,...	CY→Bitrex	CY, DY

Method

Participants and Stimuli

Thirty two undergraduate students were recruited through the participant panel in the School of Psychology at Cardiff University, and gained course credit for taking part. Of these participants, twenty three were female and nine were male, ages ranging from 18 to 27. The compound stimuli were constructed and presented in the same way as Experiment 1.

General procedure and instructions

The general procedure and instructions were identical to those of the first experiment. No feedback about participants' responses was given at any time, and they were not explicitly aware of the sequence of the experiment.

Pre-exposure, Conditioning and Test

Pre-exposure: Participants received 6 exposures to each of the compound stimuli (AX, BX, CY and DY) that were again arranged into 12 pairs: 6 forward (AX, BX) and 6 backward (DY, CY). The identities of AX/BX and CY/DY were counterbalanced so that half of the participants received forward trials with flavours (and backward with odours), and half received forward trials with odours (and backward with flavours). The forward pairs were either presented at positions 1, 3, 5, 7, 9, and 11 within the sequence and the backward pairs at positions 2, 4, 6, 8, 10, and 12, or *vice versa*. The identities of each compound were counterbalanced so that, for example, half of the participants AX was sucrose-lemon and BX was saline-lemon and for the other half the reverse was true. The conditioning and test sequences and counterbalance were identical to those of the Experiment 1.

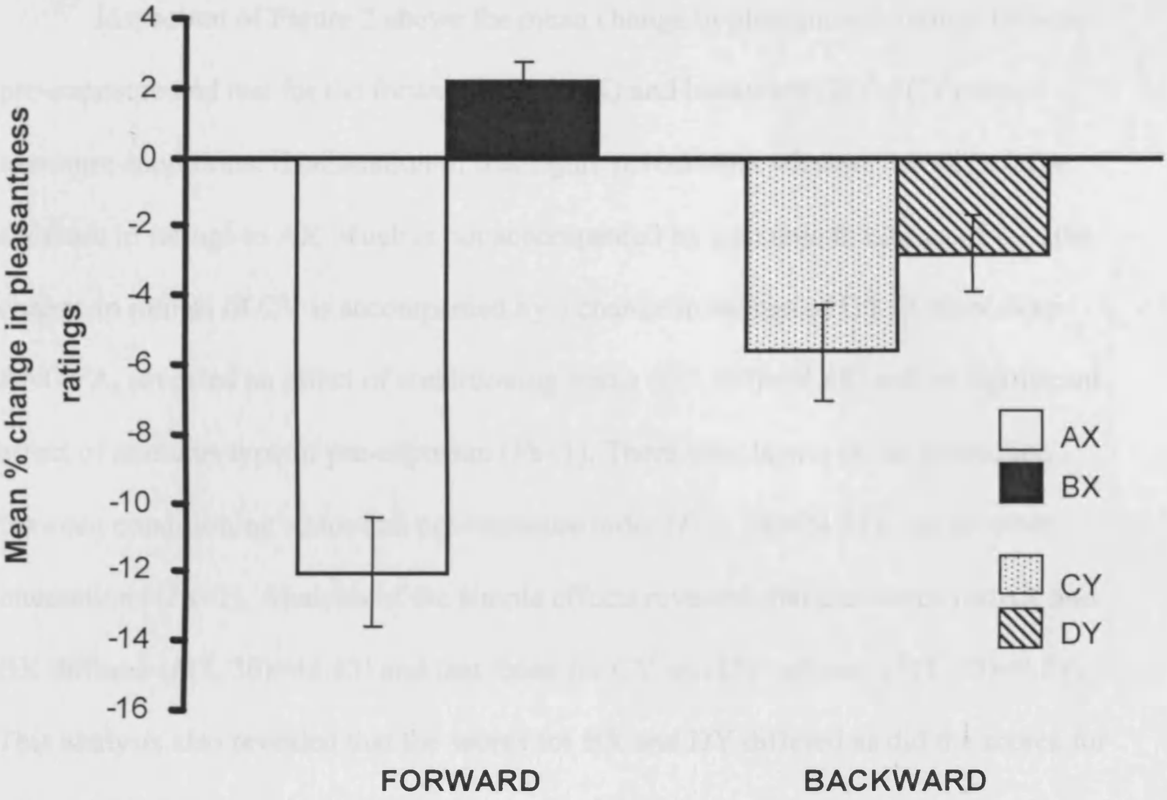


Figure 2. Forward and Backward refer to the pre-exposure order conditions to pairs of compound flavours and odours (collapsed). The scale refers to mean changes (pre-exposure → test) in pleasantness ratings for conditioned compounds AX and CY and unconditioned compounds BX and DY (±SEM).

Results

Inspection of Figure 2 shows the mean change in pleasantness ratings between pre-exposure and test for the forward (AX→BX) and backward (DY→CY) pre-exposure conditions. Examination of this figure reveals that whereas there is a large decrease in ratings to AX which is not accompanied by a change in ratings of BX, the change in ratings of CY is accompanied by a change in ratings of DY. A three-way ANOVA, revealed an effect of conditioning status ($F(1, 30)=54.48$) and no significant effect of stimulus type or pre-exposure (*F*s<1). There was, however, an interaction between conditioning status and pre-exposure order ($F(1, 30)=24.38$), but no other interactions (*F*s<1). Analysis of the simple effects revealed that the scores for AX and BX differed ($F(1, 30)=44.63$) and that those for CY and DY differed ($F(1, 30)=9.87$). This analysis also revealed that the scores for BX and DY differed as did the scores for AX and CY (smallest $F(1, 30)=10.46$). A parallel analysis of the baseline scores (*M*s: AX=8.95, BX=9.54, CY=10.09 and DY=9.21) used to calculate the change in pleasantness ratings revealed no significant effects of conditioning status, pre-exposure and modality (maximum $F(1, 30)=1.11, p=0.300$).

The mean percentages correct for the same/different judgements during pre-exposure and test for the forward condition were 48.21% and 55.50%, respectively, and for the backward condition were 55.14% and 61.07%, respectively. Separate ANOVAs conducted on the pre-exposure and test results confirmed that there were no significant effects of stimulus modality or pre-exposure type and no interaction between these factors (*F*s<1).

Before discussing the general implications of these results, one specific aspect of them requires brief consideration. In both Experiments 1 and 2 there was not only a difference between the scores for the (generalisation) test stimuli (BX and DY) but also a difference between the scores given to the conditioned stimuli (AX and CY). The scores given to AX (presented in an intermixed or forward relationship to BX) were consistently greater than those given to CY (presented in a blocked or backward relationship to DY). While there are good grounds for supposing that generalisation between AX and BX should be less marked than between CY and DY, the fact that the scores for AX and CY differed is, in some respects, unexpected. However, as it transpires, this difference was not present on the first presentations of AX and CY in either Experiment 1 (AX=-11.29 and CY=-10.52) or Experiment 2 (AX=-12.51 and CY=-11.78; largest $F(1,30)=1.89$, $p=0.179$). It seems reasonable to suppose, therefore, that the difference between AX and CY scores during test was a product of differential secondary extinction (see Pavlov, 1927, pp. 54-57) produced by intermixing BX and DY with AX and CY during testing: That is, the difference between AX and CY reflected not a difference in conditioning to these stimuli, but rather the fact that participants considered BX less similar to AX than they did DY to CY and thus exposure to DY contributed to the extinction of CY in a way that exposure to BX did not contribute to the extinction of AX.

2.4 *Discussion*

The experiments reported in this chapter were conducted with a simple aim: To investigate whether or not the mechanisms that underlie perceptual learning in rats also play a role in perceptual learning in humans. To this end, two experiments were conducted that closely parallel those conducted in rats. Experiment 1 confirmed using a within-participants procedure that intermixed pre-exposure is a more effective way of generating perceptual learning than is blocked pre-exposure. This finding replicates, using novel stimulus compounds, an effect only observed to date using between-participants procedures in humans (see Dwyer et al., 2004). This finding, demonstrated on many occasions in nonhuman animals, has been taken to support a non-associative Gibsonian analysis (see Blair & Hall, 2003; Hall, 2003; Honey et al., 1994; Symonds & Hall, 1995). The results of Experiment 2, however, are not conducive to this kind of analysis, but again parallel an important finding from the animal literature (Bennett et al., 1999). In Experiment 2, the order in which the pairs of compounds were presented was varied: forward (AX→BX) and backward (DY→CY). An aversion then established to AX and CY generalized less markedly to BX than to DY. The Gibsonian analysis is undermined by this pattern of results because both orders of pre-exposure provide equivalent opportunity for stimulus comparison. Like the findings of Bennett et al. (1999), those of Experiment 2 provide clear support for an associative analysis of perceptual learning such as that offered by McLaren et al. (1989). However, there was no significant effect of pre-exposure regime on same/different discrimination judgements between the stimuli in either experiment. The details of this kind of analysis will be discussed further in the General Discussion of this thesis (see also Dwyer et al., 2004).

This is the first time the differing effects of consistent intermixed order on discrimination have been shown in humans, explicitly demonstrating the action of inhibition in perceptual learning. Additionally, these paradigms have been demonstrated using within-subjects methods that have not previously been used, presenting the use of two different modalities of stimulus, flavour and odour, to accomplish this. At no point in the above experiments was a difference found to exist in participants' discrimination responses to the two modalities, suggesting that this methodology is a reliable means of creating within-subjects designs. Overall, the data gives support to an associative perspective on perceptual learning, consistent with the suggestion that discrimination between two complex stimuli is enhanced by the establishment of inhibitory associations between their unique elements.

Given the remarkable degree of consistency between the results of Experiments 1 and 2 and formally identical studies that have been conducted with rats, it is tempting to conclude that the associative analysis that these results support provides a compelling and general account of perceptual learning. This possibility is more closely examined in the following chapters of this thesis. Although the parallel between the results reported in Chapter 1 and animal work is significant, it has to be acknowledged that the parallel is observed using similar stimuli and procedures to those experiments conducted in animals. There are practical limitations to the kind of experiment that can be conducted with olfactory (and gustatory) stimuli. In Chapter 3 I proceed to examine perceptual learning using visual stimuli. If perceptual learning is a truly general process, then the nature of the stimulus that is to be discriminated should have little bearing on the standard perceptual learning effects that have most commonly been seen with flavour stimuli.

Chapter 3

Abstract

In Chapter 3 human participants received unsupervised exposure to difficult to discriminate stimuli (e.g., A and A′), created from photographs of faces using a morphing procedure, before learning a discrimination between them. Experiments 3 and 4 demonstrated that prior exposure enhanced later discrimination and that intermixed exposure (A, A′, A, A′ …) resulted in better subsequent discrimination than blocked exposure (B, B … B′, B′ …). These experiments establish that pictures of faces produce the same perceptual learning effects as other classes of stimuli. Experiments 5 and 6 showed that simultaneous exposure to two similar stimuli facilitated the later acquisition of both a simultaneous and a successive discrimination. This effect was observed in spite of the fact that simultaneous exposure to two stimuli fostered the development of an excitatory association between them (Experiment 7). Experiments 5-7 demonstrate a perceptual learning effect that is beyond the scope of two associative analyses, but falls within the capacity of a non-associative (Gibsonian) account. Experiment 8 demonstrates that an artificially created class of visual stimuli (chequerboards) also reveals an advantage for simultaneous presentation. This finding suggests that the results of Experiments 3-7 are not specific to face stimuli.

3.1 *Introduction*

The previous chapter examined perceptual learning phenomena in humans, using stimuli and techniques that were intentionally similar to those traditionally used with animals, revealing a remarkable consistency in the findings between species. This indicates that the general processes underpinning perceptual learning may well be the same in humans as in lower animals. However, there is evidence to suggest that the model of perceptual learning supported by those data does not capture all aspects of perceptual learning seen in other studies (see, for example: Saldanha & Bitterman, 1951). The partly non-associative account of Hall (2003), along with the fully non-associative Gibsonian accounts (e.g., Gibson 1969, Hall 1991) have been given independent empirical support (e.g., Blair & Hall, 2003; Artigas, Sansa, Blair, Hall, & Prados, 2006; Mondragón & Hall 2000), where differential learning to common and unique elements has been shown (see Section 1.7). These data suggest that in some circumstances a model of perceptual learning based on salience modulation better fits the observed learning than one based on mutual inhibition.

Gibson (1969) placed considerable emphasis on the suggestion that the process of stimulus differentiation, which she took to underlie perceptual learning, should be especially likely to operate when the stimuli are exposed in a simultaneous fashion. She assumed that simultaneous stimulus exposure should not only confer immediate benefits for the detection of differences between stimuli, but also provide an enduring basis for accurate discrimination that should be (relatively) independent of the way in which the stimuli were subsequently presented. Even without the theoretical backdrop of Gibson's analysis, it is surprising that there is no evidence that shows that simultaneous unsupervised exposure (cf. MacCaslin, 1954; Saldanha & Bitterman, 1951; Wills & Mackintosh, 1999) is a particularly effective procedure for generating perceptual learning. Of course, there are demonstrations that same/different discrimination tasks can be easier when the stimuli are displayed simultaneously than when they are displayed successively (e.g., Brown & Rebbin, 1970; for a review, see Laming and Scheiwiller, 1985). However, such findings need not indicate the two modes of exposure result in enduring differences in the discriminability of the representations of the stimuli. For example, when two stimuli are displayed simultaneously the presence or absence of a difference between them might be relatively immediately available to affect the response “same” or “different” whereas there will be greater memory component involved when the stimuli are presented successively (but see, Scott-Brown, Baker, & Orbach, 2000).

A key objective of this set of studies is to examine perceptual learning with simultaneously presented stimuli. The following experiments turned to visual discriminations based on an artificial dimension – morphed faces for Experiments 3-7 and chequerboards for Experiment 8. Although it is possible that there are specialised processes for faces (e.g., Bruce, 1982; McCarthy, Puce, Gore, & Allison, 1997; but see also Gauthier & Tarr, 2002; Heyes, 2003) previous experiments using morphed faces have demonstrated learning effects seen with more standard stimuli such as transfer along a continuum and transfer after outcome reversal (Suret & McLaren, 2003; see also Goldstone, Steyvers, & Rogosky, 2003). Furthermore, it has been common to invoke some process of perceptual learning in the context of face processing (e.g., Bruce & Burton, 2002; O’Toole, Abdi, Deffenbacher, & Valentin, 1995; Valentine, Chiroro, & Dixon 1995), especially in the discussion of how faces become familiar.

A starting point for this analysis of perceptual learning using visual stimuli is Experiment 3 which assesses whether or not brief exposure to morph-created pictures produces a perceptual learning effect that is stimulus specific. In subsequent experiments, the nature of the perceptual learning effect that is found in Experiment 3 will be explored using similar face stimuli. Subsequently, Experiment 8 confirms that any novel effects can be replicated when chequerboards are used in the place of faces.

3.2 *Experiment 3*

In common with many studies of perceptual learning in rats, flavoured stimuli have been used in previous studies of perceptual learning in humans (e.g., Dwyer et al., 2004; Chapter 2). In order to gain a degree of systematic control over the initial degree of stimulus discriminability, Experiments 3-7 used a morphing procedure to create continua between pairs of faces. Briefly, two relatively similar pictures of faces were chosen as the endpoints and a set of intermediate faces was produced. Selecting faces separated by a different number of steps along the continua allowed us to manipulate the extent of stimulus similarity. Figure 3 shows an example of the two levels of similarity used in this experiment. While these pairs will be referred to as "easy" and "hard" to discriminate, inspection of Figure 3 shows that the members of neither pair was particularly easy to discriminate. Indeed, to a first approximation, the similarity of members of both easy and hard pairs was akin to that of identical twins (for the effects *supervised training* on twin discrimination, see Stevenage, 1998; see also Robbins & McKone, 2003). In Experiment 3 four such pairs of faces were used, two easy (A and A*, B and B*) and two hard (C and C', D and D').

The design of Experiment 3 is summarized in Table 3. In the exposure stage of the experiment participants were given a limited number of exposure two pairs of faces, one easy to discriminate pair (A and A*; the Easy Exposed pair) and one hard to discriminate pair (C and C'; the Hard Exposed pair). Exposure was given to one picture at a time and participants were simply requested to give an estimate of the number of occasions on which they had seen each picture, but were not given any feedback about the pictures at this time. Another two pairs of pictures, one easy to discriminate pair (B and B*; the Easy Control pair) and one hard to discriminate pair (D and D'; the Hard Control pair) were not presented during this exposure stage. During the test stage participants learned to assign an arbitrary feature (left or right handedness) to one member of each of the four pairs of faces. The faces were shown one at a time and participants were given feedback regarding their accuracy after each trial. The issue of principal importance was whether or not the discrimination involving the exposed pairs of faces was acquired more readily than those involving the faces that were not exposed; because a within-participants procedure was being used, any improvement in discrimination for the exposed faces must reflect a stimulus-specific effect of unsupervised exposure (cf. Stevenage, 1998; see also Robbins & McKone, 2003).

Easy

Hard

Figure 3: Examples of stimuli used in the easy (upper panel) and hard (lower panel) discrimination conditions from Experiment 3.

Table 3

Design of Experiment 3.

Condition	Exposure	Discrimination
Easy Exposed	5 × A and 5 × A* in random order	A=LH and A*=RH
Easy Control	___	B=LH and B*=RH
Hard Exposed	5 × C and 5 × C' in random order	C=LH and C'=RH
Hard Control	___	D=LH and D'=RH

Note: Easy and Hard refer to the difficulty of the discrimination. A to D' represent different faces and LH and RH refer to left handed and right handed, respectively.

Method

Participants and Apparatus

Thirty-two students, 22 female and 10 male (aged 18-23) were recruited from the School of Psychology at Cardiff University. Twenty-five participants were undergraduates who participated in order to receive course credit and seven were postgraduates who did not receive any inducement to participate. All participants had normal or corrected-to-normal vision. An IBM-compatible PC running Microsoft Visual Basic™ was used to display the stimuli, using custom-written software, on a CRT monitor in an evenly lit, quiet room. A computer keyboard was used to record responses. For the purposes of the experiment, the 'A' key was covered with a coloured sticker with the letter L and was used by participants to indicate that the person depicted was left-handed and the 'L' key was covered with a coloured sticker with the letter R and was used by participants to indicate a right-handed person.

Stimuli

The stimuli were created using a software package dedicated to morphing called Morpheus 1.85™ running on an IBM-compatible PC. Four morphs were created using black and white portrait photographs of men and women, of a similar age to the participants, taken from an online yearbook. Two pairs of men and two pairs of women were selected. The members of each pair were chosen to be similar to ensure there were no anomalies in the morphing process that might have occurred had the pictures been different in some obvious manner (e.g., radically different hair styles or mouth apertures). The picture of each member of each pair (face X and face Y) were then homogenised, so that size (280 × 290 pixels), resolution, and lighting were identical and they were morphed together along a 30-point scale. In this scale, position 1 was 100% Face 1, 0% Face 2, position 15 was 50% Face 1, 50% Face 2, and position 30 was 0% Face 1, 100% Face 2. Two pairs of images were selected from each of the four morphed faces: An "easy" to discriminate pair consisting of one image from point 8 (73.3% Face 1, 26.6% Face 2), and one from point 22 (26.6% Face 1, 73.3% Face 2) and a "hard" to discriminate pair consisting of one image from continuum point 13 (56.6% Face 1, 43.3% Face 2), and one from point 17 (43.3% Face 1, 56.6% Face 2). Thus there were four different pairs of faces used in the experiment that could each be presented at two levels of similarity: two pairs of easy to discriminate faces (A and A*, B and B*) and two pairs of hard to discriminate faces (C and C', D and D'). The on-screen dimensions of the pictures were 10.2 cm × 9.9 cm (h × w).

Exposure and test procedure

Participants were seated approximately 70cm directly in front of the computer screen. Prior to the initial, exposure, stage of the study the following instructions were displayed on the screen:

> *In the following presentation, you will see several sets of 'look-alikes'. You will see each separate look-alike more than once. When prompted, please indicate using the numeric keypad how many times you think you have seen each particular person.*

Each face was displayed in the centre of the screen for two seconds, then replaced with an even grey background, after which participants were asked to input a number corresponding to how many times they had seen the face. Entering this response triggered the next trial. The inter-trial interval was thus self-paced and was normally in the region of 1-2 s. This process continued until all faces had been seen five times. The following instructions were then shown prior to the discrimination learning stage of the study:

> *You will now see a second series of look-alikes. You will have seen most of them before. One of each pair is left-handed, the other is right-handed. Your task is to select which is which. Use the key marked L to choose Left-handed people, the*

key marked R to choose Right-handed people. The computer will inform you if you are correct.

Each face was presented on screen for a maximum of 10 s, during which time participants were required to press a key indicating their response (left or right-handed), the response triggered removal of the face which was replaced by written feedback relating the accuracy of their selection (Correct or Incorrect). The feedback remained on the screen for 2 s before the presentation of the next trial. Responses under 300 ms were to be recorded but flagged as anticipation errors and not advance the presentation; there were no such responses in this or subsequent experiments. If no response was given within 10 s the stimuli was removed and the participant prompted to respond. Both the response and its latency were recorded. After every 16 trials the participant was given the opportunity to rest before pressing a key to continue to the next set of trials.

Design and counterbalancing

During the exposure stage participants were exposed to one pair of easy to discriminate pictures (A/A*) and one pair of hard to discriminate pictures (C/C'). Both pictures from one pair were presented before the presentation of the pictures from the other pair. Presentation was counterbalanced so that for half of the participants the first pair consisted of hard to discriminate pictures and the second pair consisted of easy to discriminate pictures; the remainder of the participants received to opposite pattern of exposure. Stimuli were presented one at a time and both of the faces from each pair were presented five times each with the order of presentation randomised.

Stimuli from all four pairs of faces were presented during the discrimination stage of the experiment. There were four conditions: Easy Exposed (A/A*), Easy Control (B/B*), Hard Exposed (C/C'), and Hard Control (D/D'). The assignment of faces to these four conditions was counterbalanced so that each pair of morphed faces was used equally often in each condition. Furthermore for half of the participants the easy to discriminate faces were male and the hard to discriminate faces were female; for the remaining participants the opposite was the case. One face from each pair was randomly assigned to be left-handed and the other face from each pair right handed and participants were required to learn these assignments. Participants received four blocks of trials with each of the four pairs of faces, and saw a total of four faces in each block. Each block consisted of exposure to faces from a single experimental condition, and there was one block from each of the conditions (Easy Exposed, Easy Control, Hard Exposed, and Hard Control) in each set of four blocks. The order in which the blocks were presented was randomised within each set. Four faces were presented within each block such that each face in a given pair was presented twice, with the order of presentation randomised.

Data analysis

During the exposure stage the computer software recorded participants' estimates of the number of times that they had seen each face. These estimates were inspected to reveal any aberrant patterns of responding (e.g., higher responses than the total number of stimuli presented during exposure or repeated entry of the same number) that might indicate that a participant had not been attending to the experiment or following instructions. No such patterns were observed in this experiment or the subsequent experiments of this thesis. The first response in the first block of discrimination learning for each condition had to be a guess, as participants had yet to receive feedback on any of their choices, so the accuracy of responding on this block was not directly comparable to that in the following three blocks. Thus the primary measure of performance in all of the experiments reported in this paper is the accuracy of responding (examined as the percentage correct) averaged over blocks 2-4. In order to assess any effects of the speed of responding (e.g., speed accuracy trade-offs) reaction times during these test blocks were also examined in each experiment.

Table 4.

Mean reaction times in seconds (with SEM) during discrimination training for each condition in Experiment 3.

Experiment 3	Reaction time (s)	SEM
Easy Exposed	1.770	0.086
Easy Control	1.854	0.085
Hard Exposed	1.869	0.073
Hard Control	1.742	0.078

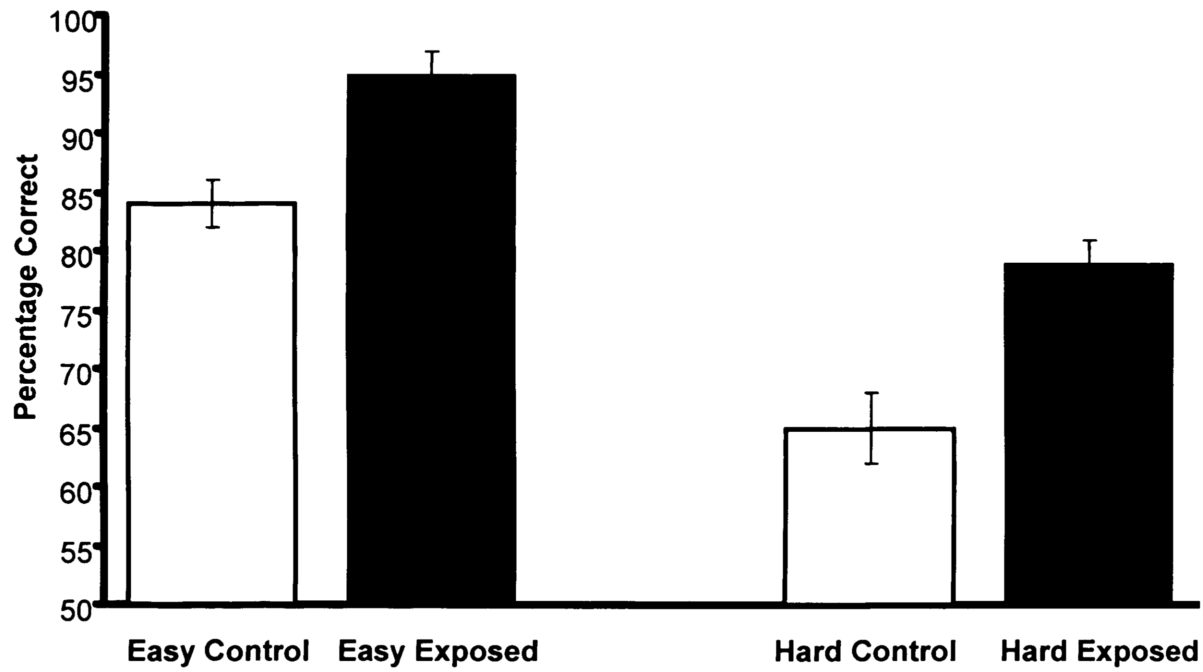


Figure 4: Mean discrimination performance (with SEM) as percentages correct in the four conditions in Experiment 3. Easy and Hard refer to the difficulty of the discrimination. Exposed and Control refer whether or not that stimuli were presented prior to the discrimination test.

Results

Figure 4 shows the discrimination scores in conditions for Experiment 3, with the two conditions involving easy-to-discriminate pictures of faces on the left (Easy Control and Easy Exposed) and the two conditions involving hard to discriminate faces on the right (Hard Control and Hard Exposed). Inspection of this figure indicates that discrimination accuracy was superior in the easy than the hard conditions, and that performance was more accurate in the exposed than the control conditions. ANOVA revealed significant effects of discrimination Difficulty (Easy versus Hard; $F(1,31)=215.00$) and Exposure (Control versus Exposed; $F(1,31)=68.00$), but no interaction between the two factors ($F(1,31)=1.44, p=0.240$). Table 4 shows the reaction time data from Experiment 3 and ANOVA revealed no significant effects of Difficulty or Exposure (Fs<1) and no interaction between these factors ($F(1,31)=2.61, p=0.116$). The absence of significant differences in reaction times across the conditions makes it unlikely that the speed with which participants responded contributed to the differences in discrimination performance between the conditions. The results of Experiment 3 thereby show that limited exposure to our morph-created pictures of faces produces a perceptual learning effect that is stimulus specific. One feature of the procedure used in Experiment 3 was that the exposed stimuli were presented in a random fashion (effectively intermixing the stimuli e.g., A, A', A, A'). Experiment 4 examined whether or not this aspect of the procedure was critical in generating a perceptual learning effect, as many theories of perceptual learning would predict to be the case. If the results of this experiment are simply a factor of stimulus familiarity then the schedule of their exposure should be of no consequence.

3.3 *Experiment 4*

The design of Experiment 4 is outlined in Table 5. There were four exposure conditions, each of which involved difficult to discriminate faces. One pair of faces were exposed in an intermixed fashion (i.e., A, A', A, A', A, A' ...) and a second pair were exposed in a blocked fashion (i.e., B, B, B ..., B', B', B' ...). Participants were also exposed to a face stimulus (C^m) that fell in the middle of a third difficult to distinguish pair of stimuli (C and C'). The participants were then required to learn a discrimination between A and A', B and B', C and C' and between a pair of novel stimuli, D and D'. Comparison of acquisition of the discrimination involving A and A' with that involving D and D' should allow the perceptual learning effect observed in Experiment 3 to be replicated; while comparison of acquisition of the discrimination involving A and A' with that involving B and B' allows an examination of the suggestion that this perceptual learning effect is some simple product of stimulus familiarity (e.g., Gaffan, 1996; Honey, 1990; Hall, 1991). If the perceptual learning effect demonstrated in Experiment 3 is based upon the operation of some process that simply reflects stimulus familiarity, then there is no basis upon which to predict a difference between the rates at which the discriminations are acquired in the intermixed and blocked conditions; for both conditions the critical stimuli have been presented on an equal number of occasions. The ability of participants to acquire the discrimination involving C and C' after exposure to C^m is of interest because according to some accounts of perceptual learning exposure to the common features of two stimuli (which can be allied to exposure to C^m) should reduce attention to these features and bias attention toward and hence learning about their novel, unique features during discrimination training (for example, McLaren et al., 1989).

Table 5

Design of Experiment 4.

Condition	Exposure	Discrimination
Intermixed	A, A', A, A', A, A', A, A', A, A'	A = LH and A' = RH
Blocked	B, B, B, B, B, B', B', B', B', B'	B = LH and B' = RH
Midpoint	C^m, C^m, C^m, C^m, C^m	C = LH and C' = RH
Control	No exposure to D or D'	D = LH and D' = RH

Note: A to D' represent different faces and C^m refers to the midpoint on the morph between faces C and C'. LH and RH refer to left handed and right handed, respectively.

Method

Participants, Stimuli, and Apparatus. Twenty five undergraduate students, 16 female and 9 male (aged 18-21), recruited from the School of Psychology at Cardiff University, were given course credit for taking part. None of the participants had taken part in Experiment 3. The four pairs of pictures used were taken from continuum points 13 (56.6% X, 43.3% Y) and 17 (43.3% X, 56.6% Y) from the four morphs used in Experiment 3; these pairs correspond to the hard discrimination. In addition, continuum point 15 (50% X, 50% Y) was selected for use as the midpoint. The apparatus used was identical to that used in Experiment 3.

Procedure. The general procedure and instructions to participants were identical to those described for Experiment 3. There were four exposure conditions in the current experiment: Intermixed, Blocked, Midpoint, and Control. During the exposure stage participants were exposed to one pair of pictures (A and A') in an intermixed fashion. A second pair of pictures (B and B') was presented in a blocked fashion with all presentations of one face in the pair preceded those of the second face in that pair. Participants were also exposed to the midpoint (C^m) on the morph between a third pair of faces (C and C'). The order in which these three exposure conditions were presented was randomised across participants. The fourth pair of pictures (D and D') were only presented during the second stage of the experiment. There were a total of 10 stimuli presented in the Intermixed and Blocked exposure conditions (five of each faces stimulus in the pair) and five presentations of C^m. Each of the four pairs of faces was used equally often in each of the four exposure conditions across participants. Faces from all four exposure conditions were presented during the discrimination learning stage of the experiment. As in Experiment 3, one face from each pair was randomly assigned to be left handed and the other face from each pair assigned to be right handed and participants were required to learn these assignments. Other details of Experiment 4 that have not been mentioned were identical to Experiment 3.

Results

Figure 5 shows the mean discrimination accuracy for the four conditions in Experiment 4. Inspection of Figure 5 indicates that discrimination accuracy was generally superior in each of the exposed conditions (Intermixed, Blocked, and Midpoint) than it was in the non-exposed Control condition, and that performance was especially good in the Intermixed condition. ANOVA confirmed that there was an effect of exposure Condition ($F(3,72)=9.77$). Pairwise comparisons, made using Fisher's least significant difference test, revealed that performance in each of the exposed conditions was better than in Control condition (minimum $F(1,24)=5.53$) and that performance in the Intermixed condition was more proficient than in the Blocked and Midpoint conditions ($F(1,24)=6.82$ and $F(1,24)=11.08$ respectively) that did not differ from one another ($F<1$). Table 6 shows the reaction time data from Experiment 4 and, as in Experiment 3, ANOVA revealed no significant effect of Condition ($F(3,72)=1.05$, $p=0.376$).

Table 6.

Mean reaction times in seconds (with SEM) during discrimination training for each condition in Experiment 4.

Experiment 4	Reaction time (s)	SEM
Intermixed	1.851	0.131
Blocked	1.884	0.164
Midpoint	1.962	0.137
Control	1.763	0.121

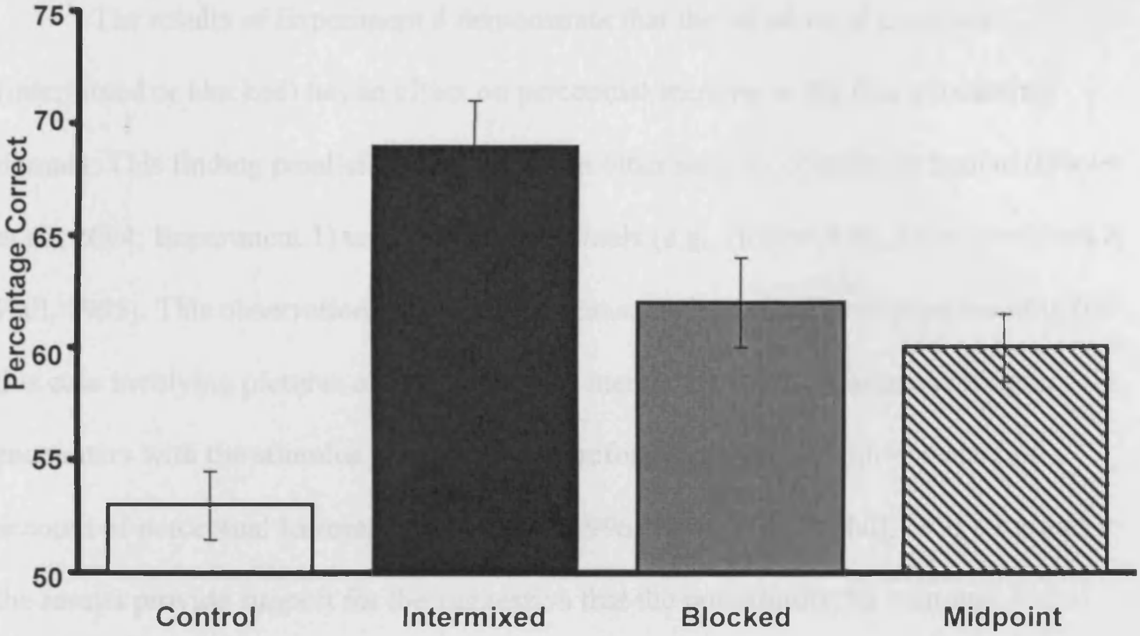


Figure 5: Mean discrimination performance (with SEM) as percentages correct in the four conditions in Experiment 4. Stimuli in the Control condition received no exposure prior to the discrimination test. Stimuli in the Intermixed and Blocked conditions were presented the same number of times prior to test, but under different schedules (see text for details). In the Midpoint condition a picture midway on the morph between the test stimuli was presented before test.

The results of Experiment 4 demonstrate that the schedule of exposure (intermixed or blocked) has an effect on perceptual learning in the face-processing domain. This finding parallels that observed in other sensory domains in human (Dwyer et al., 2004; Experiment 1) and nonhuman animals (e.g., Honey et al., 1994; Symonds & Hall, 1995). This observation is important because it shows that perceptual learning (in this case involving pictures of faces) does not merely reflect the number or length of the encounters with the stimulus *per se* and is therefore inconsistent with one class of account of perceptual learning (e.g., Gaffan, 1996; Honey, 1990; Hall, 1991). Instead the results provide support for the suggestion that the opportunity for stimulus comparison might, in some way, result in enduring changes in the discriminability of stimuli (Gibson, 1969); given the plausible assumption that the opportunity for some form of comparison would be greater in the Intermixed than the Blocked conditions. It should be acknowledged, however, that the fact that the Blocked and Midpoint conditions produce superior discrimination performance than the Control condition indicates that changes in stimulus discriminability can occur with little (Blocked) or no opportunity (Midpoint) for stimulus comparison. Detailed consideration of this pattern of results will be postponed until the General Discussion of this Thesis. In Experiment 5, I examined the effect of mode of presentation (simultaneous versus successive) on changes in stimulus discriminability.

3.4 *Experiment 5*

Table 7 shows the design of Experiment 5. Participants were exposed to the four pairs of pictures of faces used in Experiment 4. The members of two pairs were presented simultaneously, side by side on the screen (i.e., A-A' and B-B'). The members of each of the remaining two pairs of faces were presented successively, but still as part of arrays that involved two faces. Thus the presentation of one face from one pair was consistently accompanied by one of the faces from the other pair (i.e., C-D' and C'-D). Participants were subsequently required to learn to assign an arbitrary feature to one member of each of the four pairs of faces in order to assess the effects of these exposure conditions on the discriminability of the faces. The discriminability of one pair of faces from each of the simultaneous and successive exposure conditions was assessed using a successive discrimination of the same form as that employed in Experiments 3 and 4. The assay of the discriminability used for the remaining pairs of faces was a simultaneous discrimination where members of each pair were presented side by side. There were thus four conditions: Simultaneous exposure-Simultaneous test (Sim-Sim), Simultaneous exposure-Successive test (Sim-Suc), Successive exposure-Simultaneous test (Suc-Sim), and Successive exposure-Successive test (Suc-Suc). In both discriminations, the arbitrary feature that the participants assigned was marital status, rather than handedness, in order to avoid any interactions between the side of the screen on which the stimulus was presented (in the simultaneous test) and the assignment made. If the mode of stimulus exposure has an enduring effect on stimulus discriminability, then this should be evident irrespective of the way in which the test is conducted. For example, if simultaneous unsupervised exposure results in a greater increase in stimulus discriminability than successive exposure (cf. Gibson, 1969), then this should be evident irrespective of whether the test procedure involves a simultaneous discrimination (the Sim-Sim versus Suc-Sim comparison) or a successive discrimination (the Sim-Suc versus Suc-Suc comparison; cf. Brown & Rebbin, 1970; Saldanha & Bitterman, 1951).

Table 7

Design of Experiment 5.

Condition	Exposure	Discrimination
Sim–Sim	A-A’ together and B-B’ together	A-A’ together: A=Married and A’=Unmarried
Sim–Suc		B and B’ separately: B=Married and B=Unmarried
Suc–Sim	C-D together and C’-D’ together	C-C’ together: C=Married and C’=Unmarried
Suc–Suc		D and D’ separately: D=Married and D’=Unmarried

Note: The first part of each condition label refers to the exposure condition and the second part to the discrimination assay: Sim = Simultaneous and Suc = Successive; A to D’ represent different faces.

Method

Participants, Stimuli, and Apparatus

Thirty-two students, 22 female and 10 male (aged 18-24) recruited from Cardiff University participated in the study. Ten of these were undergraduate students from the School of Psychology who took part in return for course credit, 10 were postgraduate students from the School of Psychology who did not receive any inducement to participate, and 12 were students from outside the School of Psychology who were paid for their participation. None of the participants had taken part in Experiments 3 or 4. The four pairs of faces use in this experiment were those described in Experiment 4. Each picture was constructed in the same way as Experiment 3 and the on-screen dimensions of each was 10.2 cm × 9.9 cm; for the simultaneous picture presentations the on-screen dimension of the arrays was 10.2 cm × 19.8 cm (h × w). The apparatus used was identical to that of Experiment 3 with the exception of the labelling of response keys. For use in the successive discriminations, the 'Q' key was covered with a coloured sticker with the letter M and was used by the participants to indicate that the pictured person was married and the 'P' key was covered with a coloured sticker with the letter U and was used to indicate that the pictured person was unmarried. For use in the simultaneous discriminations, the 'A' key was covered with a coloured sticker with the letter L and was used to indicate that the married person was on the left side of the array and the 'L' key was covered with a coloured sticker with the letter R and was used to indicate that the married person was on the right.

Exposure and test procedure

The general procedure and instructions to participants were similar to those described for Experiments 3 and 4. The instructions were changed to reflect the nature of the stimulus presentation and test procedures. Before the exposure stage the following instructions were displayed on the screen:

> *In the following presentation, you will see several pairs of faces, your task is to count how many times you think you have seen each pair. Please enter a number into the pop-up box that follows each trial.*

Each pair of pictures was displayed in the centre of the screen for two seconds, then masked with an even grey background, after which participants were asked to input a number corresponding to how many times they had seen that pair of pictures. Entering this response triggered the next trial. This process continued until all pairs of pictures had been seen five times. The following instructions were then shown prior to the discrimination learning stage of the study:

> *You will now see a series of look-alikes. You will have seen some of them before. One of each pair is married, the other is unmarried. Your task is to select which is which. When a pair of look-alikes are presented together, as in the first sequence, you must select the person who is married by pressing 'LEFT' if you think it is the left person or 'RIGHT' for the person on the right. When the look-alikes are presented one at a time, use the 'MARRIED' key to select married people, or the 'UN-MARRIED' key to choose un-married people. The computer will inform you if you are correct.*

There were four trials in each block, after every fourth block the participant was given the opportunity to rest before pressing a key to continue to the next set of trials. For the simultaneous discriminations a pair of similar stimuli (e.g., A and A') were presented side by side for a maximum of 10 s and participants were required to press a key to indicate whether the person depicted on the left or right was married. The response triggered removal of the pictures that were replaced by written feedback (Correct or Incorrect). The feedback remained on the screen for 2 s before the presentation of the next trial. If no response was given within 10 s, then the stimulus array was replaced with an even grey mask and the participant prompted to respond. Both the response and its latency were recorded. The successive discrimination proceeded in the general manner described in Experiments 3 and 4.

Design and counterbalancing

Four pairs of similar faces were presented during the exposure stage of the experiment. Members of two pairs of faces were exposed in a simultaneous fashion, with both faces from a given pair presented side by side on the screen: A was presented alongside A' and B was presented alongside B'. The other two pairs were exposed in a successive fashion, with a face from one pair was presented alongside a face from the other pair: C was presented alongside D' and C' was presented alongside D. There were thus four arrays presented to each participant (A-A', B-B', C-D', and C'-D) with each being presented five times and the side of the screen upon which each face appeared randomised. Within each block of four exposures each array was presented once and the order in which the arrays were presented within a block was randomised. There was no break between the blocks, so participants received 20 exposure trials presented in a continuous sequence.

All four pairs of faces were presented during the discrimination stage of the experiment. One pair of faces from each of the simultaneous and successive exposure conditions was assigned to each of the two types of test discrimination (simultaneous or successive). This produced four different experimental conditions simultaneous exposure and simultaneous test (Sim–Sim), simultaneous exposure and successive test (Sim–Suc), successive exposure and simultaneous test (Suc–Sim), and successive exposure and successive test (Suc–Suc). Each pair of faces was used equally often in each condition. In both types of discrimination, one face from each pair was randomly assigned to be married and the other face from each pair unmarried and participants were required to learn these assignments. During simultaneous discrimination trials both faces from a pair were presented alongside each other (e.g., A was presented with A') and participants required to indicate whether the left or right face was married by pressing the keys marked L (left face married) and R (right face married). Faces were randomly placed on each side of the screen with the restriction that each face in a given pair was presented equally often on the right and left sides of the screen. The successive discrimination procedure, involving the other two pairs of faces, was conducted in the same manner as in Experiments 3 and 4, with the exception that the participants were required to learn whether or not the person depicted in the current picture was married or unmarried by pressing the M and U keys, respectively.

During the discrimination learning stage of the experiment participants received 16 blocks of trials separated into four sets of four blocks each. Participants were allowed to rest between each set of four blocks. In each block participants received training trials involving arrays from a single experimental condition (i.e., Sim-Sim, Sim-Suc, Suc-Sim, and Suc-Suc) and there were four trials in each block. Within each set of four blocks, the four conditions were presented in a random order. As in Experiments 3 and 4, the primary measure of performance was accuracy of responding (examined as a percentage) averaged over blocks 2-4 and the latencies to respond were also recorded.

Results

Figure 6 shows the discrimination scores for the four conditions in Experiment 5. Inspection of this figure indicates that the discriminations involving pairs of faces that were exposed in a simultaneous fashion (left-hand pair of bars) were acquired more readily than those involving pairs of faces that were exposed successively (right-hand pair of bars) and that this effect was evident irrespective of the nature of the discrimination assay (simultaneous or successive). There is also an indication that when there is a change in the conditions (simultaneous or successive presentation) between exposure and discrimination (as there was for conditions Sim-Suc and Suc-Sim, but not for Sim-Sim and Suc-Suc) performance is superior. ANOVA revealed a significant effect of Exposure condition (simultaneous or successive; $F(1,31)=65.33$), no significant effect of Test (simultaneous or successive; $F(1,31)=1.07, p=0.309$), and a significant interaction between the two factors ($F(1,31)=34.22$). An analysis of simple main effects revealed that discrimination accuracy was superior after simultaneous exposure than after successive exposure both when a simultaneous discrimination was used as an assay of perceptual learning ($F(1,31)=37.92$) and when a successive discrimination was used ($F(1,31)=70.48$). The analysis also revealed that after simultaneous exposure performance was superior on the successive than the simultaneous discrimination ($F(1,31)=12.13$) and that after successive exposure performance was superior on the simultaneous than the successive discrimination ($F(1,31)=10.96$). The latter finding suggests that, in addition to the fact that simultaneous exposure is a more effective procedure for generating perceptual learning than successive exposure, a change in conditions between exposure and discrimination training has a (stimulus-specific) facilitatory effect on discrimination learning. One obvious basis for the latter effect can be derived from the observation that latent inhibition (another consequence of stimulus exposure) is disrupted by a change in conditions between exposure and test (see, for a discussion of the effects of context change on latent inhibition and perceptual learning, Trobalon, Chamizo & Mackintosh, 1992; see also, Channell & Hall, 1981). In any case, Table 8 shows the reaction time data from Experiment 5 and ANOVA revealed no significant effects of Exposure ($F<1$) or Test ($F(1,31)=1.92, p=0.176$) and no interaction between the two factors ($F<1$).

Table 8.

Mean reaction times in seconds (with SEM) during discrimination training for each condition in Experiment 5.

	Reaction time (s)	SEM
Experiment 5		
Sim–Sim	2.290	0.120
Sim–Suc	2.227	0.164
Suc–Sim	2.374	0.156
Suc–Suc	2.272	0.178

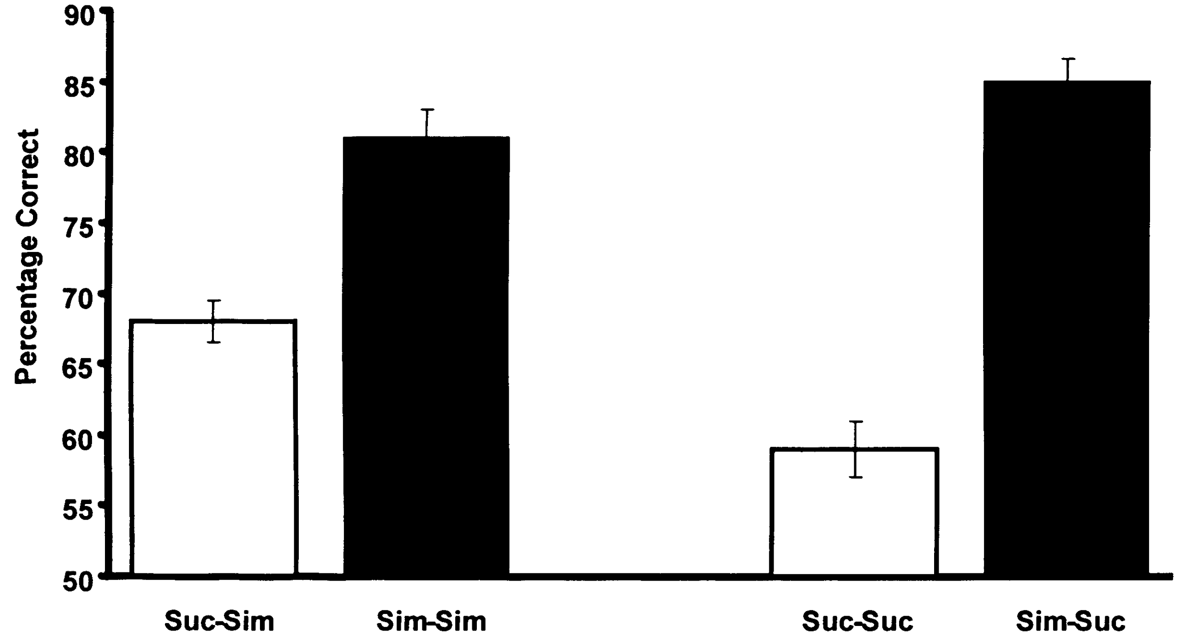


Figure 6: Mean discrimination performance (with SEM) as percentages correct in the four conditions in Experiment 5. The first part of each condition label refers to the mode of exposure and the second nature of the discrimination test: Sim = Simultaneous and Suc = Successive.

The fact that discrimination learning proceeded more readily after simultaneous than successive exposure accords with Gibson's (1969) speculations regarding the conditions that should be especially effective in producing perceptual learning. Likewise, one might also anticipate that simultaneous discrimination should be acquired more readily than the successive discrimination (cf. MacCaslin, 1954; Saldanha & Bitterman, 1951; Wills & Mackintosh, 1999), but there was no evidence that this was the case in Experiment 5. However, Experiment 5 was not run in a way that allowed a meaningful comparison to be made between performance on the two types of test discrimination because the response requirements were quite different for the simultaneous and successive discriminations. Therefore, no theoretical implications can be drawn from the fact that there was no overall difference between simultaneous and successive presentation of stimuli during the discrimination learning stage in Experiment 5.

3.5 *Experiment 6*

While the results of Experiment 5 are consistent with the idea that simultaneous exposure is particularly effective in producing perceptual learning the stimulus arrays in the successive conditions consisted of two very different faces. It is possible that this could cause participants to pay little attention to these arrays as the difference between the stimuli was obvious. In contrast, the similarity of the two faces in the simultaneous arrays may have caused participants to pay particular attention the two faces in an attempt to discern a difference between them. Given that participants are not informed as to whether a pair of faces are, or are not, the same any tendency for the similarity of the two faces in a simultaneous array to increase the attention given to both of them would be at its greatest in the limiting case when the two were identical. Experiment 6 (the design of which is shown in Table 9) thus re-examined the difference between simultaneous and successive exposure using arrays of two identical faces in the successive conditions. Participants were exposed to the four pairs of pictures of faces used in Experiments 4 and 5. The members of two pairs were presented simultaneously, side by side on the screen (i.e., A-A' and B-B'). The members of each of the remaining two pairs of faces were presented successively, but still as part of arrays that involved two faces. Two copies of the same face from each pair were presented in alternation with two copies of the other face from that pair (i.e., C-C, C'-C', D-D, D'-D'). One pair from each condition was exposed so that each array was seen five times (e.g., A-A' × 5 and C-C × 5/C'-C' × 5), and one pair from each condition was presented so that each array was seen ten times (e.g., B-B' × 10 and D-D × 10/D'-D' × 10). It should be noted that because each successive array had two copies of the same face while the simultaneous arrays had one copy of two different faces that there was twice as much exposure to each individual face in the successive conditions. Participants were subsequently required to learn to assign an arbitrary feature to one member of each of the four pairs of faces in order to assess the effects of these exposure conditions on the discriminability of the faces using a successive discrimination as in Experiment 5. If the results of Experiment 5 were produced by the difference between simultaneous and successive exposure then discrimination performance should be better after simultaneous presentation independently of the amount of exposure.

Table 9

Design of Experiment 6.

Condition	Exposure	Discrimination
Sim 5	A-A’ together × 5	A=Married and A’=Unmarried
Sim 10	B-B’ together × 10	B=Married and B=Unmarried
Suc 5	C-C and C’-C’ together × 5	C=Married and C’=Unmarried
Suc 10	D-D and D’-D’ together × 10	D=Married and D’=Unmarried

Note: The first part of each condition label refers to the exposure condition and the second part to the number of exposures to the array during initial exposure: Sim = Simultaneous and Suc = Successive; A to D’ represent different faces.

Method

Participant, Stimuli and Apparatus

Thirty-two students, 25 female and 7 male (aged 18-22), recruited from the School of Psychology at Cardiff University, were given course credit for taking part. No participants had taken part in the previous experiments. The four pairs of faces described in the previous experiments were used as stimuli in the current study and the size of the arrays was as in Experiment 5. The discrimination phase was identical to that used in the 'successive' discrimination described in Experiment 5. The apparatus used was identical to that of the previous experiments.

Exposure and test procedure

The general procedure and instructions in the exposure phase of Experiment 6 were the same as in Experiment 5. The following instructions were then shown prior to the discrimination learning stage of the study:

> *You will now see a second series of look-alikes. You have seen them all before. One of each pair is married, the other is unmarried. Your task is to select which is which. The look-alikes will be presented one at a time. Use the key marked 'M' to choose married people, and the key marked 'U' to choose unmarried people, the computer will inform you if you are correct.*

There were four trials in each block, after every fourth block the participant was given the opportunity to rest before pressing a key to continue to the next set of trials.

Design and counterbalancing

Four pairs of similar faces were presented during the exposure stage of the experiment. Members of two pairs of faces were exposed in a simultaneous fashion, with both faces from a given pair presented side-by-side on the screen. The other two pairs were exposed in a successive fashion, so that two copies of one face were presented side-by-side, followed by two copies of the partner face presented side-by-side. Thus there were six arrays presented to each participant (A-A', B-B', C-C, C'-C', D-D, D'-D'). For the simultaneous faces, the side of the screen upon which each face appeared was alternated (e.g., A-A', A'-A). The paired-successive faces were presented so that the face-copy arrays were in alternation (e.g., C-C, C'-C', C-C, C'-C'). One pair from each condition was exposed so that each face/array was seen five times (e.g., A-A' × 5 and C-C × 5/C'-C' × 5), and one pair from each condition was presented so that each face/array was seen ten times (e.g., B-B' × 10 and D-D × 10/D'-D' × 10). This produced four experimental conditions: five simultaneous exposures (Sim 5), ten simultaneous exposures (Sim 10), five paired-successive exposures (Suc 5) and ten paired-successive exposures (Suc 10). Each of the four pairs of faces was used equally often in each of the four exposure conditions across participants. The order in which each condition block was presented during exposure was randomised between participants, as was the identity of the starting array within each block. There was no break between the blocks, so participants received 45 exposure trials presented in a continuous sequence. All four pairs of faces were presented during the discrimination stage of the experiment, which was conducted in an identical manner to the 'successive' discrimination procedure used in Experiment 5.

Results

Figure 7 shows the discrimination scores for the four conditions in Experiment 6. Inspection of this figure indicates that the discriminations involving pairs of faces that were exposed in a simultaneous fashion (left-hand pair of bars) were acquired more readily than those involving pairs of faces that were exposed successively (right-hand pair of bars) and that this effect was evident irrespective of the number of pre-training exposures. There is also an indication that the increasing the number of exposures aided discrimination in the successive, but not the simultaneous conditions. ANOVA revealed a significant effect of exposure condition (simultaneous or successive; $F(1,31)=14.81$), an effect of exposure length ($F(1,31)=4.36$), and a significant interaction between the two factors ($F(1,31)=4.64$). An analysis of simple main effects revealed that discrimination accuracy was superior after simultaneous exposure than after successive exposure both after 5 ($F(1,31)=24.11$) and 10 exposures to each array ($F(1,31)=4.47$). However the analysis also revealed that while there was an effect of exposure length in the successive conditions ($F(1,31)=8.02$) this was not significant in the simultaneous exposure conditions ($F<1$). Table 10 shows the reaction time data from Experiment 6 and ANOVA revealed no significant effects of exposure ($F(1,31)=1.67, p=0.206$) or length ($F<1$) and no interaction between the two factors ($F(1,31)=2.31, p=0.139$).

Table 10.

Mean reaction times in seconds (with SEM) during discrimination training for each condition in Experiment 6.

	Reaction time (s)	SEM
Experiment 6		
Sim 5	1.931	0.140
Sim 10	1.783	0.103
Suc 5	1.896	0.119
Suc 10	1.976	0.111

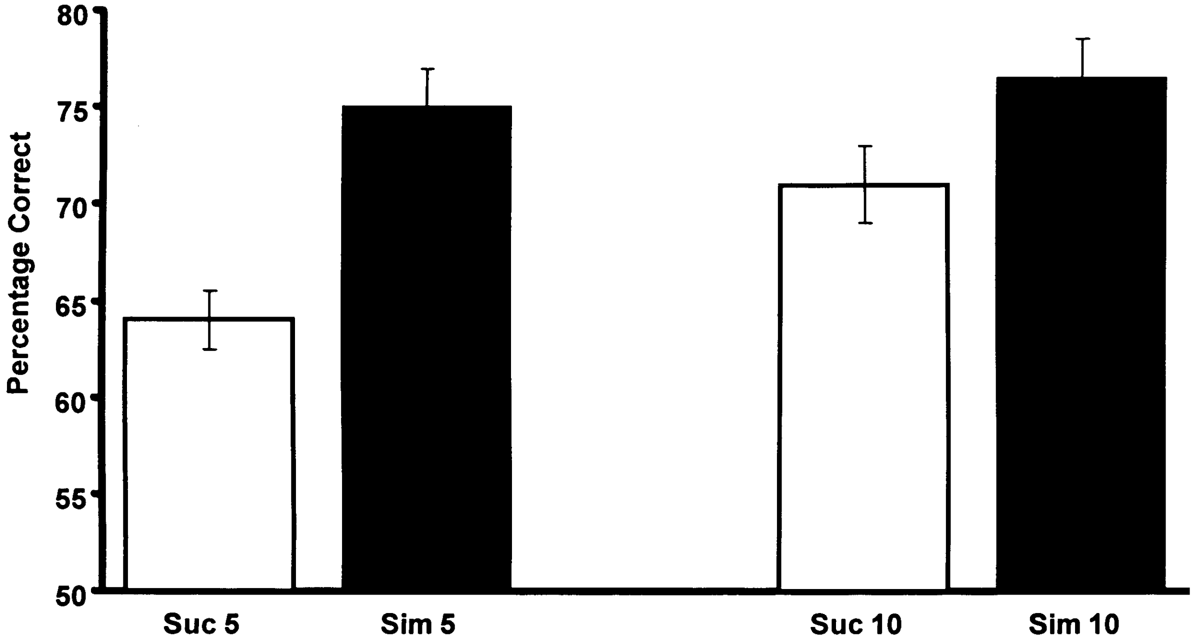


Figure 7: Mean discrimination performance (with SEM) as percentages correct in the four conditions in Experiment 6. The first part of each condition label refers to the mode of exposure: Sim = Simultaneous and Suc = Successive. The second part of each label refers to number of times each array was presented prior to the discrimination test.

Experiment 6 replicates the advantage of simultaneous exposure to the to-be-discriminated stimuli seen in Experiment 5 and confirms that this advantage was not due to the fact that the stimulus arrays in the successive conditions consisted of two very different faces. This result is especially interesting given that, in the absence of feedback to distinguish them, simultaneous pairing of two stimuli might be expected to create an association between them which would increase the tendency for anything learnt about one to generalise to the other.

Spaced training has been shown to be superior to massed training in a variety of contexts (e.g., Schmidt & Bjork, 1992). If the same is true of unsupervised exposure then it may be supposed that massing the exposure in the blocked condition could have reduced the effectiveness of that exposure. In effect this could mean that the total exposure to the stimuli was lower in the blocked than the intermixed condition in Experiment 4. However the simultaneous condition produced the same massed exposure as the blocked condition but it produced better discrimination than in the successive or alternating condition which rules out such a general effect of trial spacing as an explanation of the current experiments. That said, this result does not rule out an explanation in terms of the relative frequency of exposure to the unique and common elements of the to-be-discriminated stimuli. This idea will be taken up in the General Discussion of this Thesis.

3.6 *Experiment 7*

Experiments 5 and 6 demonstrate that simultaneous exposure to two similar stimuli results in a more marked perceptual learning effect than does intermixed exposure. This result is inconsistent with some associative accounts of perceptual learning (e.g., Hall, 2003; McLaren et al., 1989). In fact, the result is altogether paradoxical from an associative perspective: Why does simultaneous exposure not create an excitatory association between the components of the array (e.g., A and A′) that impedes the participants' later ability to learn a discrimination between those components? The obvious answer to this question is that such an association might well form, but the consequences of the association are outweighed by the fact that simultaneous exposure also results in the operation of some other (perceptual learning) process that increases the discriminability of A and A′. One implication of this suggestion is that one should be able to reveal evidence of the formation of an association between the components of a simultaneous array if the perceptual learning process that operated during this mode of presentation was rendered less consequential. One way to do so is to arrange that the components of the simultaneous arrays are intrinsically discriminable (in the current case by consisting of entirely different faces) – thereby restricting the possibility for simultaneous exposure to increase their discriminability.

The design of Experiment 7, that made use of this strategy, is shown in Table 11. Participants received exposure to two sets of arrays and the arrays in each set consisted of faces from two morphs (e.g., A-B, A′-B′ / C-D, C′-D′). These arrays were alternated during exposure. On the basis of the results of Experiments 3 and 4, one might anticipate that the similar components of the successively presented arrays (A and A′, B and B′, C and C′, D and D′) might become more discriminable from one another. More importantly here the individual components of each array (e.g., A and B) should become associated with each other. Participants then received a successive discrimination in which they were required to assign an arbitrary feature to one member of each of the four pairs of faces. For the faces from one set of arrays (A-B, A′-B′), participants were required to associate the same feature with each of the faces that had been presented together in the exposed arrays (Same condition: A=married, B=married, A′=unmarried, B′=unmarried), whereas for the other set of arrays (C-D, C′-D′) participants were required to associate different features with the faces previously presented together (Different condition: C=married, D=unmarried, C′=unmarried, D′=married). If exposure to the arrays results in the formation of an association between their components, then learning should be more rapid when the same feature has to be associated with both of the components of an array than when a different feature has to be associated with each of the components of an array: In the same condition, when participants associate A with the feature married, the A-B association will allow presentation of B to provoke the response married. However, by the same token, any transfer between the components of the other set of faces (e.g., between C and D) will result in responding that is inconsistent with what the participants are required to learn. Of course, the results of Experiments 5 and 6 suggest that simultaneous exposure (e.g., to A-B) should act to increase the discriminability of A and B which could potentially reduce the associative effect just outlined. However, as A and B are entirely different faces then their discriminability should already be maximal thus minimising any such effect.

Table 11

Design of Experiment 7.

Condition	Exposure	Discrimination
Congruent	A-B together and A’-B’ together	A = Married and A’ = Unmarried B = Married and B’ = Unmarried
Incongruent	C-D together and C’-D’ together	C = Married and C’ = Unmarried D = Unmarried and D’ = Married

Note: A to D’ represent different faces.

Method

Participant, Stimuli and Apparatus

Thirty-two students, 20 female and 12 male (aged 18-22), recruited from the School of Psychology at Cardiff University, were given course credit for taking part. No participants had taken part in the previous experiments. The four pairs of faces described in the previous experiments were used as stimuli in the current study and the size of the arrays was as in Experiments 5 and 6. The discrimination phase was identical to that used in the 'successive' discrimination described in Experiment 5. The apparatus used was identical to that of the previous experiments.

Exposure and test procedure

The general procedure and instructions in both the exposure phase and the discrimination phase of Experiment 7 were the same as in Experiment 6, with the exception that only eight blocks of testing were performed (i.e., two with each face pair). There were four trials in each block, after the fourth block the participant was given the opportunity to rest before pressing a key to continue to the next set of trials. Because responding could generalise between the faces that had previously been exposed together performance on all trials was analysed.

Design and Counterbalancing

Four pairs of similar faces were presented during the exposure stage of the experiment. The pairs were divided into two sets. Members of the first set were exposed so that one face from each pair was presented alongside one face from the other in two arrays (e.g., A-B, A'-B'). Members of the second set were presented in an identical manner (e.g., C-D, C'-D'). The side of the screen upon which each face appeared in the array was alternated. Within each set the two arrays were alternated (e.g., A-B, A'-B', A-B, A'-B'...) until each array had been seen five times. The identity of the starting set during exposure was randomised between participants, as was the identity of the starting array in each set block. Each of the four pairs of faces was used equally often in creating the exposed sets, and the combinations were randomised between participants. There was no break between the set blocks so participants received 20 exposure trials presented in a continuous sequence. The computer randomly chose one of the sets to be the 'Congruent' condition, and assigned the other to the 'Incongruent' condition. However, each pair of faces was used equally often in each condition. The discrimination phase was conducted in a similar manner to the 'successive' discrimination procedure in Experiment 5. However, pairs in the 'Congruent' condition were assigned responses that were consistent with presentation during the exposure stage, whilst pairs in the 'Incongruent' condition were assigned responses that were inconsistent with presentation during the exposure stage. Specifically, in the 'Congruent' condition faces that were presented together in an array were assigned the same arbitrary associate during discrimination (e.g., Expose: A-B and A'-B' in alternation; Discriminate: A – Married, A' – Unmarried, and B – Married, B' – Unmarried). In the 'Incongruent' condition, faces that were presented together in an array were assigned different arbitrary associates during discrimination (e.g., Expose: C-D and C'-D' in alternation; Discriminate: C – Married, C' – Unmarried, and D – Unmarried, D' – Married). Participants received two blocks of discrimination trials with each of the four face pairs, and saw a total of four faces in each block. All other methodological and counterbalancing details are identical to those of Experiment 5.

Results

The mean percentage correct across testing in the congruent and incongruent conditions were 59.7 (SEM 1.46) and 55.1 (SEM 1.85) respectively. Performance was significantly better in the congruent condition, $t(31)=2.25$. Mean reaction time in the Congruent condition was 3.225 s (SEM 0.187), and was 3.260 s (SEM 0.112) in the

Incongruent condition. There was no significant difference in reaction times, $t<1$. Experiment 7 demonstrates that an excitatory association is formed between the two dissimilar items presented simultaneously in the arrays used in the current task. This fact makes the results of Experiments 5 and 6 all the more surprising. Further consideration of this pattern of results will be presented in the discussion of this Chapter.

3.7 *Experiment 8(A and B)*

The novel effects of simultaneous exposure, demonstrated in Experiments 5 and 6, require critical consideration to be given to the notion that they might relate only to the mechanisms of processing human faces (see Section 1.8), and may not necessarily be applicable to perceptual learning more generally. In order to address this possibility, Experiment 8 makes use of non-face chequerboard stimuli to investigate whether this novel effect of simultaneous exposure is indeed general.

3.7.1 *Experiment 8A*

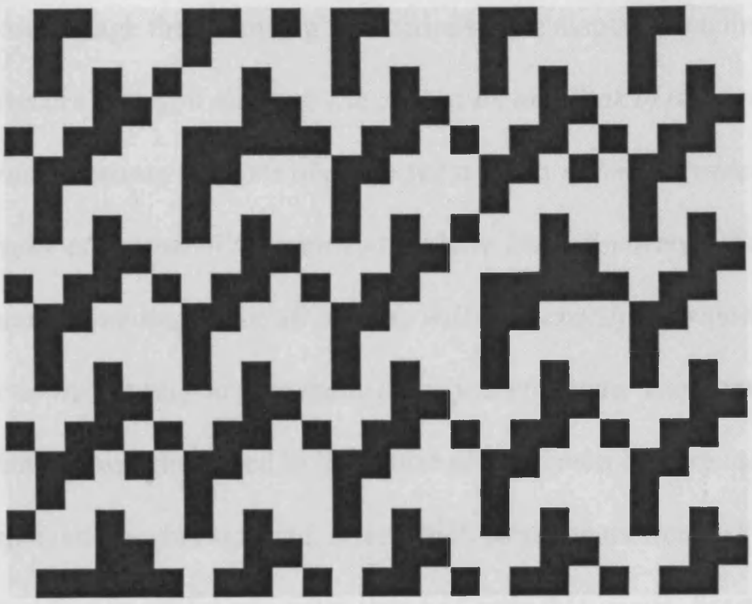
Method

Participants, Stimuli, and Apparatus

Eight participants, 6 female and 2 male (aged 23-27) were recruited from Cardiff University. All were postgraduate students or staff from the School of Psychology who did not receive any inducement to participate. The three pairs of stimuli used in this experiment were constructed in the following way: A computer program, written in Visual Basic © was used to generate a series of chequerboard images. Each image was made of squares 5x5 mm that were either white or black. The computer grouped these squares into three different and entirely random elemental patterns, coded as A, B and X. Each pattern consisted of 25 squares in a 5 x 5 square layout, with the limitation that at least 12 squares be black. In a further arrangement of these elemental patterns the computer generated two images, where the X pattern was present 22 times in a 5 x 5 layout of elements and either the A or B element was present in the three remaining positions. The location of the A and B elements within the array was randomly selected by the computer for each participant, but remained constant throughout exposure. This created a confusable pair of stimuli, AX and BX. Three such pairs were created for each participant. An example of the stimuli used can be found in Figure 8. The stimuli for this experiment had been piloted previously so as to guarantee their suitability for this task. The ratio of 22:3 common to unique (X:A/B) elements was ascertained by trialling a number of permutations. If the ratio was increased then the stimuli became too difficult to discriminate and if it was reduced then the discrimination became trivially easy.

The apparatus used was identical to that of Chapter 3 with the exception of the labelling of response keys. For use in the test phase discriminations, the ‘Q’ key was covered with a coloured sticker with the letter A and was used by the participants to indicate that the pictured stimulus was identified as ‘A’. The ‘P’ key was covered with a coloured sticker with the letter B and was used to indicate that the pictured stimulus was identified as ‘B’.

AX



BX

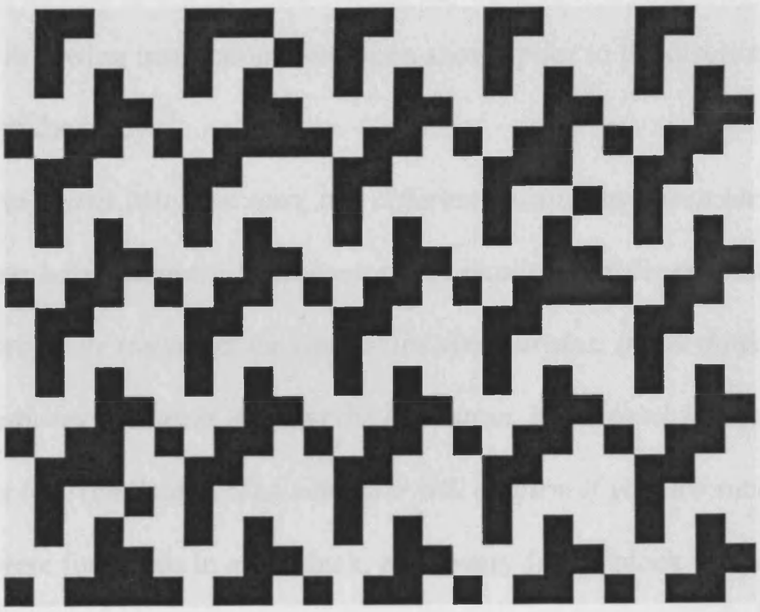


Figure 8: Examples of stimuli used in Experiment 8.

Exposure and test procedure

Before the exposure stage the following instructions were displayed on the screen:

> *'Scientists are trying to discover the cure to an outbreak of previously unrecorded diseases. You are about to see a series of images which show the RNA profile of several of the viruses that have been discovered. Each virus has more than one strain, so not all profiles will look exactly the same. Please indicate using the keypad how many times you encounter each image'.*

Each stimulus was displayed in the centre of the screen for three seconds, then replaced with an even grey background, after which participants were asked to input a number corresponding to how many times they had seen that image. Entering this response triggered the next trial. This process continued until all images had been seen ten times. The following instructions were then shown prior to the discrimination learning stage of the study:

> *'For every virus you have seen, two different strains have been identified. Scientists have discovered that each strain requires a different treatment. Select the appropriate treatment for each of the virus strains. If you think the presented virus requires treatment A, press the left button, if you think it requires treatment B, press the right button. The computer will confirm if you are successful'*

There were four trials in each block, after every fourth block the participant was given the opportunity to rest before pressing a key to continue to the next set of trials. During the test phase a single stimulus (e.g., AX) was presented on screen for a maximum of 10 s and participants were required to press a key to indicate whether the they thought it would require treatment 'A' or treatment 'B'. The response triggered removal of the stimulus which was replaced by written feedback (Correct or Incorrect). The feedback remained on the screen for 2 s before the presentation of the next trial. If no response was given within 10 s, then the stimulus array was replaced with an even grey mask and the participant prompted to respond. Both the response and its latency were recorded.

Design and counterbalancing

Two pairs of chequerboards were presented during the exposure stage of the experiment. Members of one of the pairs were exposed in an intermixed fashion, (AX, BX…). Another pair was exposed in a blocked fashion (CY, CY… DY, DY...). The exposure stage was arranged so that each image was seen ten times. There was no break between the blocks, so participants received 40 exposure trials presented in a continuous sequence. An example of such a sequence is below:

AX, BX, BX, AX…, CY, CY…, DY, DY…

The presentations were counterbalanced so that half of the participants received intermixed presentations before blocked presentations, with the remainder receiving the opposite. Both of the exposed pairs were presented during the discrimination stage of the experiment, along with a pair that had not been seen before. This produced three different experimental conditions: Intermixed exposure, Blocked Exposure and Novel. One image from each pair was randomly assigned to be responded to as ‘A’ and the other image from each pair was designated ‘B’ and participants were required to learn these assignments. Participants received four blocks of trials with each of the three pairs of images, and saw a total of four images in each block. Each block consisted of exposure to images from a single experimental condition, and there was one block from each of the conditions in each set of three blocks. The order in which the blocks were presented was randomised within each set. Four images were presented within each block such that each image in a given pair was presented twice, with the order of presentation randomised. As in the previous experiments of Chapter 3, the primary measure of performance was accuracy of responding (examined as percentage correct) averaged over blocks 2-4 and the latencies to respond were also recorded.

Results

Figure 8a shows the discrimination scores for the three conditions in this Experiment. Inspection of this figure indicates that the discriminations involving pairs of images that were exposed in an intermixed fashion were acquired more readily than those involving pairs of images that were exposed in blocks. Both exposure conditions produced better subsequent discrimination than the non-exposed control. ANOVA confirmed that there was an overall effect of condition ($F(2, 14)=12.54$) and an effect of exposure (exposed versus Novel, $F(1,7)=17.96$). Pairwise analysis revealed that performance in each of the exposed conditions was better than in the Novel condition (minimum $F(1,7)=12.50$) and that performance in the Intermixed condition was more proficient than in the Blocked condition ($F(1,7)=6.51$). Mean reaction time data for this experiment was as follows: Intermixed 2.97 s (SEM 0.236), Simultaneous 2.61 s (SEM 0.284), and Novel 2.88 s (SEM 0.293). ANOVA revealed no significant effect of condition ($F<1$). These results parallel those seen in Experiment 4 suggesting that the schedule effect generalises to a new class of visual stimuli. Experiment 8B now addresses whether the advantage for simultaneous exposure (see Experiments 5 & 6) is also seen with chequerboard stimuli.

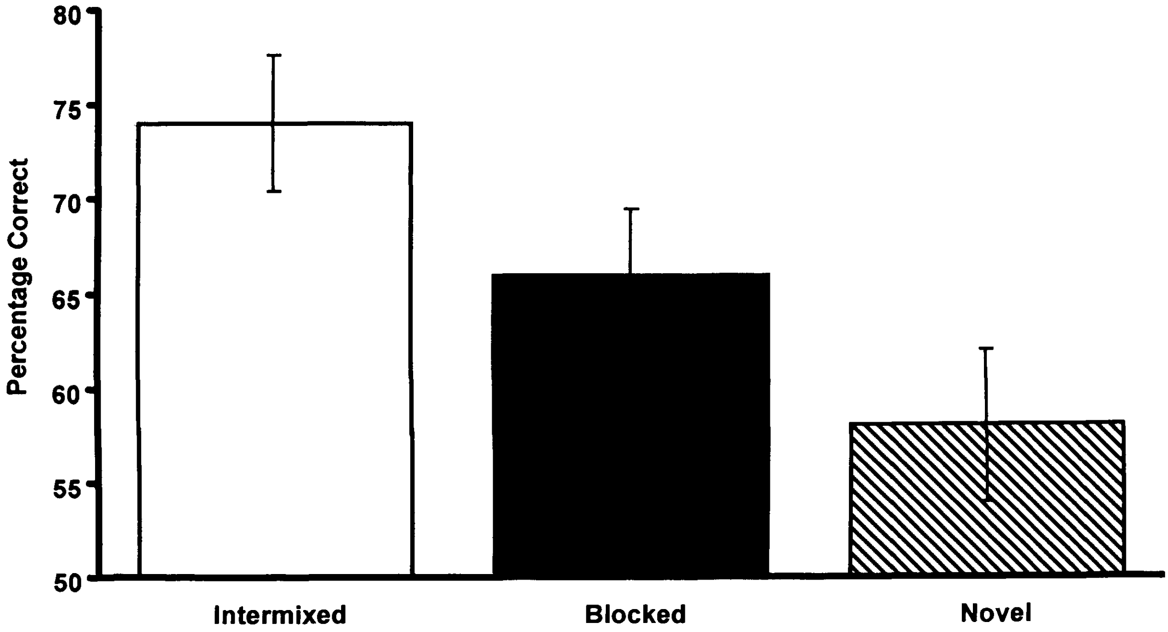


Figure 8a: Mean discrimination performance (with SEM) as percentages correct in the three conditions.

3.7.2 *Experiment 8B*

Method

Participants, Stimuli, and Apparatus

Twelve students, 10 female and 2 male (aged 18-24) recruited from Cardiff University participated in the study. Two of these were undergraduate students from the School of Psychology who took part in return for course credit, 10 were postgraduate students from the School of Psychology who did not receive any inducement to participate. The method of creating the three pairs of stimuli, and the apparatus used in this experiment were identical to those used in Experiment 8a.

Exposure and test procedure

The general procedure and instructions were identical to Experiment 8A, with the exception that the instructions were changed to reflect that pairs of stimuli were now being presented during pre-exposure:

Before the exposure stage the following instructions were displayed on the screen:

> *'Scientists are trying to discover the cure to an outbreak of previously unrecorded diseases. You are about to see a series of images which show the RNA profile of several of the viruses that have been discovered. Each virus has two strains, but not all have been successfully identified, scientists are attempting to pair the correct strains together. Please indicate using the keypad how many times you encounter each pair'.*

The following instructions were then shown prior to the discrimination learning stage of the study:

> *'For every virus you have seen, the two different strains have now been identified. Scientists have discovered that each strain requires a different treatment. Select the appropriate treatment for each of the virus strains. If you*

think the presented virus requires treatment A, press the left button, if you think it requires treatment B, press the right button. The computer will confirm if you are successful'

Design and counterbalancing

Two pairs of chequerboards were presented during the exposure stage of the experiment. Members of one of the pairs were exposed in a simultaneous fashion, with both images from a given pair presented side by side on the screen: AX was presented alongside BX and the side on which each appeared was randomised. The other pair was exposed in a successive fashion, with two copies of one image presented side-by-side, followed by two copies of the second image: CY-CY then DY-DY. Thus there were four arrays presented to each participant (AX-BX, BX-AX, CY-CY, and DY-DY). The exposure stage was arranged so that each image AX-BX/BX-AX (5x each), CY-CY, and DY-DY was seen ten times. There was no break between the blocks, so participants received 30 exposure trials presented in a continuous sequence. The presentations followed a pseudo-random sequence with the constraints that the presentations of CY-CY and DY-DY occurred in pairs, separated by a presentation of either AX-BX or BX-AX, for example:

AX-BX, CY-CY, DY-DY, BX-AX, DY-DY, CY-CY...

Both of the exposed pairs were presented during the discrimination stage of the experiment, along with a pair that had not been seen before. This produced three different experimental conditions: Simultaneous exposure, Successive Exposure and Novel. All other details are identical to those of Experiment 8A.

Results

Figure 8b shows the discrimination scores for the three conditions in this Experiment. Inspection of this figure indicates that the discriminations involving pairs of images that were exposed in a simultaneous fashion were acquired more readily than those involving pairs of images that were exposed successively. Both exposure conditions produced better subsequent discrimination than the non-exposed control. ANOVA confirmed that there was an overall effect of condition ($F(2, 22)=25.31$) and an effect of exposure (exposed versus Novel, $F(1,11)=33.36$). Pairwise comparisons revealed that performance in each of the exposed conditions was better than in the Novel condition (minimum $F(1,11)=7.60$) and that performance in the Simultaneous condition was more proficient than in the Successive condition ($F(1,11)=15.89$). Mean reaction time data for this experiment was as follows: Successive 2.56 s, Simultaneous 2.37 s, and Novel 2.63 s. ANOVA revealed no significant effect of condition ($F(2,10)=1.04, p=0.389$). This data confirms that simultaneous pre-exposure is the most effective means tested here of generating perceptual learning, in agreement with the predictions of Gibson (1969) and replicating the findings of Experiments 5 and 6.

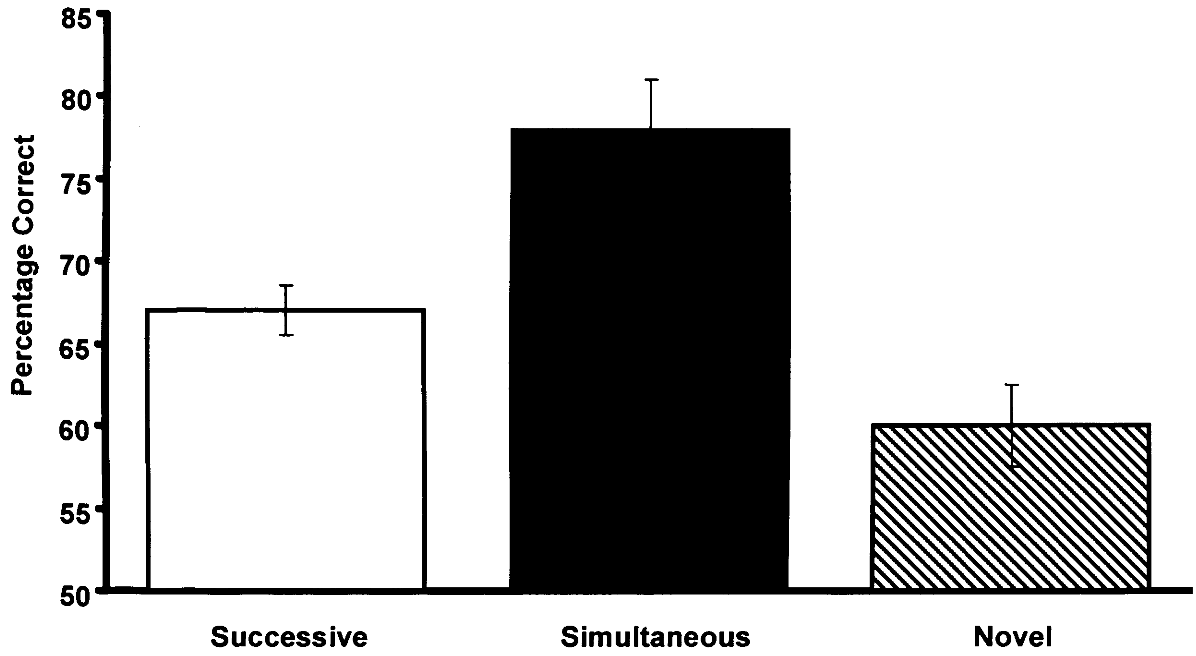


Figure 8b: Mean discrimination performance (with SEM) as percentages correct in the three conditions.

3.8 *Discussion*

Each experiment presented here examined the effect of a period of brief unsupervised exposure to similar stimuli on participants' subsequent ability to learn a supervised discrimination involving them. Experiment 3 used a within-participants design and demonstrated that exposure to a pair of similar stimuli facilitated later discrimination between them relative to stimuli that were unfamiliar at the outset of discrimination training. This finding represents an instance of perceptual learning and confirms that such an effect can be observed with morphed pictures of faces and reflects a stimulus-specific change in their discriminability. Experiment 4 demonstrated that the schedule of presentation (intermixed versus blocked) influences the degree to which exposure facilitated later discrimination and also that exposure to the midpoint between the to-be-discriminated stimuli facilitated discrimination between them. Experiments 5 and 6 showed that the mode of presentation (simultaneous versus successive) affected the process of perceptual learning: With simultaneous exposure promoting subsequent discrimination learning relative to successive exposure. Experiment 7 demonstrated that excitatory associations are formed between simultaneously presented stimuli. Finally, Experiment 8 showed that the results of this chapter are relevant and applicable to perceptual learning in general, rather than a specific instance of face perception, by demonstrating that simultaneous exposure is more effective at promoting discrimination than successive exposure in non-face visual stimuli. The results of Chapter 3 have implications for accounts of perceptual learning in general and have particular relevance to the divergent predictions of associative and non-associative theories.

Experiments 3 and 4 simply demonstrate that effects seen in other stimuli and other species can be replicated in the discrimination of pictures of human faces. Experiments 5, 6 and 8B provide no support for associative models of these perceptual learning effects. Simultaneous presentation should result in association between the two stimuli which should hinder subsequent discrimination. Evidence that associations of this sort are acquired during simultaneous exposure to pictures of highly discriminable faces was found in Experiment 7. However, using hard to discriminate stimuli that routinely produce perceptual learning effects simultaneous exposure not only did not retard discrimination but actually facilitated it relative to successive exposure. This pattern of results poses considerable difficulty for associative theories of perceptual learning. The data in this chapter indicates that the associative analyses under consideration do not represent the sole explanation for perceptual learning in these experiments. This point will be considered in more detail in the General Discussion.

One possible mechanism that can encompass all of the effects seen in this chapter is that of attentional weighting. Whilst detailed discussion of this idea will be reserved for the General Discussion, a brief outline is provided below. During intermixed presentation the frequency between exposures to unique features is twice that between those of common features, whilst this is not the case during blocked exposure. During simultaneous exposure the common features have recently been encountered each time a participant shifts gaze between the sides of the array. This difference in the frequency of exposure to the common and unique elements should produce differential adaptation or habituation. The difference in habituation to common and unique elements must result in a relatively long-lasting change in stimulus representations. For example, the unique elements become better represented and are thus more readily available to be learned about, indicating an interaction between the low-level adaptation or habituation processes and higher-level representational/attentional processes (for a more detailed consideration see Section 5.4).

The theoretically important scheduling effects demonstrated in this chapter, in particular, the effect of simultaneous exposure, were shown using both face and chequerboard stimuli. These generality of these effects are consistent with the idea that perceptual learning involving pictures of faces and other visual stimuli are governed by common principles or perhaps even a common mechanism. However, this interpretation assumes that the pictures of faces used here were indeed processed as faces. Before moving to consider the implications of schedule effects for models of face processing, Chapter 4 will investigate whether the face stimuli we have used will exhibit the previously demonstrated hallmarks of human face processing. Furthermore, Chapter 4 will also investigate whether the perceptual learning effects demonstrated here contribute to the acquisition of face familiarity.

Chapter 4

Abstract

In Chapter 4 the ability of participants to discriminate between novel faces or those to which they had received brief, unsupervised, exposure (e.g., 5 × 2 seconds each) was assessed. Four experiments examined whether the stimuli used in the previous chapter were processed as faces. In all four experiments prior exposure to the faces improved later discrimination between them. In Experiment 9 this improvement was selective to the internal features of the faces. In Experiments 10A-C, overall discrimination was better when faces were presented upright, but the influence of exposure was evident for both upright and inverted faces. In addition, Dwyer, Mundy, Valdeanu and Honey (2006) report an experiment where an advantage of exposure was present regardless of a change in face profile angle between exposure and test. These findings indicate that the perceptual learning effect observed following brief exposure to pictures of faces exhibit established hallmarks of familiar face processing (i.e., an internal feature advantage, inversion effects and viewpoint invariance). Considered alongside the results from Chapter 3 the current findings suggest that some qualitative changes in face perception due to familiarity do not require supervised training and occur relatively rapidly.

4.1 *Introduction*

The results reported in Chapter 3 encourage the view that there might be an important continuity in the mechanisms that underlie perceptual learning involving faces and perceptual learning in other stimuli and species. However, while clearly demonstrating perceptual learning, the same pictures were used in both the exposure and test phases of those experiments in Chapter 3 and some people have suggested that processing of familiar faces is independent of the particular pictures used (e.g., Bruce, 1982). Moreover, the fact that the stimuli were morphs of faces rather than real faces raises the possibility that they might be processed by mechanisms other than those recruited by real faces. The nature of the morphing process means that a face is changed more or less evenly along all dimensions, many of which may not be dimensions along which faces might normally differ. Thus it is at least possible that my data is open to the criticism that the effects observed above might well reflect the operation of general 'pictorial' processes that are content independent, having nothing to do with face processing *per se* (e.g., Bruce 1982). Ignoring the fact that the pictures used in the previous experiments clearly depicted faces and the morphing process produced pictures whose differences were configural as opposed to featural, it might be argued that the perceptual learning effects observed in Chapter 3 relied on quite different mechanisms to those ordinarily engaged by real faces. It was with these concerns in mind that the four experiments reported here were conducted. In particular, it was investigated whether the results reported above reflected a change in the processing of the internal features of the faces or their external features (cf. Ellis et al., 1979; Experiment 9) and whether the stimuli used above are subject to the inversion effects normally seen with faces (cf. Yin, 1969; Experiments 10A-C). Demonstrating inversion effects and an acquired advantage for the use of internal features would be prime evidence that the stimuli used here really do engage face processing mechanisms as these effects are central to accounts of face processing.

4.2 *Experiment 9*

The design of Experiment 9 is summarised in Table 12 and examples of the stimuli used are shown in Figure 9. Experiments 9 and 10 used the morphing procedure described in Chapter 3 to create a set of new stimuli. Participants were initially exposed to two pairs of faces (A and A', B and B') without explicit feedback while a further two were not exposed (C and C', D and D'). During the test stage participants made same/different judgements about sequentially presented faces with immediate feedback, i.e., they decided whether or not the first face presented was the same as or different to the second face presented. Due to the nature of the manipulations, assigning an arbitrary feature to a face in order to demonstrate discrimination would not have been appropriate here. Furthermore, Shepard (1986) has argued that learning to categorise stimuli requires both discriminating between the stimuli and linking those stimuli to the categories, although Shepard also argues that discrimination will be the limiting factor when the stimuli initially difficult to discriminate as they were in the previous chapter. Thus it is possible that exposure, rather than increasing the discriminability of the stimuli, increased the readiness with which links between the stimuli and categories were acquired. As an assay of exposure, same/different judgements give no requirement for the categories into which the stimuli are placed to be learnt. Under these circumstances, if an effect of exposure was observed it could be more safely attributed to a change in the discriminability of the stimuli.

Two sets of faces were used to confirm that our exposure treatment would create an improvement in detecting whole faces changes (A and A', C and C'). This was important as it is possible that different measures of discrimination are affected by pre-exposure in different ways. The remaining faces were used to investigate whether any improvement was specific to internal features (B and B', D and D'). The issue of principal importance was whether discriminations involving the exposed pairs of faces were better than those involving faces that were not exposed and whether this reflected an advantage for exposed stimuli with respect only to internal face features.

Whole face change

Internal feature change

External feature change

Figure 9: Examples of stimuli used in Experiment 9, showing whole face change (upper panel), internal feature change (middle panel) and external feature change (lower panel).

Table 12

Design of Experiment 9.

Condition	Exposure	Discrimination
Whole		
Exposed	5 × A and 5 × A’ intermixed	A versus A’
Control		C versus C’
Internal-External		
Exposed	5 × B and 5 × B’ intermixed	B versus $B’^{INT}$ B versus $B’^{EXT}$
Control		D versus $D’^{INT}$ D versus $D’^{EXT}$

Note: A to D’ represent different faces. The superscript INT refers to a change in the internal features of the face only while the superscript EXT refers to a change in the external features of the face only. The discrimination test involved same-different judgements on sequentially presented stimuli.

Method

Participants and Apparatus

Thirty-two students, 23 female and 9 male (aged 18-23), recruited from the School of Psychology at Cardiff University, were given course credit for taking part. All participants had normal or corrected-to-normal vision. An IBM-compatible PC was used to display the stimuli, using custom-written software, on a LCD screen in an evenly lit, quiet room. On a standard keyboard the 'A' key was covered with a green coloured sticker labelled YES, the 'L' key was covered with a red coloured sticker labelled NO, and these were used by participants to indicate their same/different judgements.

Stimuli

The stimuli were created using a software package dedicated to morphing called Morpheus 1.85™. Four morphs were created using black and white portrait photographs of two men and two women. The pictures of each pair (Face 1 and Face 2) were homogenised so that size, resolution, and lighting were identical and they were morphed together along a 30-point scale. Position 1 was 100% Face 1, 0% Face 2, position 15 was 50% Face 1, 50% Face 2, and position 30 was 0% Face 1, 100% Face 2. A pair of images was selected from each morphed continuum at point 13 (56.6% Face 1, 43.3% Face 2) and at point 17 (43.3% Face 1, 56.6% Face 2). These pairs of pictures formed the set from which 'Whole' face-change pairs were drawn from. Copies of each of the faces in the four face-pairs were further processed, using Adobe Photoshop 6 ™, so that the internal features (eyes, nose and mouth) of one face replaced those of the second face, and *vice versa*. This created a further pair of faces corresponding to each of the original four pairs: for example one containing the internal features of A and the external features of A' ($A^{INT}A'^{EXT}$) and one containing the internal features of A' and the external features of A ($A'^{INT}A^{EXT}$). This formed the set from which 'Internal' and 'External' face-change pairs could be drawn. Presented on screen all images measured 10.2cm × 9.9cm (h × w).

Exposure and test procedure

Participants were seated approximately 70cm directly in front of the computer screen. Prior to the initial stage of the study the following instructions were displayed:

> *In the following presentation, you will see several sets of 'Look-alikes'. You will see each separate look-alike more than once. When prompted, please indicate using the numeric keypad how many times you think you have seen each particular person.*

Each face was displayed in the centre of the screen for two seconds, replaced with an even grey background and the participants were asked how many times they had seen that face. Entering a response triggered the next trial. The inter trial interval was thus self-paced and was normally in the region of 1-2s. This process continued until all faces had been seen five times. The following instructions were then shown prior to the change detection stage of the study:

> *You will now see a second series of look-alikes. You will have seen some of them before. The face will flash and you will be asked 'Does the face change?'. Use the 'GREEN' key for YES and the 'RED' key for NO. The computer will inform you if you are correct.*

The first face was presented on screen for 0.5 s then replaced with an even grey background for 0.3 s. A second face was then presented for 0.5 s and replaced with an even grey background. The participants were then required indicate whether the face had changed. The response triggered written feedback (Correct or Incorrect) which remained on screen for 2 s before the presentation of the next trial. Responses under 300 ms were to be recorded but flagged as anticipation errors and not advance the presentation. However, there were no such responses in Experiments 1 or 2. If no response was given within 10 s the participant was prompted to respond.

Design and counterbalancing

During the exposure stage the participants were exposed to two pairs of faces (e.g., A and A', B and B') randomly selected from the four face pairs. Stimuli were presented one at a time and both of the faces from each pair were presented five times each with the order of presentation randomised. Both pictures from one pair were presented before the presentation of the other pair.

One of the exposed pairs and one of the non-exposed pairs were randomly assigned to the 'Whole-change' condition (e.g., A and A', C and C'). The remainder were assigned to the 'Internal/External-change' condition (e.g., B and B', D and D'). Assignment was constrained so that across participants each face was used equally often in each condition. Participants received four blocks of trials with each of the four pairs of faces from each experimental condition (whole-change exposed, whole-change control, internal/external exposed, internal/external control). The order in which blocks of face pairs were presented was randomised with the restriction that participants received one block with each face pair before being given the opportunity to rest prior to continuing.

Each test block consisted of eight trials. During a 'whole-change' block, the identities of face 1 and face 2 was randomised with the constraint that in every block, four trials showed no change between face 1 and 2 (e.g., A→A or A'→A'), four trials showed a change from one face to its partner (e.g., A→A' or A'→A), and so that each face was seen equally often as its partner within a block. During an 'internal/external-change' block the identity of face 1 was randomised with the constraint that each face

(B or B') was used equally often. The identity of face 2 was randomly chosen from a set of four faces (B, B', $B^{INT}B'^{EXT}$, $B'^{INT}B^{EXT}$), with the constraint that in every block there were to be at least two 'internal' changes, where the external features of face 1 were retained in face 2, but the internal features were swapped for those of its partner (e.g., $B \rightarrow B'^{INT}B^{EXT}$ or $B' \rightarrow B^{INT}B'^{EXT}$), two 'external' changes, where the internal features of face 1 were retained in face 2, but the external features were swapped for those of its partner (e.g., $B \rightarrow B^{INT}B'^{EXT}$, $B' \rightarrow B'^{INT}B^{EXT}$), and two trials where there was no change between face 1 and 2 (e.g., $B \rightarrow B$, or $B' \rightarrow B'$).

Data analysis

During the exposure stage, participants' estimates of the number of faces that they had seen in each exposure set was recorded. There were no aberrant patterns of responding (e.g., higher responses than the total number of stimuli presented during exposure) that might indicate that a participant had not been attending to the experiment or following instructions in Experiment 9 and 10. The primary measure of performance in Experiments 9 and 10 was the accuracy of responding (examined as the percentage correct) averaged over test. Reaction times were also examined to assess any effects of the speed of responding on accuracy.

Table 13

Mean reaction times in seconds (with SEM) during discrimination training for each condition in Experiment 9.

		Reaction time (s)	SEM
Whole			
	Exposed	1.020	.040
	Control	1.078	.050
Internal			
	Exposed	1.070	.053
	Control	.969	.051
External			
	Exposed	1.065	.062
	Control	.929	.056

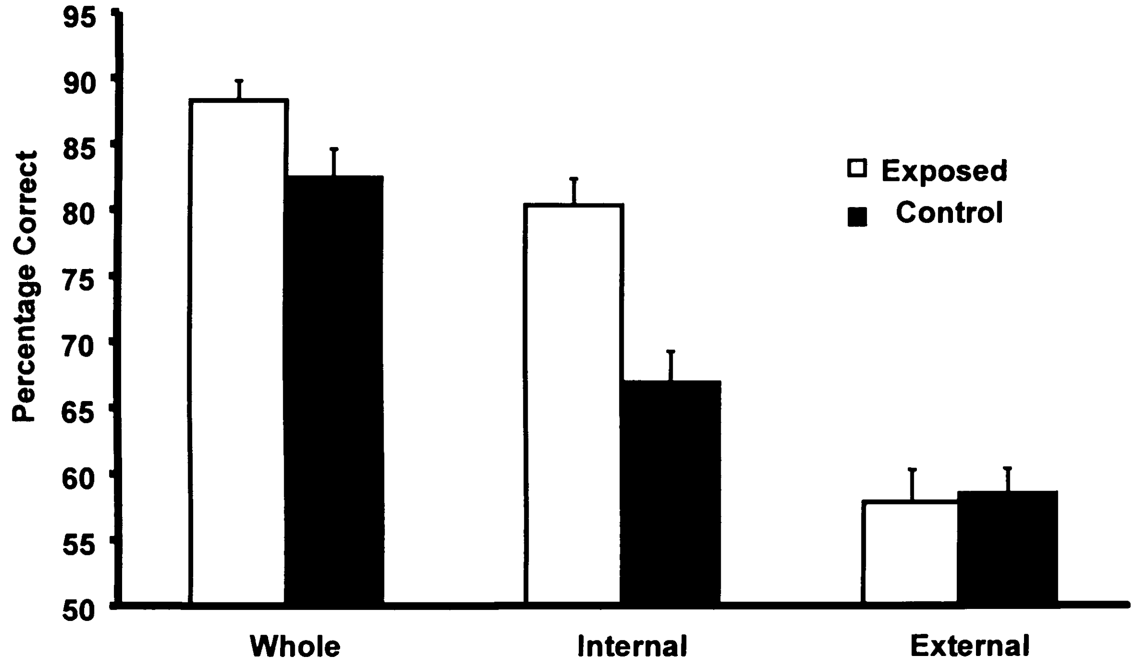


Figure 10: Mean discrimination performance (with SEM) as percentages correct Experiment 9. Whole, internal and external refer to the nature of the features that differed on test while exposed and control refer to whether or not the faces had been presented prior to test.

Results

Figure 10 shows the discrimination scores for Experiment 9. Inspection of the left hand portion of the figure indicates that change-detection performance was more accurate after exposure (white bar) than it was without exposure (black bar). Inspection of the right hand portion of the figure indicates an advantage produced by exposure only in the internal-change conditions (central pair of bars) and not in the external change conditions (right-hand pair of bars). The exposure advantage was significant when changes involved the whole face ($F(1,31)=19.87$). With respect to the internal- and external-change conditions a further ANOVA showed there were significant effects of exposure ($F(1,31)=23.78$) and change type ($F(1,31)=48.76$). Crucially there was also a significant interaction between these factors ($F(1,31)=5.42$). Exploring the interaction revealed an advantage for exposure in the internal-change conditions ($F(1,31)=18.81$) but no difference in the external-change conditions ($F<1$). The failure to find an exposure advantage in the external-change conditions is unlikely to be due to a floor effect as performance was above chance in all cases (minimum $t(31)=3.13$).

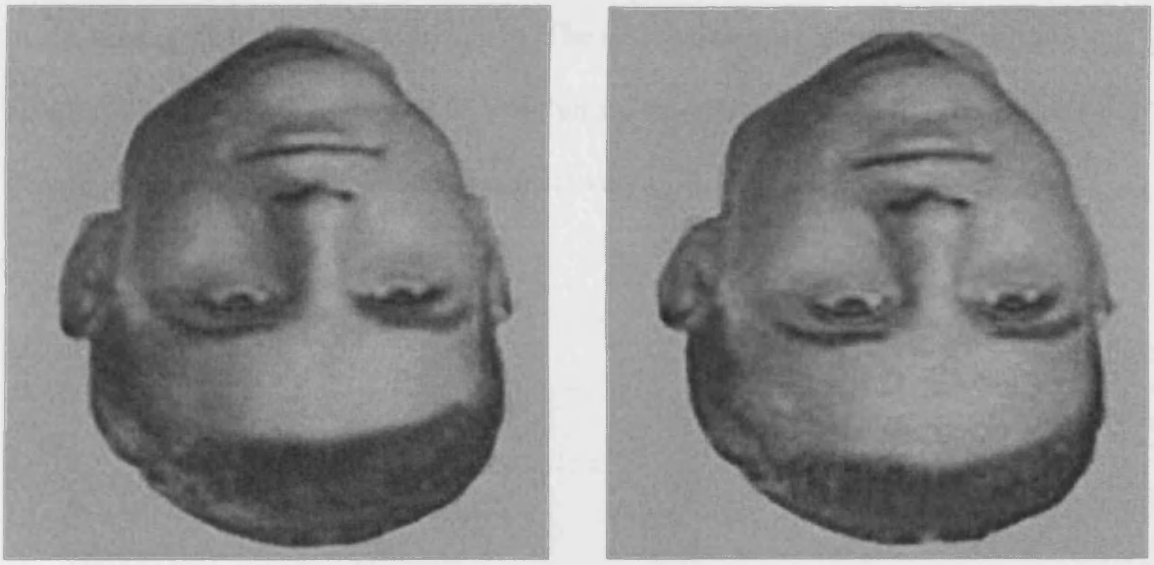
Table 13 shows mean reaction times from Experiment 9. There was no significant effect of exposure in the whole change conditions ($F<1$). With respect to the internal- and external-change conditions reaction times were significantly longer in the exposed conditions ($F(1,31)=5.06$). Crucially there was no significant effect of change type or interaction between the two factors (Fs<1). The absence of significant differences in reaction times in the crucial interaction between exposure and change type indicates that it is unlikely that the speed with which participants responded contributed to the differences in discrimination performance.

Experiment 9 demonstrates that brief exposure to pictures of faces produces a perceptual learning effect that is selective to internal features. This reflects the pattern of results seen in face stimuli that have become familiar over longer periods. One aspect of previous results not reflected here is an advantage for external features with novel faces (e.g., Bruce, Henderson, Greenwood, Hancock, Burton, & Miller 1999). However, this advantage may be dependant on particular aspects of the stimuli used. For example, O'Donnell and Bruce (2001) showed good change detection of a complete change in hairstyle. In the present case the morphing process eliminates such obvious differences removing any advantage for external features.

4.3.1 *Experiment 10A*

The design of Experiment 10A is summarised in Table 14 and examples of stimuli used are shown in Figure 11. In the exposure stage, participants were given a limited number of exposures to two pairs of faces (A and A', C and C'), while a further two pairs of faces were not exposed (B and B', D and D'). Of the two exposed pairs, one was exposed in an upright orientation (A and A'), and one was exposed inverted (C and C'). Participants were given no explicit feedback about the pictures during the exposure stage. During the test stage participants were required to learn a discrimination between A and A', and C and C', and between the two pairs of novel stimuli B and B', and D and D'. Of the two novel stimuli, one was tested in an upright orientation (B and B'), whilst the other was tested in an inverted orientation (D and D'). For the two exposed pairs, both were tested in the orientation experienced during pre-exposure. The issue of principle importance was whether or not discriminations involving exposed pairs of faces were better than those involving faces that were not exposed, particularly whether this was true if the face was inverted. If a large 'Inversion Effect' were to be seen here, then this could be taken to support the contention that these stimuli are being processed as faces, rather than a more general class of pictorial stimuli (which do not show a disproportionate detriment to recognition when inverted).

Upright Faces



Inverted Faces

Figure 11: Examples of stimuli used in Experiment 10, showing upright faces (upper panel) and inverted faces (lower panel).

Table 14

Design of Experiment 10A.

Condition	Exposure	Discrimination
Upright – exposed	5 × A and 5 × A’ intermixed Upright faces	A = LH and A’ = RH: Upright
Upright – control	No Exposure	B = LH and B’ = RH: Upright
Inverted – exposed	5 × C and 5 × C’ intermixed Inverted faces	C = LH and C’ = RH: Inverted
Inverted – control	No Exposure	D = LH and D’ = RH: Inverted

Note: A to D’ represent different faces and Upright/Inverted face represents the orientation at which the face was shown. The discrimination test involved learning an arbitrary feature assigned to each face within a pair, presented sequentially. LH and RH denote left-handed and right-handed respectively.

Method

Participants, Apparatus and Stimuli.

Thirty-two students, 25 female and 7 male (aged 18-23), recruited from the School of Psychology at Cardiff University, were given course credit for taking part. All participants had normal or corrected-to-normal vision, and none had taken part in the previous Experiments. The apparatus used was identical to that of Experiment 9. For the purposes of the experiment, the 'A' key was covered in a red coloured sticker with the letter M and was used by participants to indicate that the pictured person was married, and the 'L' key was covered with a green coloured sticker with the letter U, and was used by participants to indicate whether the pictured person was unmarried. The set of morphed stimuli were created using the methods described in the previous chapter, the size of the images presented on screen was 10.2cm × 9.9cm (h × w). Four different pairs of faces were used in this experiment.

Exposure and test procedure

The general procedure and instructions to participants during the exposure phase of Experiment 10A were similar to those described for Experiments in the previous chapter, with the exception that the instruction wording was altered to reflect the fact that some faces would be seen inverted:

> *In the following presentation, you will see several sets of 'Look-alikes'. You will see each separate look-alike more than once, and some may be upside-down. When prompted, please indicate using the numeric keypad how many times you think you have seen each particular person.*

Once all exposed faces were seen five times the following instructions were shown prior to the test phase of the study:

> *You will now see a second series of 'Look-alikes'. You will have seen most*

> *of them before. One of each pair is married, the other is unmarried. Your task is to select which is which. Use the RED key marked M to choose married people, and chose the GREEN key marked U to chose the unmarried people. The computer will inform you if you are correct.*

Each face was displayed in the centre of the screen for a maximum of 10 s, during which time participants were required to press a key indicating their response (married or unmarried), the response triggered removal of the face which was replaced by written feedback relating the accuracy of their selection (Correct or Incorrect). The feedback remained on the screen for 2 s before the presentation of the next trial. If no response was given within the 10 s the stimuli was removed and the participant prompted to respond. Both the response and latency were recorded. After every 16 trials the participant was given the opportunity to rest before pressing a key to continue to the next set of trials.

Design and counterbalancing

During the exposure stage participants were exposed to two pairs of faces, one upright (e.g., A and A'), and one inverted (e.g., C and C'). The computer randomly chose the exposed faces from a selection of four pairs (two male, two female), with the limitation that one was to be female, and one male. Presentation of pictures from one pair was made before the presentation of pictures from the next pair. Presentation was counterbalanced so that for half of the participants the first pair consisted of inverted faces, whilst the second pair was of the upright orientation; the remainder of the participants received the opposite arrangement. Stimuli were presented one at a time and both of the faces from each pair were presented five times with the order of presentation randomised.

Stimuli from both pairs of faces were presented during the discrimination stage of the experiment, along with two further pairs of faces that were not previously exposed. There were four conditions: Upright – exposed, Upright – control, Inverted – exposed, Inverted – control. The assignment of faces to these four conditions was as follows: the exposed upright face was tested in the same orientation (the Upright – exposed condition); the exposed inverted face was tested in the same orientation (the Inverted – exposed condition); one of the novel faces was randomly selected to be tested in the upright orientation (the Upright – control condition), and the remaining novel face was tested inverted (the Inverted – control condition). Each pair of faces was used equally often in each condition. One face from each pair was randomly assigned to be married and the other face from each pair unmarried and participants were required to learn these assignments. Participants received four blocks of trials with each of the four pairs of faces, and saw a total of four faces in each block. Each block consisted of exposure to faces from a single experimental condition, and there was one block from each of the conditions in each set of four blocks. The order in which the blocks were presented was randomised within each set. Four faces were presented in each block such that each face in a given pair was presented twice, with the order of presentation randomised.

Table 15

Mean reaction times in seconds (with SEM) during discrimination training for each condition in Experiment 10A.

	Reaction time (s)	SEM
Upright - Exposed	1.678	0.123
Inverted - Exposed	1.774	0.099
Upright - Control	1.872	0.086
Inverted - Control	1.671	0.105

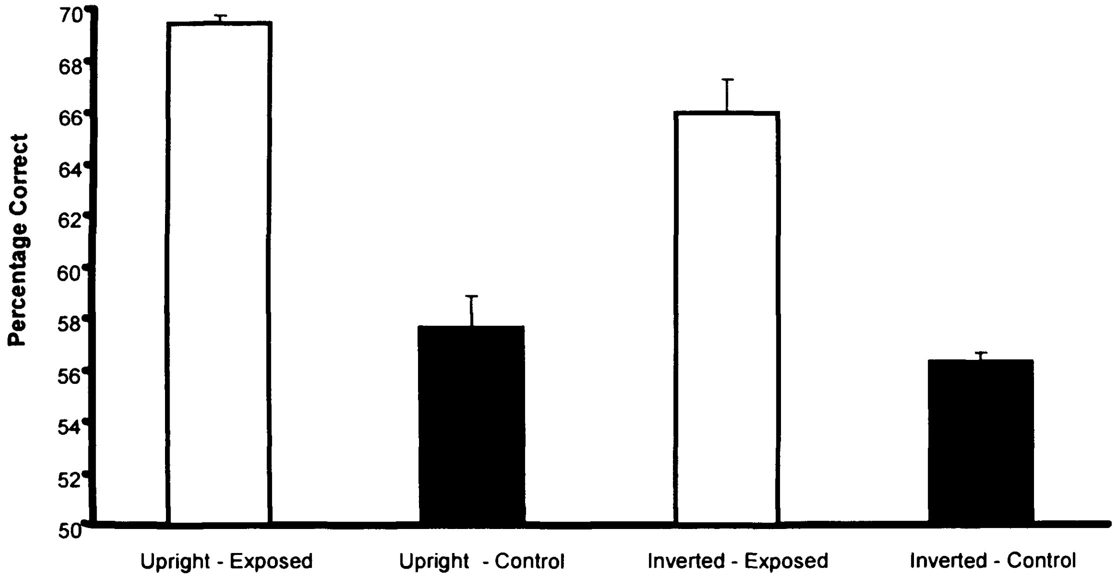


Figure 12: Mean discrimination performance (with SEM) as percentages correct in Experiment 10A. Exposed refers to stimuli that were pre-exposed, Control refers to stimuli that were new at test, Inverted refers to inverted faces, Upright refers to upright faces.

Results and Discussion

Figure 12 shows the discrimination scores in conditions for Experiment 10A. Inspection of this figure indicates an inversion effect, where upright performance is more accurate overall than inverted performance. It also shows that discrimination performance was superior in the exposed conditions than the novel conditions, in both the upright (first pair of bars) and inverted (second pair of bars) orientations. ANOVA revealed significant effects of exposure ($F(1, 31)=38.56$) and orientation ($F(1, 31)=22.66$). There was no interaction between these factors ($F<1$). Performance was above chance in all conditions (minimum $t(31)=3.87$). Table 15 shows the reaction time data from Experiment 10A and ANOVA revealed no significant effects of exposure or orientation, and no interaction between these factors (Fs<1), indicating that inspection time on test was not a factor in the effects reported here. The critical result shows an inversion effect of the kind normally associated with face stimuli, supporting the suggestion that these artificially morphed stimuli are being processed as faces. An advantage of brief exposure to the discrimination of inverted faces is also present. Experiments 10B and 10C sought to explore this advantage further.

4.3.2 *Experiment 10B*

The design of Experiment 10B is summarised in Table 16. In the exposure stage of the experiment participants were given a limited number of exposures to two pairs of inverted faces (A and A', B and B'). An example of these faces can be seen in the lower portion of Figure 11. One pair was exposed according to an Intermixed schedule (A, A', A, A'), and one was exposed according to a Blocked schedule (B, B, B..., B', B', B'...). Participants were given no explicit feedback about the pictures during the exposure stage. During the test stage participants were required to learn a discrimination between A and A', and B and B'. Both pairs were tested in the inverted orientation. The issue of principle importance was whether or not discriminations involving pre-exposed pairs of inverted faces were affected by the schedule of pre-exposure presentation in a similar manner to that seen with upright faces in the previous chapter. If there were to be an advantage of intermixed schedule over blocked, this would show that it is not merely the number of exposures to an inverted face that are critical to its accurate discrimination (thus the benefit of exposure is some simple product of face familiarity (e.g., Gaffan, 1996; Honey, 1990; Hall, 1991), but the nature of the exposure is also important. This would support the idea that similar mechanisms contribute to perceptual learning with inverted and upright faces.

Table 16

Design of Experiment 10B.

Condition	Exposure	Discrimination
Intermixed	A, A', A, A', A, A'...	A = LH and A' = RH: Inverted
Blocked	B, B, B... B', B', B'...	B = LH and B' = RH: Inverted

Note: A to B' represent different faces and Intermixed/Blocked represents the schedule of pre-exposure presentation. The discrimination test involved learning an arbitrary feature assigned to each face within a pair, presented sequentially. LH and RH denote left-handed and right-handed respectively.

Method

Participants, Apparatus and Stimuli.

Thirty-two students, 26 female and 6 male (aged 18-23), recruited from the School of Psychology at Cardiff University, were given course credit for taking part. All participants had normal or corrected-to-normal vision, and none had taken part in the previous Experiments. The apparatus used was identical to that of Experiment 10A.

Exposure and test procedure

The general procedure and instructions to participants during the exposure and test phase of Experiment 10B was identical to that described for Experiment 10A.

Design and counterbalancing

During the exposure stage participants were exposed to two pairs of inverted faces (one male, one female), one in an intermixed schedule (e.g., A and A'), and one in a blocked schedule (e.g., B and B'). Each pair of faces was used equally often in each condition. Presentation of pictures from one pair was made before the presentation of pictures from the next pair. Presentation was counterbalanced so that for half of the participants the first pair consisted of intermixed faces, whilst the second pair was presented in a blocked schedule; the remainder of the participants received the opposite arrangement. These groups were further subdivided so that for half of the participants the intermixed schedule began with face A, and for the remainder the schedule began with A'. Further to this, for half of the participants the first block of faces in the blocked schedule was face B, whilst the remainder received a block of face B'. Stimuli were presented one at a time and both of the faces from each pair were presented five times.

Stimuli from both pairs of faces were presented during the discrimination stage of the experiment. One face from each pair was randomly assigned to be married and the other face from each pair unmarried and participants were required to learn these assignments. Participants received four blocks of trials with each of the two pairs of faces, and saw a total of four faces in each block. Each block consisted of exposure to faces from a single experimental condition, and there was one block from each of the conditions in each set of two blocks. The order in which the blocks were presented was randomized within each set. Four faces were presented in each block such that each face in a given pair was presented twice, with the order of presentation randomized.

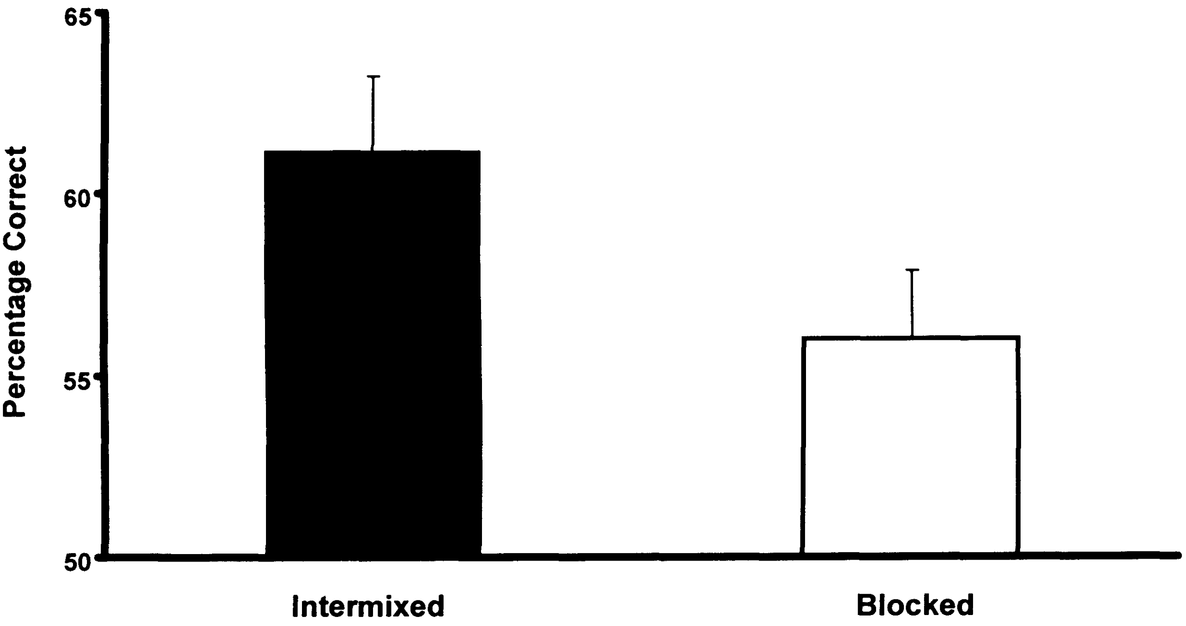


Figure 13: Mean discrimination performance (with SEM) as percentages correct in Experiment 10B.

Results and Discussion

Figure 13 shows the discrimination scores in conditions for Experiment 10B. Inspection of this figure indicates that discrimination performance was improved in the Intermixed condition, compared to the Blocked condition. There was a significant effect of schedule ($t(31)=12.56$). Performance was above chance in both conditions (minimum $t(31)=4.77$). Mean reaction time for the intermixed and blocked conditions were 1.599 s (SEM 0.076) and 1.734 s (SEM 0.100) respectively. There was no significant effect of schedule ($t<1$). The critical result shows that schedule of pre-exposure has an effect on subsequent discrimination for inverted faces, indicating that schedule of exposure affects the perceptual learning that occurs with pictures of faces that have been rotated through 180°. Gibson's (1969) comparison account of perceptual learning would predict that comparison between two faces can occur regardless of their orientation. What remains to be seen is if the perceptual learning effect reflects, for example, the extraction of the same features irrespective of orientation. One way to assess this possibility is to examine whether or not the advantage produced by exposure survives image rotation between exposure and test. Evidence of a lack of transfer would accord with the suggestion (e.g., Bartlett & Searcy, 1993, 1996; Robbins & McKone, 2003) and direct evidence (Freire, Lee, & Symons, 2000), that the inversion effect is caused by an impairment in the ability to encode configural information about inverted faces and thus different features are used to discriminate between inverted and upright faces.

4.3.3 *Experiment 10C*

The design of Experiment 10C is summarized in Table 17 and examples of stimuli used are shown in Figure 11. In the exposure stage of the experiment participants were given exposure to four pairs of faces (A and A’, C and C’, E and E’, F and F’), while a further two pairs of faces were not exposed (B and B’, D and D’). Of the four exposed pairs, two were presented in an upright orientation (A and A’, E and E’), and two were presented inverted (C and C’, F and F’). Participants were given no explicit feedback about the pictures during the exposure stage. As in the previous experiments, participants were required to learn a discrimination between the six pairs of faces. Of the two upright exposed pairs, one was tested in this orientation (A and A’), whilst the other was tested in an inverted orientation (E and E’). For the two inverted exposed pairs, one was tested inverted (C and C’), the other was tested in an upright orientation (F and F’). One of the novel pairs was tested in an upright orientation (B and B’), whilst the other was tested in an inverted orientation (D and D’). The issue of principle importance was whether or not discriminations involving exposed pairs of faces were better than those involving faces that were not exposed, and whether there was any transfer of perceptual learning between different orientations of the same pairs of faces.

Table 17

Design of Experiment 10C.

Condition	Exposure	Discrimination
Upright – exposed	5 × A and 5 × A' intermixed Upright faces	A = LH and A' = RH: Upright
Upright – control	No Exposure	B = LH and B' = RH: Upright
Inverted – exposed	5 × C and 5 × C' intermixed Inverted faces	C = LH and C' = RH: Inverted
Inverted – control	No Exposure	D = LH and D' = RH: Inverted
Upright→Inverted	5 × E and 5 × E' intermixed Upright faces	E = LH and E' = RH: Inverted
Inverted→Upright	5 × F and 5 × F' intermixed Inverted Faces	F = LH and F' = RH: Upright

Note: A to F' represent different faces and Upright/Inverted face represents the orientation at which the face was shown. The discrimination test involved learning an arbitrary feature assigned to each face within a pair, presented sequentially. LH and RH denote left-handed and right-handed respectively.

Method

Participants, Apparatus and Stimuli.

Thirty-two students, 20 female and 12 male (aged 18-23), recruited from the School of Psychology at Cardiff University, were given course credit for taking part. All participants had normal or corrected-to-normal vision, and none had taken part in the previous experiments. The apparatus used was identical to that of Experiments 10A-B. Six different pairs of faces were used in this experiment.

Exposure and test procedure

The general procedure and instructions to participants during the exposure phase of Experiment 9c were similar to those described for Experiments 10A-B with the exception that since participants received discrimination trials with six pairs of faces they were given the opportunity to rest after every 24 trials before pressing a key to continue to the next set of trials.

Design and counterbalancing

During the exposure stage participants were exposed to four pairs of faces, two upright (e.g., A and A’, E and E’), and two inverted (e.g., C and C’, F and F’). The computer randomly chose the exposed faces from a selection of six pairs (three male, three female), with the limitation that two were to be female, and two male, with one of each gender in each of the two orientations. Both pictures from one pair were presented before the presentation of pictures from the next pair. Presentation was counterbalanced so that for half of the participants the first and third pair consisted of inverted faces, whilst the second and fourth pairs were upright; the remainder of the participants received inverted faces as the second and fourth pairs, whilst the first and third pairs were upright. Stimuli were presented one at a time and both of the faces from each pair were presented five times with the order of presentation randomised.

Stimuli from all four pairs of faces were presented during the discrimination stage of the experiment, along with two further pairs of faces that were not previously exposed. There were six conditions: Exposed Upright, No Exposure Upright, Exposed Inverted, No Exposure Inverted, Expose Inverted test Upright and Expose Upright test Inverted. The assignment of faces to these six conditions was as follows: the computer randomly selected one of the exposed pairs of upright faces to be tested in the same orientation (the Exposed Upright condition); the remaining exposed upright pair was tested inverted (the Expose Upright test Inverted condition). One of the exposed inverted pairs was randomly selected to be tested in the same orientation (the Exposed Inverted condition); the remaining exposed inverted pair was tested upright (the Expose Inverted test Upright condition). One of the pairs of novel faces was randomly selected to be tested in the upright orientation (the No Exposure Upright condition), and the remaining novel pair was tested inverted (the No Exposure Inverted condition). One face from each pair was randomly assigned to be married and the other face from each pair unmarried and participants were required to learn these assignments. Participants received four blocks of trials with each of the six pairs of faces, and saw a total of four faces in each block. Each block consisted of exposure to faces from a single experimental condition, and there was one block from each of the conditions in each set of six blocks. The order in which the blocks were presented was randomized within each set. Four faces were presented in each block such that each face in a given pair was presented twice, with the order of presentation randomized.

Table 18

Mean reaction times in seconds (with SEM) during discrimination training for each condition in Experiment 10C.

	Reaction time (s)	SEM
Exposed Upright	1.866	0.091
Exposed Inverted	1.918	0.076
No Exposure Upright	1.883	0.077
No Exposure Inverted	1.855	0.099
Expose Upright test Inverted	1.883	0.092
Expose Inverted test Upright	1.908	0.075

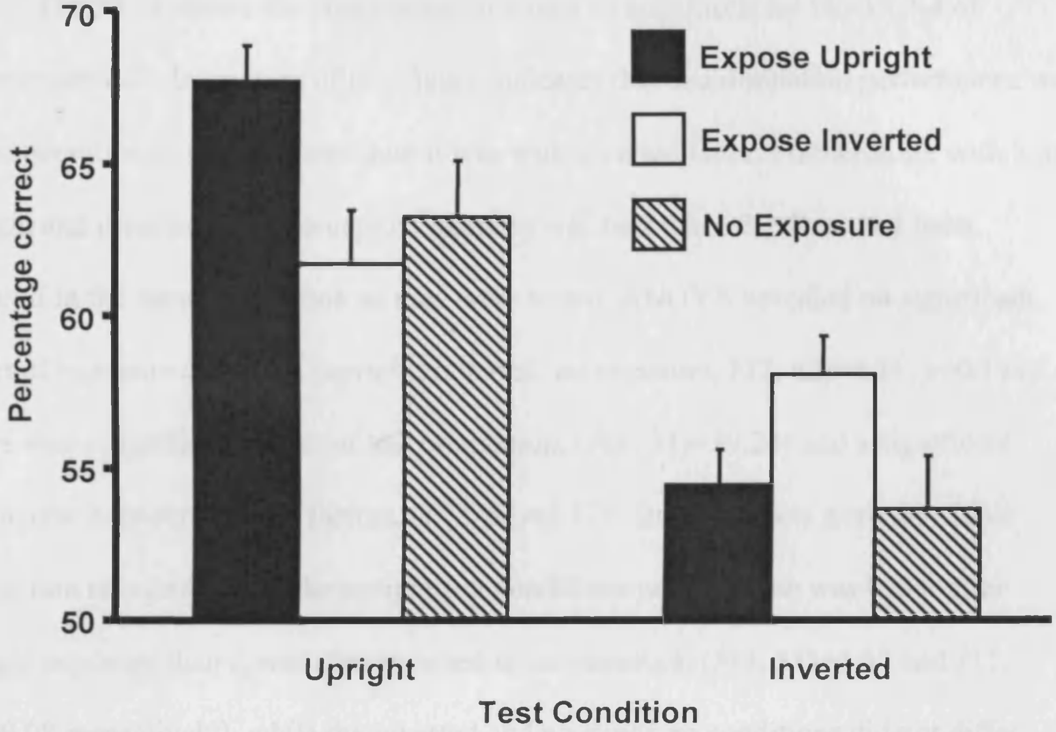


Figure 14 Mean discrimination performance (with SEM) as percentages correct in Experiment 10C.

Results and Discussion

Figure 14 shows the discrimination scores in conditions for blocks 2-4 of Experiment 10C. Inspection of this figure indicates that discrimination performance was better overall with upright faces than it was with inverted faces. Furthermore, with both upright and inverted faces perceptual learning was best when the faces had been exposed in the same orientation as they were tested. ANOVA revealed no significant effect of exposure condition (upright, inverted, no exposure, $F(2, 62)=2.25$, $p=0.114$). There was a significant effect of test orientation, ($F(1, 31)=39.24$) and a significant interaction between the two factors, ($F(2, 62)=5.12$). Simple effects analysis of this interaction revealed that in the upright test conditions performance was better after upright exposure than it was after inverted or no exposure, ($F(1, 31)=4.52$ and $F(1, 31)=9.08$ respectively), while the inverted and no exposure conditions did not differ, ($F<1$). In the inverted test conditions performance was better after inverted exposure than it was after upright or no exposure, ($F(1, 31)=6.36$, and $F(1, 31)=4.25$ respectively), while the upright and no exposure conditions did not differ, ($F<1$). Performance in all conditions was above chance (minimum $t(31)=2.08$). Table 18 shows the reaction time data from Experiment 10C and ANOVA revealed no significant effects of exposure condition or test orientation, or interaction between these factors (Fs<1).

As in Experiment 10A an inversion effect is seen here, suggesting that these stimuli are indeed being processed as faces. Moreover the benefit of exposure is only apparent when the test orientation is the same as that experienced during pre-exposure. This lack of transfer is at least consistent with the idea that different features are used in the processing of upright and inverted faces, for example, the specific idea that the representation of upright faces depends on the use of configural or holistic information not available in the processing of inverted faces (e.g., Bartlett & Searcy, 1993, 1996;

Robbins & McKone, 2003; Friere et al., 2000). Another important implication the lack of transfer of perceptual learning is that the effect itself cannot be based on the participant extracting some obvious or global pictorial cues, such as luminance differences.

4.4 *Discussion*

Experiment 9 revealed that exposure to a face produces an advantage in discrimination on internal features but not with external features. Experiments 10A-C demonstrated that discrimination of these face stimuli was easier when the faces were upright than inverted and that perceptual learning also occurs when a face is exposed inverted. In addition, there was no transfer of perceptual learning between upright and inverted orientations. Furthermore, using very similar methodology and stimuli to the experiments described above, Dwyer, Mundy, Vladeanu and Honey (2006) report an experiment which demonstrates that exposure produces better discrimination regardless of whether or not there is a change in the angle at which the faces are viewed between exposure and test. Full and three-quarter portrait views of faces were presented to participants during a pre-exposure stage, and same/different judgements were made in a subsequent simultaneous discrimination. Performance was more accurate in both the exposed-same orientation (either full-face to full-face or three-quarter-face to three-quarter-face) and exposed-changed orientation (either full-face to three-quarter-face or *vice versa*) conditions than in the non-exposed control condition. The result reported by Dwyer et al. (2006), showing that perceptual learning can transfer between two images of the same face, is consistent with Bruce (1982), who shows that the recognition of familiar faces is independent of viewpoint. In so far as the inversion effect, viewpoint invariance and the selective use of internal features are indicative of familiar face processing, then the results of Experiments 9-10C, and Dwyer et al. (2006) show that the faces used in the experiments reported in this thesis actually engage face processing mechanisms.

The results reported by Dwyer et al. (2006) are particularly interesting because they demonstrate that the perceptual learning seen with the kinds of stimuli used in the experiments reported in this thesis does not simply reflect ‘pictorial’ processing. Further indirect evidence that supports this contention comes from the results of Experiment 4. In this experiment, exposure to the midpoint resulted in a perceptual learning effect in spite of the fact that the midpoint was not presented during the test. Similarly, the lack of transfer in Experiment 10C is also inconsistent with the use of gross pictorial features.

It is worth noting here that there is one important difference between the experiments reported in Chapters 3 and 4, and those traditionally reported with face stimuli. The current tasks involving discrimination, either learning to categorise people as left or right handed or married or unmarried, differ from many other studies of face processing based on recognition. The emphasis on recognition directly reflects one of the key goals of face processing - the ability to identify individuals. However, identifying an individual is not simply a process of matching from a stored sample to a target, but also requires the ability to discriminate between that sample and non-targets. It could be suggested that the discrimination tasks used here are distinctly different from the recognition tasks used elsewhere. This is not to say that recognition and discrimination tasks address entirely separate aspects of behaviour: for example while Ellis et al. (1979) used recognition tasks in their demonstration that the representation of familiar faces is weighted more to internal features than it is in unfamiliar faces, O'Donnell and Bruce (2001) used a discrimination task to demonstrate that this internal advantage was selective to the eye region. So, although the current tasks focus on discrimination of similar faces, there is no reason to suppose that they do not inform us about the nature of face processing more generally. I will return to this in the General Discussion.

Inversion effects, an advantage for internal features in the processing of familiar faces, and the fact that the processing of familiar faces is not disrupted by a change in image have all been demonstrated previously in the context of face processing (e.g., Bruce, 1982; Bonner et al., 2003; Ellis et al., 1979; O'Donnell & Bruce, 2001, Yin, 1969). These face processing phenomena have been reproduced here using stimuli that were created using a morphing procedure, and learning has taken place over a carefully structured, brief period, indicating that well established face processing phenomena are influenced by perceptual learning with my morphed faces. By reporting data in line with those shown in experiments which use far longer periods of exposure (e.g., Bonner et al., 2003), Chapter 4 adds weight to the claim, that the studies reported in Chapter 3, not only inform our understanding of perceptual learning in general but also its role in face processing in particular.

Chapter 5

General Discussion

5.1 *Summary of results*

In Chapter 2, two experiments using flavoured cues in humans were reported that closely parallel those conducted in rats. Experiment 1 confirmed using a within-participants procedure that intermixed exposure (to AX and BX) is a more effective way of generating perceptual learning than is blocked exposure. In Experiment 2, the order in which the pairs of compounds were presented was varied, revealing that the forward order (i.e., to-be-conditioned compound presented consistently before the non-conditioned compound, AX→BX) was more effective in producing perceptual learning than a backward order.

Chapter 3 used visual stimuli to examine perceptual learning in humans. Experiment 3 confirmed that brief exposure to morph-created pictures of human faces produced a perceptual learning effect that is stimulus specific, whilst Experiment 4 established that schedule of pre-exposure (intermixed or blocked) is critical in producing the perceptual learning effect. Taken together these two experiments demonstrated that the stimuli and procedures used in the bulk of this Chapter (discrimination of pictures of faces) produced a perceptual learning effect that was sensitive to the same manipulations as other classes of stimuli. Experiments 5 and 6 assessed whether or not simultaneous and successive modes of stimulus presentation result in differences in perceptual learning that were independent of how discriminability was assessed. The results indicated that simultaneous exposure promotes subsequent discrimination learning relative to successive exposure. Experiment 7 demonstrated that, at least when the stimuli were quite different, simultaneous exposure also resulted in an excitatory association forming between the two stimuli, making the results of Experiments 5 and 6 all the more surprising. Experiment 8 confirmed that the effects seen in Experiments 5-7 were also evident when the stimuli were pictures of chequerboards rather than pictures of faces.

Chapter 4 considered the specific contribution of perceptual learning to face processing, with the face stimuli used in Chapter 3. Experiment 9 revealed that exposure to a face increased discriminability to the internal features but not the external features. Experiment 10 showed that discrimination of upright faces was better than inverted faces and that perceptual learning occurs with both orientations, although there was no transfer of perceptual learning between theses orientations.

5.2 *Inhibitory associations contribute to perceptual learning in humans*

In Experiment 2, the order in which the pairs of compounds were presented was varied: forward (AX→BX) and backward (DY→CY). An aversion then established to AX and CY generalized less markedly to BX than to DY. Such a difference in generalisation has previously been taken to be good evidence for the contribution of inhibition to perceptual learning in rats. By the same token, the results of Experiment 2 can be taken as evidence for the role of inhibition in human perceptual learning. On the face of it, a Gibsonian analysis is undermined by this pattern of results because both orders of pre-exposure provide equivalent opportunity for stimulus comparison. It is possible that Gibson could be defended by suggesting that whilst both orders support good discrimination, only the backward order supports an excitatory link from D to C. Therefore when DY is presented at test the participants are aware it is not CY, but respond regardless as CY is predicted. It should be recognised that this defence of Gibson's comparison theory itself rests on an assumption; namely, the fact that CY can activate DY at test is more influential than the fact that AX can activate BX during training (providing a source of mediated conditioning to BX).

There are other aspects of the results that are more consistent with an associative analysis than a Gibsonian analysis. In particular, same/different judgements were not differentially affected by the types of pre-exposure given in Experiments 1 and 2. Unlike the Gibsonian analysis, associative models of perceptual learning are not constrained to predict that all measures of discrimination should be affected in the same way (see Dwyer et al., 2004, where a similar dissociation in assays of discriminability was observed). However, no firm conclusion can be drawn from same/different judgement data in both Experiments 1 and 2 since all results were at chance levels throughout the training and test sequences. This could simply be due to the fact that this assay of discrimination is simply not a sensitive enough measure. The explicit knowledge of the nature of transition from one stimulus to the next is clearly not required for the more sensitive test of discrimination, generalisation of aversion measured by ratings of pleasantness, to be accessible.

The results of Experiment 2 are also inconsistent with Hall's (2003) salience modulation account of perceptual learning. Hall (2003) suggested that, while repeated presentation of a stimulus reduces its effectiveness, repeated activation of the representation of a stimulus in its absence might increase (or at least maintain) its effectiveness. However, in Experiment 2 both forward and backward orders should result in the preserved salience of unique elements. In both presentation orders, the salience of the unique cues should be maintained as the common element will repeatedly activate their representations in their absence. This suggests that both orders should be equally effective in reducing generalisation. Indeed, it is possible to interpret Hall's ideas as being even less consistent with the current results: Given that AX precedes BX, retrieval of A in its absence may be impaired due to residual activation from its actual presentation and thus the degree to which its salience is maintained may be lower than that of the unique element presented second. In this case, X would gain more associative strength when AX is trained than would Y when CY is trained. This implies that perceptual learning should be *reduced* after forward training, which is the opposite of the results observed in Experiment 2.

The parallels between the data reported in Chapter 2 and those currently in the animal learning literature are clear. It appears that inhibition contributes to perceptual in humans as well as animals. On this evidence alone, one might thus conclude that mutual inhibition accounts for all cases of perceptual learning. However, this conclusion is not supported by the results of the other experiments reported in this thesis in which the critical stimuli were visual stimuli. In Experiments 5, 6 and 8 it was shown that discrimination learning proceeded more readily after simultaneous exposure to stimuli than after successive/intermixed exposure to them. This pattern of results is inconsistent with the associative analysis because simultaneous exposure to two stimuli will result in a positive association between them, producing increased generalisation. In contrast, in the intermixed case it is likely that inhibitory associations will form. The apparent contrast in results between Experiments 1 and 2 and Experiments 5 to 8 suggests that more than one process contributes to perceptual learning and that the associative mechanism of inhibition, and the Gibsonian mechanism of differentiation are good candidates to examine in this context.

5.3 *Comparing the contribution of associative and Gibsonian accounts of perceptual learning*

The finding from Experiment 4 that exposure to the midpoint on the morph between two stimuli improved subsequent discrimination between them is, to my knowledge, the first demonstration of such an effect (with faces). This effect can be explained with a relatively simple interpretation in terms of well established associative principles (e.g., McLaren & Mackintosh, 2000; 2002). If complex stimuli are thought of as a collection of simpler features (although these will be described as elemental there is nothing in this approach which prevents such features reflecting relational or configural information) then the degree of similarity between two stimuli is related to the degree to which they share features: similar stimuli will have many features in common while different stimuli will share few features. Due to the fact that similar stimuli share a large proportion of features these common elements will, other things being equal, predominate in the perception and learning about such stimuli. However, simple exposure to the common elements will reduce the degree to which those elements will enter into later associations/learning by a process of latent inhibition (see Lubow, 1989; or a reduction in salience, see Hall, 2003) and thus allow the unique elements (that are experienced less) to play a greater role. In the current case, the midpoint on the morph between two stimuli should contain most of the features common to both of the target stimuli and few of the features unique to each. Thus, exposure to this midpoint should result in the unique features of the two stimuli playing a proportionally greater role than the common elements.

In addition to outlining how latent inhibition could contribute to perceptual learning McLaren and Mackintosh (2000) note that associative principles can also account for the advantage of intermixed over blocked exposure, through the action of mutual inhibition. As described earlier, this account implies that as perceptual learning is based on the formation of inhibitory links between the unique features of two stimuli, anything which reduced the impact of these inhibitory links or interfered with their formation should also interfere with perceptual learning. Presenting the to-be-discriminated stimuli side by side, as in Experiments 5, 6 and 8, should not allow the formation of inhibitory links; indeed it should produce the opposite, namely the formation of excitatory connections based on the simultaneous occurrence of all features (see Experiment 7). Thus the McLaren and Mackintosh model is constrained to predict that simultaneous exposure should produce worse performance than successive exposure. The fact that simultaneous exposure produced better discrimination than successive exposure in Experiments 5, 6 and 8 implies that the formation of inhibitory associations (or indeed, any of mechanisms of McLaren & Mackintosh, 2000) cannot offer a complete explanation of the perceptual learning effects that have been observed[4].

One potential reason that inhibition may not have played a role in the current results might be that exposure was brief. The formation of inhibitory associations is reliant upon the prior formation of excitatory within-compound associations. Thus, inhibition would be expected to emerge relatively late in training: an idea supported by simulations of the McLaren and Mackintosh model (Artigas, Chamizo, & Peris, 2001). Indeed, Prados, Hall, and Leonard (2004) have demonstrated that evidence for perceptual learning in a conditioned taste aversion procedure can emerge before evidence of inhibition. So there simply may not have been enough presentations of the stimuli during exposure for inhibitory links to form between their unique features. That said, in Experiments 5, 6 and 8 successive exposure was not merely no better than simultaneous exposure at underpinning perceptual learning, but it was significantly inferior. This suggests that in addition to the associative processes outlined by McLaren and Mackintosh (2000) a second process must be operating to account for the facilitation of discrimination produced by simultaneous presentation. Of course this

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[4] Bennett and Mackintosh (1999, see also Honey and Bateson, 1996) reported that very rapid alternation (effectively simultaneous exposure) to two flavoured cues AX and BX supported less perceptual learning than alternating exposure which contrasts with the results of Experiments 5, 6 and 8. Bennett and Mackintosh's results may be an artefact of the stimuli they used. Simultaneous exposure to compound stimuli AX and BX creates an ambiguous situation akin to exposure to an ABX compound thus creating mutually excitatory links between the elements of the compound. However, the visual stimuli used here maintain the presentation of two separate cues thus resolving any ambiguity.

second process could be contributing to the perceptual learning produced by exposure more generally.

This second process need not prevent associative processes though it must produce a more powerful perceptual learning effect than inhibition and also be strong enough to outweigh the excitatory associations formed between two simultaneously presented stimuli. The fact that such excitatory associations are formed was shown in Experiment 7, at least when the stimuli were quite different. The idea that two processes are engaged by presenting two stimuli together is not new (see Honey, et al., 1994 for an earlier discussion of this idea) but it leaves open the question of what this second process might be. Gibson's (1969) idea of stimulus differentiation is an obvious candidate in that she clearly specifies that the conditions which favour differentiation are exactly the simultaneous exposure conditions found here to produce the strongest perceptual learning effects. In her own words "simultaneous comparison is no doubt the simplest for differentiation of two stimulus objects and the discovery of contrasts and feature differences must begin in this way" (Gibson, 1969, p.145). However, while the conditions that favour stimulus differentiation are well specified, Gibson gives very little idea of what mechanisms might underpin this process thus raising the question of whether previously proposed development of Gibson's (1969) ideas can provide an adequate account of the current results, namely those of Hall (2003) and Saksida (1999).

Unlike the original, Hall's (2003) extension of Gibson's (1969) comparison account can also explain the facilitatory effects of exposure to the common elements of a pair of stimuli because it predicts the reduction in effectiveness of repeatedly presented features in the absence of comparison. Although Hall's suggestion that activating a stimulus in its absence will raise its salience has some independent empirical support (e.g., Blair & Hall, 2003; Artigas, Sansa, Blair, Hall, & Prados, 2006) it too fails to explain the results of Experiments 5, 6 and 8. Simultaneous presentation is unlikely to provide an opportunity for the repeated activation of the representation of the unique features of the two stimuli in their absence because all linked stimuli are always presented together.

Another development of Gibson's ideas is presented by Saksida (1999) who implemented a form of the differentiation account in a connectionist model of perceptual learning. Unfortunately this model also fails to account for Experiments 5, 6 and 8 in that simultaneous exposure should lead to the formation of a single unified representation of the compound stimulus. One might address this issue by considering simultaneous presentation as effectively producing rapid alternation between the stimuli. However, the fact remains that in Experiment 7 simultaneous exposure produced excitatory associations. Within Saksida's model, associations between the elements of a stimulus can only be represented within the hidden layer which makes it implausible to suggest that simultaneous exposure can produce both excitatory associations and produce perceptual learning. Thus it appears that previous attempts to reformulate Gibson's informal idea of stimulus differentiation have actually failed to preserve the key feature of her account, namely that simultaneous comparison will best support perceptual learning.

5.4 *Attentional weighting and perceptual learning*

It is a relatively straightforward matter to envisage why *supervised discrimination training* might bring about a shift in attentional weighting toward the unique features of two stimuli and away from their common features. For example, during the discrimination learning stage of Experiment 4 the unique features of the novel pair of faces D and D′ (i.e., D-unique and D′-unique) are predictive or diagnostic with respect to which of the depicted people is right- and which left –handed, whereas the common features (D,D′-common) are not. It has been argued that under such circumstances the amount of attention should become greater to the predictive, unique features than to the common features (for example, see Lawrence, 1949, Mackintosh, 1975) or that the representations of the two faces should become increasingly distinct (for example, see Gluck & Myers, 1993; Honey & Ward-Robinson, 2002). Of course, during the *unsupervised exposure* used in the first stages of the current experiments the impetus for these kinds of process to operate (the relative predictive value of the unique and common features) is absent and these processes therefore provide no obvious basis for the effects observed here.

One simple way in which changes in attentional weightings might be brought about during simple exposure is based on the observation that during exposure to two stimuli (e.g., A and A′ in Experiment 4) the features that they share are presented twice as often (they are present in both A and A’ trials) as their unique features. If one supposed that presentation of a stimulus results in a decline in the effective processing that a stimulus received (through a process of adaptation or habituation), then the common elements would be more likely to suffer from such a decline than the unique elements. Provided that this effect was maintained between the exposure and discrimination learning stages (see below) then it might provide a basis for most of the perceptual learning effects observed in Experiment 3 and 4. Indeed, thus far, this is simply a more general statement of the analysis provided by McLaren and Mackintosh (2000) that considers processes other than latent inhibition. However, there are other aspects of these results that appear to be less readily accommodated by the suggestion that exposure to two similar stimuli results in differential exposure to their unique and common features. In Experiment 4, the number of occasions on which the faces were presented in the intermixed and blocked conditions was equated, with the necessary consequence that the number of exposures to the unique and common features of the pairs of faces in the two conditions was also equated. However, subsequent discrimination learning proceeded more rapidly in the intermixed than the blocked condition. Similarly, in simultaneous and successive modes of presentation the numbers of exposures to the pairs of faces is equated (Experiment 5 and 8), or was greater in the successive mode (Experiment 6) and yet discrimination learning proceeded more rapidly in the simultaneous mode of exposure. Clearly, if one is seeking a general explanation for the perceptual learning effects observed here in terms of changes in attentional weighting, then it must also be able to provide an account for the effects of both the schedule of exposure (intermixed versus blocked) and the mode of exposure (simultaneous versus successive).

One such account follows from the observation that although the two schedules of exposure and the two modes of presentation equate the number of exposures to the pairs of faces they clearly do not equate the relative frequency of exposure to the unique and common features. Thus, during intermixed exposure the interval between presentations of the unique features is twice that between those of the common elements, whereas this is not the case during blocked exposures. Similarly, during simultaneous exposure when participants shift gaze between one side of the array and the other, the common features have very recently been encountered whereas this will not be the case during successive exposures. These differences in the patterning of exposure to the unique and common elements might be a particularly effective means of adapting or habituating the common features of the two stimuli and leaving their unique features to have greater impact in the intermixed than the blocked conditions and in the simultaneous than successive conditions. This process of short-term habituation is unlikely to have a direct effect on discrimination learning, because the exposure and discrimination stages are separated by many minutes and training procedures involving other stimuli. Instead, it seems that one must suppose that the differences in the processes of adaptation/habituation, that are brought about by the mode (and schedules) of presentation, results in some long-lasting change wherein the unique elements become better represented and available to be learnt about subsequently. That is, the operation of short-term adaptation/habituation effect has enduring repercussions for the attentional weighting given to the unique and common features. This kind of approach, involving the interaction between low level habituation processes and higher level attentional or representational processes has been entertained on more than one occasion (see Ahissar & Hochstein, 2004; Honey & Bateson, 1996) and allows a coherent explanation to be provided for the results of Experiments 3-8. It is also the case that this process will be less likely to operate when the stimuli that are simultaneously presented share relatively few common elements (cf. Experiment 7). One way in which this general approach could be instantiated is within a connectionist framework. I will illustrate this with respect to a connectionist model that has recently been applied to aspects of face processing although the general features of the account would be equally applicable to any stimulus domain.

5.5 *Perceptual learning, face processing and neural networks*

The results reported in Chapters 3 and 4 are clearly relevant to face processing. With this in mind, it is now worth considering the general interpretation of the results of Chapter 3 with specific reference to face processing. The theoretical analysis of Experiments 3-8 focussed on a variety of ways in which the attentional weighing given to the unique and common 'features' might change as the result of simple stimulus exposure. In the face processing literature there have been attempts to establish the features or components of faces that are potentially available using principal component analysis (PCA, e.g., Burton et al., 1999a; Furl, Phillips, & O'Toole, 2002; O'Toole et al., 1995). Interestingly, some recent models (e.g., Moghaddam & Pentland, 1998; Zhao, Krishnaswamy, Chellappa, Swets, & Weng, 1998) have added a second stage to the PCA-based feature extraction where the PCA derived space is warped to improve the discrimination between the individuals represented. It transpires that such models give a better account of one experience-based effect on face processing, the own-race bias, than purely PCA-based models (Furl et al., 2002). This improvement highlights the fact that simply extracting the relevant dimensions on which face stimuli vary might not be a complete description of perceptual learning and that modifications in the weights (i.e., warping the space) given to these factors might also play an important role. One way to implement this general suggestion is within the kind of connectionist model of face recognition described by Burton (1994).

Burton (1994) assumes that the presentation of a face produces a pattern of activity across a set of input units. It is supposed that initially these input units are fully connected to a layer of hidden units (face recognition units, FRUs) by links with random weights. On encountering a new face, it is assumed the links between the input units activated by that face and a specific FRU are strengthened (according to Hebbian-learning principles) and that this FRU comes to represent or 'recognise' that specific face. One way in which this kind of model could account for the results presented in Experiments 3-8 is to make the simple and plausible additional assumption that the input units that are activated by the unique and common features of two faces are subject to short-term adaptation or habituation. In other words, this would produce effective differentiation at an early stage in the representation of stimulus elements. Thus, when two similar faces are presented close together in time this will mean that the input units that are uniquely activated by each face will be more active (as these are encountered intermittently) than the units which are activated by their common features (as these are encountered on every trial and thus fatigued or habituated). Similarly, selective presentation of the common features alone (as in the midpoint condition in Experiment 4) would reduce the activity of the input units excited by these common features while leaving the activity of the units representing the unique features intact. One consequence of this will be that the unique input units will have greater opportunity to become linked to the two faces' FRUs than will the units that are commonly activated by both faces. In short, the operation of a short-term adaptation/habituation process will bias the system to link the unique features of similar faces to different FRUs and enhance the long-term discriminability of those faces.

One obvious problem with this analysis is that without additional assumptions the unique features of simultaneously presented faces (e.g., A-unique and A'-unique) would come to activate the same FRU. This is similar to the problem identified with Saksida's (1999) model. This possibility could be avoided by supposing that excitatory associations between simultaneously presented elements could occur in the input layer, while it is differential representation in the hidden (or FRU) layer that will be critical when attempting to learn a difficult discrimination. Also worth consideration in this context is the suggestion (see McLaren & Mackintosh 2000) that the unique features of a stimulus will be sampled more variably than the common features (which become fatigued or lose salience), allowing unique features of the same stimulus to be associated together, strengthening the ability of future reactivation of any subset of elements to allow discrimination. The idea of including variable sampling and allowing direct associations between elements in the input layer provides a further basis to allow the unique elements of similar stimuli to activate different FRUs.

5.6 *Open Questions*

Perceptual learning has been seen to be general, robust and is based on the operation of multiple mechanisms. I have shown that both Gibsonian and associative mechanisms are required for perceptual learning, but it remains to be established when each mechanism contributes, and to what degree: For instance, it is a clear possibility that simultaneous exposure that enables Gibsonian processes to operate might only help discrimination when the stimuli are already perceived as individual objects (i.e., AX and BX), as in the case of human faces. If taste is considered, simultaneous exposure would presumably result in a single representation (akin to ABX). In this case Gibsonian comparison processes, of the kind considered above, would not be expected to act since there is nothing to compare the stimulus with. This possibility needs to be explored, given the suggestion that variable sampling might allow separate activation of AX and BX despite the fact that A, B and X are simultaneously present. A related possibility is that the operation of Gibsonian processes early in training might provide the pattern of effective stimulation upon which associative processes can work. Only when two stimuli are discriminable from one another can associative links form between them. This suggests that whilst simultaneous exposure might at first result in improved discrimination, extended simultaneous exposure could result in excitatory links that could outweigh this reduction in generalisation.

It was noted at the end of Chapter 4 that many studies in the area of face processing have used recognition tasks, in contrast to the discrimination tasks reported here. Although there is nothing in the analysis of perceptual learning presented here that would suggest the two types of task reflect different mechanisms, it is at least possible that the discrimination tasks here do not tap a process of face recognition *per se*. With this in mind, it may be worth replicating the effects of schedule of exposure using a test of recognition in order to demonstrate that perceptual learning effects result in an improved representation of a face (with respect to all other faces), rather than simply improving its discriminability from one similar face.

Another important aspect that remains to be discovered is whether perceptual learning is a general mechanism, operating for all domains, or resulting from a series of domain specific mechanisms which operate in a similar manner to one another.

Detecting the area(s) of the brain responsible for perceptual learning will in part help to address this point. The superiority of simultaneous exposure compare to successive exposure is seen with both chequerboards and human faces. This suggests that the two modalities reflect the operation of a common mechanism. However, recent neuropsychological evidence suggests that the two may depend on different neural substrates (Graham, Scahill, Hornberger, Barense, Lee, Bussey, & Saksida, 2006). Graham et al. (2006) show that lesions to different areas of the temporal cortex differentially affected the perceptual learning of faces, compared to other visually complex scenes. The possibility that a common mechanism supports perceptual learning across multiple substrates (and is thus domain-neutral) needs to be examined, not least because this addresses the notion that faces are special. Perhaps the most effective way might be to examine perceptual learning using neuroimaging tools. Functional magnetic resonance imaging should shed light on the neural location(s) of perceptual learning, and perhaps give a clue as to whether it results from domain-specific or domain-neutral processing.

Finally, the conclusions made in this thesis regarding a mechanism of perceptual learning that results from a process of short-term adaptation or habituation accompanied by long-term changes to the attentional weighting of the unique and common features of stimuli remain untested. Using the chequerboard stimuli, the relative frequency of exposure to the common elements can be manipulated, allowing a comparison to be made between massed and spaced exposure to the unique elements independent of the schedule of exposure to the entire stimulus.

5.7 *Concluding remarks*

The results presented in Chapter 3 and Chapter 4 suggest that the perceptual learning effect produced by brief exposure to pictures of similar stimuli can be captured by the operation of simple mechanism(s) producing greater habituation/adaptation to the common features of such stimuli. In turn, these short-lived processes affect the relative attentional weighting of the unique and common features of the target stimuli. Incorporating such general process mechanisms of perceptual learning within (connectionist) models of face processing allows them to provide a powerful analysis of how (unsupervised) experience modifies the discriminability of faces. More generally, the results that I have described are ones that any adequate theory of face processing and indeed any theory of perceptual learning will need to address.

My preferred analysis for some of the novel results that I have presented, and the results themselves, are generally consistent with Gibson's (1969) speculation regarding the origin of perceptual learning. Other, associatively based models of perceptual learning (e.g., Hall, 2003; McLaren & Mackintosh, 2000) that might otherwise have provided a computational mechanism for the processes described by Gibson, are contradicted by the fact that simultaneous exposure produced superior perceptual learning than did successive exposure. However, Chapter 2 shows that a Gibsonian model cannot account for the fact that order of pre-exposure effects later discrimination. The most straightforward explanation for these results is that based on the associative model of McLaren and Mackintosh (2000) in which inhibition plays a significant role. It has been argued elsewhere, and from a variety of perspectives, that multiple mechanisms will almost certainly contribute to perceptual learning (e.g., Artigas et al., 2006; Dwyer et al., 2004; Goldstone, 1998; Hall, 2003; Honey et al., 1994; McLaren & Mackintosh, 2000; Prados et al., 2004). Taken as a whole, this thesis demonstrates that perceptual learning is evident across a broad range of circumstances and appears to be underpinned by general processes. Mechanisms seen to be acting in animals have also been identified in humans, with a surprising degree of similarity. Moreover, many of the same mechanisms are apparent regardless of the modality of the stimulus in question. In particular, I have identified parallels between the perceptual learning processes involved with faces, a class of stimuli that has been considered by many to be unique, and other visual stimuli and indeed gustatory stimuli. These parallels are not only evident across different classes of stimuli but are also apparent across species.

Bibliography

Ahissar, M., & Hochstein, S. (2004). The reverse hierarchy theory of visual perceptual learning. *Trends on Cognitive Sciences*, *8*, 457-464.

Alonso, G., & Hall, G. (1999) Stimulus comparison and stimulus association processes in the perceptual learning effect. *Behavioural Processes*, *48*, 11-23.

Artigas, A. A., Chamizo, V. D., & Peris, J. M. (2001). Inhibitory associations between neutral stimuli: A comparative approach. *Animal Learning & Behavior, 29*, 46-65.

Artigas, A.A., Sansa, J., & Prados, J. (2006). The Espinet and perceptual learning effects in flavour aversion conditioning: Do they depend on a common inhibitory mechanism? *Quarterly Journal of Experimental Psychology*, *59*, 471-481.

Atkinson, J. (1984). Human visual development over the first six months of life: A review and a hypothesis. *Human Neurobiology*, *3*, 61-74.

Bartlett, J. C., & Searcy, J. (1993) Inversion and configuration of faces. *Cognitive Psychology*, *25*, 281-316.

Bäuml, K. H., Schnelzer, M., & Zimmer, A. (1997). Discrimination and association processes for faces and non-faces: the effect of rotation. *Acta Psychologica*, *95*, 107-118.

Beale, J. M., & Keil, F. C. (1995). Categorical Effects in the Perception of Faces. *Cognition*, *57*, 217-239.

Bennett, C. H., & Mackintosh, N. J. (1999). Comparison and contrast as a mechanism for perceptual learning? *The Quarterly Journal of Experimental Psychology: Comparative and Physiological Psychology*, *52*, 253-272.

Bennett, C. H., Scahill, V. L., Griffiths, D. P., & Mackintosh, N. J. (1999). The role of inhibitory associations in perceptual learning. *Animal Learning & Behavior, 27*, 333-345.

Bennett, C. H., Wills, S. J., Wells, J. O., & Mackintosh, N. J. (1994). Reduced generalisation following preexposure: latent inhibition of common elements or a difference in familiarity? *Journal of Experimental Psychology: Animal Behavior Processes, 20*, 232-239.

Blair, C. A. J., & Hall, G. (2003). Perceptual learning in flavor aversion: Evidence for learned changes in stimulus effectiveness. *Journal of Experimental Psychology: Animal Behavior Processes, 29*, 39-48.

Blair, C. A. J., Wilkinson, A., & Hall, G. (2004). Assessments of changes in the effective salience of stimulus elements as a result of stimulus preexposure. *Journal of Experimental Psychology: Animal Behavior Processes, 30*, 317-324.

Bonner, L., Burton, A. M., & Bruce, V. (2003). Getting to know you: How we learn new faces. *Visual Cognition, 10*, 527-536.

Broadbent, D. E. (1958). *Perception and communication.* New York: Pergamon Press.

Brown, B.R., & Rebbin, T.J. (1970). Simultaneous vs sequential discriminations of Markov-generated stimuli. *Perception & Psychophysics, 8*, 353-357.

Bruce, V. (1982). Changing Faces - Visual and Non-Visual Coding Processes in Face Recognition. *British Journal of Psychology, 73*, 105-116.

Bruce, V., & Burton, A. M. (2002). Learning new faces. In T. Poggio & M. Fahle (Eds.), *Perceptual learning* (pp. 317-334). Cambridge, MA, US: MIT Press.

Bruce, V., Henderson, Z., Greenwood, K., Hancock, P. J. B., Burton, A. M., & Miller, P. (1999). Verification of face identities from images captured on video. *Journal of Experimental Psychology: Applied, 5*, 339-360.

Bruner, J. S. (1957). Going beyond the information given. In *Contemporary approaches to cognition.* Cambridge, Mass.: Harvard University Press.

Burton, A. M. (1994). Learning new faces in an interactive activation and competition model. *Visual Cognition, 1*, 313-348.

Burton, A. M., Bruce, V., & Hancock, P. J. B. (1999a). From pixels to people: A model of familiar face recognition. *Cognitive Science, 23*, 1-31.

Burton, A. M., Wilson, S., Cowan, M., & Bruce, V. (1999b). Face recognition in poor-quality video: Evidence from security surveillance. *Psychological Science, 10*, 243-248.

Bushnell, I. W., Sai, F., & Mullin, J. T. (1989). Neonatal recognition of the mother's face. *British Journal of Developmental Psychology, 7*, 3-15.

Buttle, H., & Raymond, J. E. (2003). High familiarity enhances visual change detection for face stimuli. *Perception & Psychophysics, 65*, 1296-1306.

Carey, S. (1992). Becoming a face expert. *Philosophical Transactions of the Royal Society of London B, 335*, 95-103.

Channell, S., & Hall, G. (1981). Facilitation and retardation of discrimination learning after exposure to the stimuli. *Journal of Experimental Psychology: Animal Behavior Processes, 7*, 437-446.

Czerwinski, M., Lightfoot, N., & Shiffrin, R. M. (1992). Automatization and training in visual search. *American Journal of Psychology, 105*, 271-315.

De Gelder, B., & Rouw, R. (2001). Beyond localisation: A dynamical route account of face recognition. *Acta Psychologica, 107*, 183-207.

Diamond, R., & Carey, S. (1986). Why faces are and are not special: an effect of expertise. *Journal of Experimental Psychology: General, 115*, 107-117.

Dwyer, D. M., Bennett, C.H., Mackintosh, N.J. (2001). Evidence for inhibitory associations between the unique elements of two compound flavours. *Quarterly Journal of Experimental Psychology, 54B*, 97-109.

Dwyer, D. M., Hodder, K. I., & Honey, R. C. (2004). Perceptual learning in humans: Roles of preexposure schedule, feedback, and discrimination assay. *Quarterly Journal of Experimental Psychology, 57B*, 245-259.

Dwyer, D.M., & Mackintosh, N. J. (2002). Alternating exposure to two compound flavors creates inhibitory associations between their unique features. *Animal Learning and Behavior, 30*, 201-207.

Dwyer, D.M., Mundy, M.E., Vladenau, M., & Honey, R.C. (2006). Brief exposure to pictures of similar faces produces perceptual learning: specificity to internal features and orientation but generalisation across viewpoints. Submitted to: *Quarterly Journal of Experimental Psychology.*

Easterbrook, M. A., Kisilevsky, B. S., Hains, S. M. J., & Muir, D. W. (1999). Faceness or complexity: Evidence from newborn visual tracking of facelike stimuli. *Infant Behavior and Development, 22*, 17-35.

Ellis, H. D., & Shepherd, J. W. (1992). Face memory – theory and practise. In M.M. Gruneburg & P.E. Morris (Eds.), *Aspects of memory: Vol. 1. The practical aspects.* London: Routledge.

Ellis, H. D., Shepherd, J. W., & Davies, G. M. (1979). Identification of familiar and unfamiliar faces from internal and external features: Some implications for theories of face recognition. *Perception, 9*, 431-439.

Ewing, M. F., Larew, M. B., & Wagner, A. R. (1985). Distribution-of-trials effects in Pavlovian conditioning: An apparent involvement of inhibitory backward conditioning with short intertrial intervals. *Journal of Experimental Psychology: Animal Behavior Processes, 11*, 537-547.

Farah, M. J. (1992). Is an object an object an object? Cognitive and neuropsychological investigations of domain-specificity in visual object recognition. *Current Directions in Psychological Science, 1*, 164-169.

Farah, M. J., Wilson, K. D., Drain, M., & Tanaka, J. N. (1998). What is "special" about face perception? *Psychological Review, 105*, 482-498.

Freire, A., Lee, K., Symons, L. A. (2000). The face-inversion effect as a deficit in the encoding of configural information: Direct evidence. *Perception, 29*, 159 –170.

Furl, N., Phillips, P. J., & O'Toole, A. J. (2002). Face recognition algorithms and the other-race effect: computational mechanisms for a developmental contact hypothesis. *Cognitive Science, 26*, 797-815.

Gaffan, D. (1996). Associative and perceptual learning and the concept of memory systems. *Cognitive Brain Research, 5*, 69-80.

Gagné, R., & Gibson, J. J. (1947) Research on the recognition of aircraft. Ch 7 in J. J. Gibson (Ed.) *Motion picture training and research.* Report No.7, Army Air Force Aviation Psychology Program, Research Reports, U. S. Government Printing Office, Washington D.C.

Gautheir, I., & Tarr, M. J. (1997). Becoming a "Greeble" expert: exploring mechanisms for face recognition. *Vision Research*, 37, 1673-1682.

Gauthier, I., Tarr, M. J., Anderson, A. W., Skudlarski, P., & Gore, J. C. (1999). Activation of the middle fusiform "face area" increases with expertise in recognising novel objects. *Nature Neuroscience, 2*, 568-573.

Gibson, E. J. (1963). Perceptual Learning. *Annual Review of Psychology, 14*, 29-56.

Gibson, E. J. (1963a). Perceptual development. Ch 4 in H. W. Stevenson, J. Kagan, & C. Spiker (Eds.), *Child Psychology*, 62nd Yearbook of the National Society for the Study of Education, 144-195.

Gibson, E. J. (1969). *Principals of perceptual learning and development.* New York: Appelton-Century-Crofts.

Gibson, E. J., & Walk, R. D. (1956). The effect of prolonged exposure to visually presented patterns on learning to discriminate them. *Journal of Comparative and Physiological Psychology, 49,* 239-242.

Gibson, J. J., & Gibson, E. J. (1955). Perceptual learning: Differentiation or enrichment? *Psychological Review, 62,* 32-41.

Gluck, M.A., & Myers, C.E. (1993). Hippocampal mediation of stimulus representation: A computational theory. *Hippocampus, 3,* 491-516.

Goldstone, R. L. (1994). Influences of categorisation on perceptual discrimination. *Journal of Experimental Psychology: General, 123,* 178-200.

Goldstone, R. L. (1995). Effects of categorisation on colour perception. *Psychological Science, 6,* 298-304.

Goldstone, R. L. (1996). Isolated and interrelated concepts. *Memory and Cognition, 24,* 608-628.

Goldstone, R.L. (1998). Perceptual learning. *Annual Review of Psychology, 49,* 585-610.

Goldstone, R. L., Schyns, P. G., & Medin, D. L. (1997). *The Psychology of Learning and Motivation,* San Diego: Academic.

Goldstone, R. L., Steyvers, M., & Rogosky, B. J. (2003). Conceptual interrelatedness and caricatures. *Memory and Cognition. 31,* 169-180.

Gollin, E. S. (1960). Tactual form discrimination: Developmental differences in the effects of training under conditions of spatial interference. *Journal of Experimental Psychology, 60,* 126-129.

Graham, K. S., Scahill, V. L., Hornberger, M., Barense, M. D., Lee, A. C. M., Bussey, T. J., & Saksida, L. M. (2006). Abnormal categorisation and perceptual learning in patients with hippocampal damage. *Journal of Neuroscience, 26*, 7547-7554.

Graham, S. (1999). Retrospective revaluation and inhibitory associations: Does perceptual learning modulate our perception of the contingencies between events? *Quarterly Journal of Experimental Psychology Section B- Comparative and Physiological Psychology, 52*, 159-185.

Grossberg, S. (1984). Unitisation, automaticity, temporal order, and word recognition. *Cognitive Brain Theory*, *7*, 263-283.

Grossberg, S. (1991). Nonlinear neural netoworks: Principles, mechanisms and architectures. In *Pattern Recognition by Self-Organising Networks,* GA Carpenter & S Grossberg (Eds.). pp36-109. Cambridge, MA: MIT Press.

Haig, N. D. (1985). How faces differ: A new comparative technique. *Perception*, 14, 601-615.

Haig, N. D. (1986). Exploring recognition with interchanged facial features. *Perception, 15*, 235-247.

Hall, G. (1991) *Perceptual and associative learning*: New York, NY, US Clarendon Press / Oxford University Press.

Hall, G. (2003). Learned changes in the sensitivity of stimulus representations: Associative and nonassociative mechanisms. *Quarterly Journal of Experimental Psychology Section B- Comparative and Physiological Psychology, 56*, 43-55.

Hancock, P. J., Bruce, V., & Burton, M. A. (1998). A comparison of two computer-based face identification systems with human perceptions of faces. *Vision Research*, *38*, 2277-2288.

Heyes, C. (2003). Four Routes of Cognitive Evolution. *Psychological Review*, *4*, 713-727.

Honey, R. C., Bateson, P., & Horn, G. (1994). The Role of Stimulus Comparison in Perceptual-Learning - an Investigation with the Domestic Chick. *Quarterly Journal of Experimental Psychology, 47B*, 83-103.

Honey, R.C. (1990). Stimulus generalization as a function of stimulus novelty and familiarity in rats. *Journal of Experimental Psychology: Animal Behavior Processes, 16*, 178-184.

Honey, R.C., & Bateson, P. (1996). Stimulus comparison and perceptual learning: Further evidence and evaluation from an imprinting procedure. *Quarterly Journal of Experimental Psychology, 49B*, 259-269.

Honey, R.C., & Hall, G. (1989). Enhanced discriminability and reduced associability following flavor preexposure. *Learning and Motivation, 20*, 262-277.

Honey, R.C., & Ward-Robinson, J. (2002). Acquired equivalence and distinctiveness of cue: I. Exploring a neural network approach. *Journal of Experimental Psychology: Animal Behavior Processes, 28*, 378-387.

Ishai, A., Ungerleider, L. G., Martin, A., Maisog, J. M., & Haxby, J. V. (1997). fMRI reveals differential activation in the ventral object vision pathway during the perception of faces, houses and chairs. *Neuroimage, 5*, S149.

James, W. (1890). *The principles of psychology*. Oxford, England: Holt.

Johnson, M. H. (1999). Ontogenetic constraints on neural and behavioural plasticity: Evidence from imprinting and face processing. *Canadian Journal of Experimental Psychology, 53*, 77-90.

Karni, A., & Sagi, D. (1991). Where practise makes perfect in texture discrimination: evidence for primary visual cortex plasticity. *Proceedings of the National Academy of Sciences*, USA, *88*, 4966-4970.

Kanwisher, N. (2000). Domain specificity on face perception. *Nature Neuroscience, 3*, 759-763.

Laming, D., & Scheiwiller, P. (1985). Retention in perceptual memory: A review of models and data. *Perception & Psychophysics*, *37*, 189-197.

Lawrence, D.H. (1949). Acquired distinctiveness of cues. I: Transfer between discriminations on the basis of familiarity with the stimulus. *Journal of Experimental Psychology*, *39*, 770-784.

Lawrence, D. H. (1952). The transfer of discrimination along a continuum. *Journal of comparative and physiological Psychology*, *45*, 511-516.

Levin, D. T. (2000). Race as a visual feature: Using visual search and perceptual discrimination tasks to understand face categories and the cross-race recognition. *Journal of Experimental Psychology-General, 129*, 559-574.

Levin, D. T., & Beale, J. M. (2000). Categorical perception occurs in newly learned faces, other- race faces, and inverted faces. *Perception & Psychophysics, 62*, 386-401.

Lewis, M. B. (2004). Face Space-R: Towards a unified account of face recognition. *Visual Cognition*, *11*, 29-69.

Liu, C. H., & Chaudhuri, A. (2003). What determines whether faces are special? *Visual Cognition*, *10*, 385-408.

Lubow, R. E. (1989). *Latent inhibition and conditioned attention theory*. New York: Cambridge University Press.

Luce, R. D., Green, D. M., & Weber, D. L. (1976). Attention bands in absolute identification. *Perception and Psychophysics*, *20*, 49-54.

MacCaslin, E. F. (1954). Successive and simultaneous discrimination as a function of stimulus-similarity. *American Journal of Psychology*, *67*, 308-314.

Mackintosh, N. J. (1969). Further analysis of the overtraining reversal effect. *Journal of Comparative and Physiological Psychology*, *67*, 1-18.

Mackintosh, N. J. (1974). A search for contrast effects in discrete-trial discrimination learning by pigeons. *Learning and Motivation, 5,* 311-327.

Mackintosh, N.J. (1975). A theory of attention: Variations in the associability of stimuli with reinforcement. *Psychological Review, 82,* 276-298.

Mackintosh, N. J., Kaye, H., & Bennett, C. H. (1991). Perceptual learning in flavour aversion conditioning. *The Quarterly Journal of Experimental Psychology: Comparative and Physiological Psychology, 43,* 297-322.

Maier, S. F., Rapaport, P., & Wheatly, K. L. (1976). Conditioned inhibition and the UCS-CS interval. *Animal Learning and Behavior, 4,* 217-220.

McLaren, I. P. L. (1997). Categorisation and perceptual learning: an analogue of the face inversion effect. *The Quarterly Journal of Experimental Psychology: Human Experimental Psychology, 50,* 257-273.

McLaren, I. P. L., Kaye, H., & Mackintosh, N. J. (1989). An associative theory of the representation of stimuli: Applications to perceptual learning and latent inhibition. In R.G.M. Morris (Ed), *Parallel distributed processing: Implications for psychology and neurobiology.* (pp.102-130). New York, NY, US: Clarendon Press/Oxford University Press.

McLaren, I. P. L., & Mackintosh, N. J. (2000). An elemental model of associative learning: I. Latent inhibition and perceptual learning. *Animal Learning and Behavior, 28,* 211-246.

McLaren, I. P. L., & Mackintosh, N. J. (2002). Associative learning and elemental representation: II. Generalization and discrimination. *Animal Learning & Behavior, 30,* 177-200.

Miller, N.E., & Dollard, J. (1941). *Social learning and imitation.* London: Kegan Paul, Trench, Trubner & Co.

Moghaddam, B., & Pentland, A. (1998). Beyond linear eigenspaces: Bayesian matching for face recognition. In H. Wechsler, P. J. Phillips, V. Bruce, F. F. Soulie & T. S. Huang (Eds.), *Face recognition: From theory to applications* (pp. 230-243). Berlin: Springer-Verlag.

Mondragón, E., & Hall, G. (2002). Analysis of the perceptual learning effect in flavour aversion learning: evidence for stimulus differentiation. *The Quarterly Journal of Experimental Psychology: Comparative and Physiological Psychology, 55*, 153-169.

Morton, J., & Johnson, M. H. (1991). CONSPEC and CONLERN: A two-process theory of infant face recognition. *Psychological Review, 98*, 164-181.

Moscovitch, M., Winocur, G., & Behrmann, M. (1997). What is special about face recognition? Nineteen experiments on a person with visual object agnosia and dyslexia but normal face recognition. *Journal of Cognitive Psychology, 9*, 555-604.

O'Donnell, C., & Bruce, V. (2001). Familiarisation with faces selectively enhances sensitivity to changes made to the eyes. *Perception, 30*, 755-764.

O'Hara, W. (1980). Evidence in support of word unitization. *Perception and Psychophysics, 27*, 390-402.

O'Toole, A. J., Abdi, H., Deffenbacher, K. A., & Valentin, D. (1995). A perceptual learning theory of the information in faces. In T. Valentine (Ed.), *Cognitive and computational aspects of face recognition: Explorations in face space* (pp. 159-182). London: Routledge.

O'Toole, A. J., Peterson, J., & Deffenbacher, K. A. (1996). An 'other-race' effect for categorising faces by sex. *Perception, 25*, 669-676.

Pavlov, I.P. (1927). *Conditioned reflexes*. Oxford: Oxford University Press.

Poggio, T., Fahle, M., & Edelman, S. (1992). Fast perceptual learning in visual hyperacuity. *Science, 256*, 1018-1021.

Prados, J., Hall, G., & Leonard, S. (2004). Dissociation between the Espinet and perceptual learning effects in flavour aversion conditioning. *Behavioural Processes, 65*, 221-229.

Recanzone, G. H., Merzenich, M. M., & Jenkins, W. M. (1992). Frequency discrimination training engaging a restricted skin surface results in an emergence of a cutaneous response zone in cortical area 3a. *Journal of Neurophysiology, 67*, 1057-1070.

Rescorla, R. A., & Wagner, A. R. (1972). A theory of Pavlovian conditioning: Variations in the effectiveness of reinforcement and non-reinforcement. In A.H. Black & W.F. Prokasy (Eds.), *Classical Conditioning II: Current research and theory*, pp. 81-111, Hillsdale, NJ: Erlbaum.

Rhodes, G. (1988). Looking at faces: First-order and second-order feature as determinates of facial appearance. *Perception, 17*, 43-63.

Rhodes, G., Brake, S., & Atkinson, A. P. (1993). What's Lost in Inverted Faces. *Cognition, 47*, 25-57.

Robbins, R., & McKone, E. (2003). Can holistic processing be learned for inverted faces? *Cognition, 88*, 79-107.

Roberts, T., & Bruce, V. (1989). Repetition Priming of Face Recognition in a Serial Choice Reaction-Time-Task. *British Journal of Psychology, 80*, 201-211.

Rumelhart, D. E., & Zipser, D. (1986). Feature discovery by competitive learning. In D.E. Rumelhart, J.L. McClelland, & the PDP Research Group (Eds.), *Parallel distributed processing: Explorations in the microstructure of cognition. Vol. 1: Foundations.* Cambridge, MA: MIT Press, Bradford Books.

Ryan, T. A., & Schwartz, C. B. (1956). Speed of perception as a function of mode of representations. *American Journal of Psychology, 69*, 60-69.

Saarinen, J., & Levi, D. M. (1995). Perceptual learning in vernier acuity: What is learned? *Vision Research, 35*, 519-527.

Saksida, L. M. (1999). Effects of similarity and experience on discrimination learning: A nonassociative connectionist model of perceptual learning. *Journal of Experimental Psychology-Animal Behavior Processes, 25*, 308-323.

Salasoo, A., Shiffrin, R. M., & Feustel, T. C. (1985). Building permanent memory codes: codification and repetition effects in word identification. *Journal of Experimental Psychology: General, 114*, 50-77.

Saldanha, E. L., & Bitterman, M. E. (1951). Relational learning in the rat. *American Journal of Psychology, 64*, 37-53.

Schmidt, R. A., & Bjork, R. A. (1992). New Conceptualizations of Practice - Common Principles in 3 Paradigms Suggest New Concepts for Training. *Psychological Science, 3*, 207-217.

Schyns, P.G., Goldstone, R.L., & Thibaut, J-P. (1998). The development of features in object concepts. *Behavioral and Brain Sciences, 21*, 1-54.

Scott-Brown, K.C., Baker, M.R., & Orbach, H.S. (2000). Comparison blindness. *Visual Cognition, 7*, 253-267.

Shapiro, P. N., & Penrod, S. D. (1986). Meta-analysis of face identification studies. *Psychological Bulletin, 100*, 139-156.

Shepard, R. N. (1986). Discrimination and Generalization in Identification and Classification - Comment on Nosofsky. *Journal of Experimental Psychology-General, 115*, 58-61.

Shiffrin, R. M., & Schneider, W. (1977). Controlled and automatic human information processing. II. Perceptual learning, automatic attending and a general theory. *Psychological Review, 84*, 127-190.

Slater, A., Bremner, G., Johnson, S. P., Hayes, R., & Brown, E. (2000). Newborn infant's preference for attractive faces: The role of internal and external features. *Infancy, 1*, 265-274.

Stevenage, S. V. (1998). Which twin are you? A demonstration of induced categorical perception of identical twin faces. *British Journal of Psychology, 89*, 39-57.

Suret, M., & McLaren, I. P. L. (2003). Representation and discrimination on an artificial dimension. *The Quarterly Journal of Experimental Psychology. B, Comparative and Physiological Psychology. 56*, 30-42.

Symonds, M., & Hall, G. (1995). Perceptual learning in flavor aversion conditioning: Roles of stimulus comparison and latent inhibition of common stimulus elements. *Learning and Motivation, 26*, 203-219.

Tanaka, J. W., & Gauthier, I. (1997). Expertise in object and face recognition. In R. L. Goldstone, P.G. Schyns, & D.L. Medin (Eds.), *Psychology of learning and motivation*, pp. 83-125. San Diego, CA: Academic Press.

Tanaka, J., & Taylor, M. (1991). Object categories and expertise: Is the basic level in the eye of the beholder? *Cognitive Psychology, 23*, 457-482.

Trobalon, J.B., Chamizo, V.D., & Mackintosh, N.J. (1992). Role of context in perceptual learning in maze discriminations. *Quarterly Journal of Experimental Psychology, 44B*, 57-73.

Valentine, T. (1988). Upside-down faces: a review of the effect of inversion upon face recognition. *The British Journal of Psychology, 79*, 471-491.

Valentine, T. (1991). A unified account of the effects of distinctiveness, inversion, and race in face recognition. *Quarterly Journal of Experimental Psychology: Human Experimental Psychology, 43*, 161-204.

Valentine, T., Chiroro, P., & Dixon, R. (1995). An account of the own-race bias and the contact hypothesis on a "face space" model of face recognition. In T. Valentine (Ed.), *Cognitive and computational aspects of face recognition: Explorations in face space* (pp. 69-94). London: Routledge.

Wagner, A. R. (1981). SOP: A model of automatic memory processing in animal behavior. In N. E. Spear & R. R. Miller (Eds.), *Information processing in animals: Memory Mechanisms* (pp. 5-47). Hillsdale, NJ: Erlbaum.

Wills, S., & Mackintosh, N. J. (1999). Relational learning in pigeons? *Quarterly Journal of Experimental Psychology, 52B*, 31-52.

Wills, A. J., & McLaren, I. P. (1998). Perceptual learning and free classification. *The Quarterly Journal of Experimental Psychology: Comparative and Physiological Psychology, 51*, 235-270.

Yin, R. K. (1969). Looking at upside-down faces. *Journal of Experimental Psychology, 81*, 141-145.

Young, A. W., Hay, D. C., McWeeny, K. H., Flude, B. M., & Ellis, A. W. (1985). Matching Familiar and Unfamiliar Faces on Internal and External Features. *Perception, 14*, 737-746.

Young, A. W., Hellawell, D., & Hay, D. C. (1987). Configurational Information in Face Perception. *Perception, 16*, 747-759.

Young, A. W., Newcombe, F., De Haan, E. H. F., Small, M., & Hay, D. C. (1993). Face perception after brain injury: Selective impairments affecting identity and expression. *Brain, 116*, 941-959.

Zhao, W., Krishnaswamy, A., Chellappa, R., Swets, D. L., & Weng, J. (1998). Discriminant analysis of principal components for face recognition. In H. Wechsler, P. J. Phillips, V. Bruce, F. F. Soulie & T. S. Huang (Eds.), *Face recognition: From theory to applications* (pp. 71-85). Berlin: Springer-Verlag.