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The effect of categorisation on sensitivity to second-order relations in novel objects

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Abstract. Adults appear to be more sensitive to configural information, including second-order relations (the spacing of features), in faces than in other objects. Superior processing of second-order relations in faces may arise from our experience of identifying faces at the individual level of categorisation (eg Bob versus John) but other objects at the basic level of categorisation (eg table versus chair; Gauthier and Tarr, 1997 *Vision Research* **37** 1673 – 1682). We simulated this learning difference with novel stimuli (comprised of blobs) by having two groups view the same stimuli but learn to identify the objects only at the basic level (based on the number of constituent blobs) or at both the basic level and individual level (based on the spacing, or second-order relations, of the blobs) of categorisation. Results from two experiments showed that, after training, observers in the individual-level training group were more sensitive to the second-order relations in novel exemplars of the learned category than observers in the basic-level training group. This is the first demonstration of specific improvement in sensitivity to second-order relations after training with non-face stimuli. The findings are consistent with the hypothesis that adults are more sensitive to second-order relations in faces than in other objects, at least in part, because they have more experience identifying faces at the individual level of categorisation.

1 Introduction

Adults are experts at face recognition. They can recognise thousands of individual faces easily and rapidly. Except with special training, adults do not demonstrate the same expertise with any other object category. Functional magnetic resonance imaging (fMRI) and event-related potentials (ERPs) studies suggest the existence of specialised neural mechanisms that respond more to faces than to non-face objects (eg Bentin et al 1996; Downing et al 2006; Goffaux et al 2003; Golari et al 2007; Grill-Spector et al 2004, 2006; Haxby et al 1994; Kanwisher et al 1997; McCarthy et al 1997; Scherf et al 2007; Tong et al 2000). On the basis of behavioural evidence, Yin (1969) suggested that faces are processed differently from non-face objects by being the first to report that inversion disrupts the recognition of faces more than the recognition of other mono-oriented objects, such as houses. Later studies revealed that, although inversion impairs the use of all cues to identity, the use of configural information (relational information about facial features) appears to be particularly degraded by inversion, suggesting its importance in the processing of upright faces (eg Barton et al 2001; Diamond and Carey 1986; Farah et al 1998; Goffaux and Rossion 2007; Rhodes et al 1993).

Configural processing can be divided into at least three types of processing: sensitivity to the first-order relations of a face (ie the common configuration shared by all faces, with two eyes being above the nose above the mouth), holistic processing (processing of all features of a face as a Gestalt or single percept), and sensitivity to second-order relations—the metric differences in the spatial relations among features (eg spacing between two eyes) that can be used to distinguish individual facial identities (Maurer et al 2002). Recent evidence suggests that the identity of faces becomes harder to recognise when the faces are inverted, at least in part, because of a disruption to adults' unusually acute sensitivity to second-order relations in upright faces

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(eg Collishaw and Hole 2000; Freire et al 2000; Leder and Bruce 2000; Leder and Carbon 2006; Malcolm et al 2004; Mondloch et al 2002, 2006b; Rhodes et al 2006; Tanaka and Sengco 1997), although inversion can also disrupt the processing of feature shapes (Rhodes et al 2006; Riesenhuber et al 2004; Sekuler et al 2004; Yovel and Kanwisher 2004, 2005). Haig (1984) examined adults' sensitivity to second-order relations in upright faces by slightly displacing the eyes, nose, or mouth in a set of face photographs. He found that observers were highly sensitive to such feature displacements: they noticed an upward movement of the mouth as small as 1 min of arc, very close to the visual acuity limit. Furthermore, the second-order relations of a familiar face appear to be recalled accurately, because adults are as sensitive to changes in second-order relations of a highly familiar face as in two unfamiliar faces presented simultaneously side-by-side (Ge et al 2003).

Adults' remarkable sensitivity to second-order relations takes many years to develop, such that only in adolescence do children demonstrate adult-like sensitivity to second-order relations (eg Freire et al 2000; Mondloch et al 2003b, 2004, 2006a—but see Gilchrist and McKone 2003 for evidence of earlier development for judgments of distinctiveness rather than identity). Experience appears to play an important role in this protracted development of sensitivity to second-order relations. Indeed, adults are more sensitive to second-order relations in upright human faces than upright monkey faces (Mondloch et al 2006b), and in faces of their own race rather than another race (eg Caucasian versus Chinese faces—Rhodes et al 2006), although they are nevertheless above chance with monkey and other-race faces. The effects of species and race presumably arise from greater experience processing human faces and faces of their own race, respectively. These findings suggest that the particular type of experience influences the development of sensitivity to second-order relations, and that it does not generalise completely to a class of similar stimuli with which the observer has little experience.

Our typical experience of processing faces versus non-face objects differs in the level of categorisation involved in identification. Faces are usually identified at the individual (or subordinate) level of categorisation (eg Bob versus John), whereas other objects are usually identified at the basic level of categorisation (eg chair versus table—Rosch et al 1976). One exception to this difference in categorisation between faces and non-face objects is in the case of experts, who tend to categorise their objects of expertise at the subordinate level (eg cardinal) rather than at the basic level of categorisation (eg bird—Johnson and Mervis 1997; Tanaka and Taylor 1991). Interestingly, there is evidence to suggest that experts demonstrate what are traditionally considered 'face-specific' effects. For example, when tested with their objects of expertise and compared to novices tested with the same objects, experts show a larger inversion effect (eg Diamond and Carey 1986—but see Robbins and McKone 2007 for failure to replicate this inversion effect), and greater activation of the right fusiform face area (FFA—Gauthier et al 2000). Like subjects tested with upright faces (eg Tanaka and Farah 1993), laboratory-trained adults show holistic processing of nonsense objects (greebles): superior recognition of parts when they are presented in the context of the whole relative to when they are presented in isolation (Gauthier and Tarr 1997). Similarly, real-world experts demonstrate holistic processing of their objects of expertise. Accuracy of fingerprint experts on a match-to-sample task is degraded more than the performance of novices by removing partial information in the fingerprints (Busey and Vanderkolk 2005), and it is more difficult for car experts to judge two bottom halves of cars to be the same if they are combined with the top halves of two different cars, than if they are combined with upside-down top halves, presumably because inversion disrupts holistic processing of cars (Gauthier and Curby 2005—but see Tanaka et al 1996, as cited in Tanaka and Gauthier 1997 and Robbins and McKone 2007 for failure to demonstrate increased holistic processing with greater expertise). Therefore, learning to identify any category of visually similar objects at the individual level of categorisation may encourage holistic processing. However, to date, we are not aware of any study that specifically examined sensitivity to second-order relations as a cue to identity in a trained object category, other than faces.

Recently, Tanaka et al (2005) examined directly the effects of level of categorisation on the ability to discriminate novel examples of a trained category in a laboratory setting. Specifically, they used real-world stimuli (owls and wading birds) to compare directly the role of subordinate-level learning to basic-level learning on the ability to discriminate novel examples of the learned birds. Adult observers learned 10 species (subordinate-level identification: eg barn own, barrel owl, elf owl, etc) of one family (owls) over seven consecutive days, while the other family learned only at the basic level of categorisation (wading birds). Subordinate-level training, but not basic-level training, led to better recognition of new examples of the learned species, and of new species of the learned family (see Scott et al 2006 for a replication of this study and associated changes in ERP to the trained-bird category). This finding suggests that subordinate-level training facilitates the development of perceptual expertise, and thus, subordinate-level training may improve sensitivity to second-order relations more than basic-level training.

Previous studies examining how training affects visual discriminability of objects have involved several days of training (eg Gauthier and Tarr 1997; Rainer and Miller 2000; Robbins and McKone 2003; Tanaka et al 2005—for a review see Fine and Jacobs 2002), and/or stimuli that differed on a number of cues (eg Gauthier et al 2003; Goldstone 1994; Goldstone et al 2001; Livingston et al 1998). In the present study, we investigated how the level of categorisation affects learning of novel objects in a single session, and limited the cues to identity to second-order relations. We predicted that training observers to identify objects at the individual level would lead to greater sensitivity to second-order relations than training at the basic level of categorisation. Whether training observers to identify the stimuli only at the basic level would also lead to increased sensitivity to second-order relations was more difficult to predict, because some perceptual learning studies have demonstrated that observers can learn information about the stimuli that are not task-relevant (eg see Seitz and Dinse 2007 for a review). For example, observers can demonstrate increased sensitivity to local motion through mere exposure, without task-relevance or even awareness (Watanabe et al 2001). Observers can also learn objects from passive viewing of complex visual scenes (Fiser and Aslin 2001), and their recognition can be altered by visual statistics that do not reach awareness (Cox et al 2005). Interestingly, mere exposure can also induce neural changes even at the level of primary visual cortex (Frenkel et al 2006). Therefore, observers learning to identify objects at the basic level of categorisation, for which second-order relations are not a necessary cue, may still demonstrate increased sensitivity to second-order relations in those stimuli. However, the extent to which mere exposure can affect later processing is not consistent across tasks (Karni and Bertini 1997). For example, Vernier offset discrimination does not improve with mere exposure (Fahle 2004). Furthermore, the current paradigm differs from many perceptual learning tasks (eg Fine and Jacobs 2002; Gold et al 1999) because observers are required to learn the names of specific stimuli, requiring some semantic memory. Therefore, the basic-level training group may not demonstrate improved sensitivity to second-order relations, analogous to our typical experience of being exposed to many individual exemplars of non-face objects (eg cars) without developing an acute sensitivity to second-order relations in those objects.

In order to relate the findings to face processing, the variation in second-order relations in the training and test stimuli was restricted to the variation that naturally exists in faces. Specifically, the pre-test and post-test stimuli were created by replacing the eyes, nose, and mouth of the faces used by Mondloch et al (2002) to test developmental changes in face processing, but the stimuli were inverted so as to not appear face-like. If these objects had been recognised as faces, previous experience categorising faces at the individual level might have transferred differently to the two training tasks. Therefore, these 4-blob objects were face-like only in terms of their second-order relations, and referred to as 'Bobos'. It was also important to use novel stimuli, because tasks that use familiar stimuli generally demonstrate less learning than tasks using less familiar stimuli (Fine and Jacobs 2002). Previous learning can interfere with attempts to learn novel distinctions in familiar stimuli (Werker and Tees 2005), which may account for the small amount of learning observed after training to identify common objects relative to various other perceptual learning tasks (Furmanski and Engel 2000, as reviewed in Fine and Jacobs 2002). Therefore, we chose to use stimuli that would not be easily perceived as a real-world object. If the level of categorisation influences the development of sensitivity to second-order relations, observers who are trained to identify individual exemplars should show greater sensitivity to second-order relations in novel exemplars than those who are simply trained to recognise the objects at the basic level of categorisation. Because the degree to which training stimuli differ from the test stimuli influences whether learning transfers to novel stimuli (Karni and Bertini 1997), we ensured that the variation among the training Bobos was similar to the variation among the test Bobos, as is true of the faces one normally encounters.

2 Experiment 1

To test the effects of learning, we chose a discrimination task rather than a recognition task, because we were interested in how the level of categorisation affects perceptual abilities, rather than memory or semantic strategies. Additionally, some studies have reported benefits of sleep in memory consolidation for perceptual learning (Mednick et al 2002, 2003). Therefore, participants were also tested 24 h later to determine whether sleep enhanced the training effect without any additional training on the second day.

2.1 *Methods*

2.1.1 *Participants.* Participants were fifteen undergraduate students in the individual-level training group—ILTG (five male; mean age 19.4 years) and fifteen undergraduate students in the basic-level training group—BLTG (six male; mean age 19.1 years) participating for credit in a first-year introductory psychology course or second-year cognitive psychology course at McMaster University. All had normal or corrected-to-normal vision.

2.1.2 *Pre-test and post-test stimuli.* Each stimulus contained four dark blurred circles (blobs), roughly 13 mm in diameter (0.74 deg from a viewing distance of 100 cm). The 'original' stimulus was created by placing four dark circles in the locations of the eyes, nose, and mouth of a female face with the features near an average position, that had been used previously by Mondloch et al (2002) to study adults' sensitivity to second-order relations in faces. In order to simulate real facial features that do not have sharp edges, we then blurred the circles using the Gaussian blur tool (radius, 10.0 deg) in the graphics software Adobe Photoshop to create blobs. Mondloch et al created four more faces from the original female face by moving the eyes 4 mm (0.23 deg from 100 cm) up, down, closer together, or farther apart relative to the original, while simultaneously moving the mouth 2 mm (0.12 deg) up or down. The blobs were moved in an analogous manner, such that the locations of the eyes, nose, and mouth in the five faces used by Mondloch et al were represented with blobs used for each feature. The five 4-blob stimuli were then inverted so that the stimuli did not appear face-like, and referred to as Bobos (figure 1a). They were the stimuli used for both the pre-test and post-test.

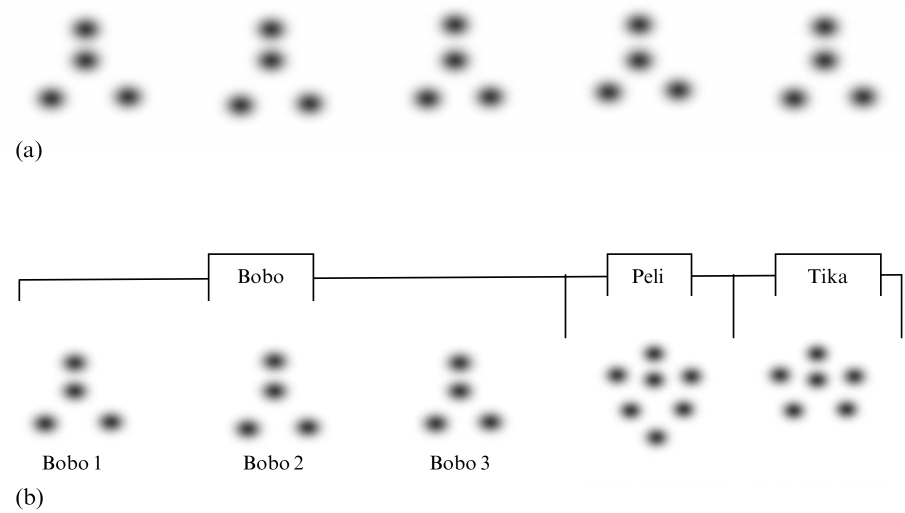

Figure 1. (a) Pre-test and post-test stimuli for measuring sensitivity to second-order relations. The actual stimuli were much larger (see text). (b) Training stimuli. Basic-level category labels are shown along the top. The ILTG was also required to learn the individual names of the Bobos, shown along the bottom. The actual stimuli were much larger (see text).

2.1.3 *Training stimuli.* The training stimuli consisted of three additional Bobos, created by recombining the interocular spacing and mouth locations used in the pre-test and post-test Bobos. As in the pre-test and post-test stimuli, the bottom two blobs were moved 4 mm (0.23 deg from 100 cm) in, out, and down relative to the original, while the top blob was moved 2 mm (0.12 deg) up or down. These Bobos were named 'Bobo 1', 'Bobo 2', and 'Bobo 3' for the participants in the ILTG, whereas all three stimuli were simply referred to as 'Bobo' for the participants in the BLTG. Two additional categories (a single exemplar per category) were created by adding more blobs to the original Bobo: Tika has 6 blobs and Peli has 7 blobs (figure 1b).

2.1.4 *Apparatus and procedure.* The stimuli were presented on a 22-inch computer monitor (screen size = 47.0 cm × 30.0 cm; 25.2 deg × 16.7 deg of visual angle from a viewing distance of 100 cm), controlled by a Power Mac G4 Cube computer on Mac OS 9.1 software, with Cedrus Superlab software. This study was approved by the research ethics board of McMaster University. The procedure was briefly explained and informed consent was obtained from all participants at the beginning of the experiment. Observers were seated 100 cm from the monitor in a dimly lit room.

2.1.5 *Pre-test.* Observers first performed the pre-test that measured their initial sensitivity to second-order relations in the 4-blob stimuli, and that was modeled on the procedure used by Mondloch and colleagues (2002). There were five 4-blob images. The task required observers to indicate whether two sequentially presented 4-blob images were the same or different using a Macally iShock controller. There were 30 trials (15 same and 15 different). The first image was shown for 200 ms, followed by a checkerboard mask for 390 ms, and then the second image remained on the screen until the observer made a response (figure 2). No feedback was given. The trials were presented in a random order. Observers were asked to respond as quickly but as accurately as possible.

2.1.6 *Training.* Following the pre-test, participants were randomly assigned to the ILTG or the BLTG. Participants in both groups were informed that they would undergo a training procedure in which they were required to learn the names of blob stimuli.

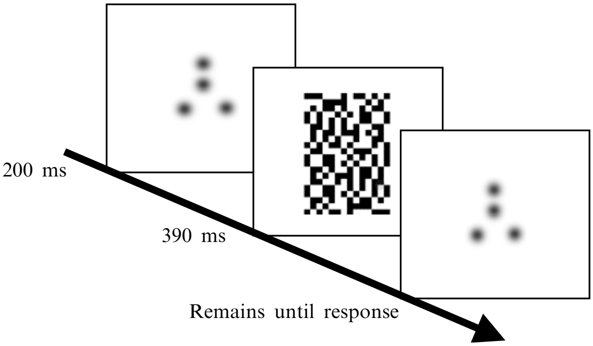

Figure 2. An example of a pre-test and post-test trial.

The training paradigm was modeled after previous studies in which observers were trained to discriminate highly similar visual stimuli, such as sets of artificial objects called greebles (Gauthier and Tarr 1997), or sets of female twins (Robbins and McKone 2003). On each trial a label was presented, followed by an image, and the participants' task was to indicate whether the label matched the image. Importantly, all observers, regardless of the training group, saw the same images for an equal number of trials and duration. Only the level at which the three Bobos were learned (ie Bobos 1, 2, 3 versus the basic-level categorisation of 'Bobo') differed between the two groups. There were 32 trials in each training block, 24 trials of which involved a Bobo. Every observer completed six blocks of training, regardless of performance.

During each trial, a label on the screen appeared for 1000 ms, followed by a central fixation point for 300 ms, and then the target stimulus (a blob image). For the first two training blocks, the target was shown for 1000 ms, but in order to increase task difficulty with increasing trials, the presentation time was decreased to 500 ms in the 3rd and 4th blocks, and 200 ms in the 5th and 6th blocks. The participant's task was to hit the button for "yes" if the label matched the target (matched trials), and "no" if it did not (mismatched trials). Half the trials were matched trials. Auditory feedback was given immediately after the response was made, with a different sound for correct versus incorrect responses, followed by a repeat presentation of the target with the correct label shown underneath for 3000 ms, regardless of whether the participant had answered correctly or not (see figure 3). Participants were encouraged to study the label and the image while they were shown together at the end of each trial in order to learn the correct pairings. Participants then initiated a new trial by pressing the space bar.

Although the presentation of the target images was equated between the two groups, the labels given to the target images differed between groups when a Bobo stimulus was presented: participants in the ILTG had to indicate whether the stimulus was (or was not) Bobo 1, Bobo 2, or Bobo 3 (see figure 3), whereas participants in the BLTG were only required to indicate whether the stimulus was (or was not) a Bobo. For trials with the Peli/Tika stimuli, both groups responded at the basic level. For example, the basic-level version of the mismatched trial shown in figure 3 would have instead started with a label at the basic level of categorisation, such as "Peli?", followed by the same Bobo image for the same duration, so that the correct answer for this trial would still be "no" (a mismatch). Similarly, the correct label shown after auditory feedback would have been at the basic level (ie "Bobo").

2.1.7 *Post-tests.* Following the training task, participants completed the post-test in which they were asked to indicate whether two sequentially presented 4-blob images (now referred to as Bobos) were the same or different. The task was identical to the pre-test. Accuracy and reaction times were recorded. Participants then returned 24 h later to perform the same post-test again (5 Bobos, 30 trials).

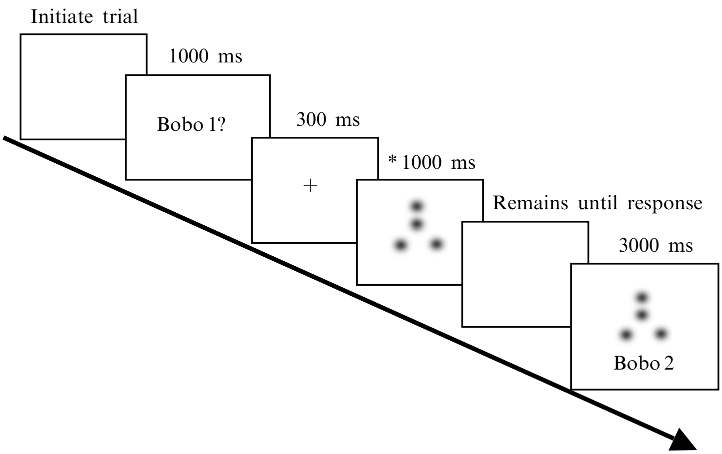

Figure 3. An example of a mismatched training trial for the ILTG. * Presentation times of the stimulus were decreased over the 3rd and 4th blocks to 500 ms, and again over the 5th and 6th blocks to 200 ms.

2.2 *Results*

2.2.1 *Training.* A 2×6 repeated-measures ANOVA on accuracy during the training blocks, with group (ILTG versus BLTG) as the between-subjects variable and training block (training blocks 1 – 6) as the within-subjects variable, revealed a significant main effect of training block ($F_{5,140} = 38.05$, $p < 0.01$), indicating that participants improved over time. The main effect of group was also significant, with the participants in the BLTG performing better [mean (M) = 97.3%, SD = 4.5%] than the participants in the ILTG (M = 78.9%, SD = 13.2%) ($F_{1,28} = 77.73$, $p < 0.01$). The better performance of the BLTG is not surprising because learning only the category label of 'Bobo' is expected to be much easier than learning the individual Bobos. There was also a significant interaction ($F_{1,28} = 10.76$, $p < 0.01$), indicating that the ILTG improved more across the training blocks (M = 63.8% on block 1 versus M = 86.0% on block 6) than did the BLTG (M = 90.0% on block 1 versus M = 98.5% on block 6).

An ANOVA on observers' median reaction times on correct trials also showed a main effect of training block ($F_{5,28} = 0.39$, $p < 0.01$), indicating that all observers responded faster with more training. There was also a main effect of group ($F_{1,28} = 414.56$, $p < 0.01$), with the BLTG (M = 402 ms, SE = 37 ms) responding faster than the ILTG (M = 653 ms, SE = 37 ms). However, unlike the analyses on accuracy, there was no significant training block × group interaction ($F_{5,24} = 0.12$, $p = 0.99$).

2.2.2 *Pre-tests and post-tests—all observers.* A 2×3 repeated-measures ANOVA was conducted using d' on the pre-tests and post-tests to compare the effect of group (ILTG versus BLTG), a between-subjects variable, and test (pre-test versus immediate post-test versus post-test 24 h later), a within-subjects variable. Only the main effect of test was significant ($F_{2,27} = 9.64$, $p < 0.01$), indicating that participants in both groups improved their ability to detect spacing changes in the Bobos following training (see figure 4a). *t*-Tests comparing the test means, with a Bonferroni correction, indicated that accuracy was higher on both the immediate and 24-h post-tests than on the pre-test (both ps < 0.01), with no difference between the two post-tests ($p = 1.0$). The main effect of group ($F_{1,28} = 2.21$, $p = 0.15$) and the group × test interaction ($F_{2,27} = 0.98$, $p = 0.39$) were not significant.

Similarly, a 2×3 repeated-measures ANOVA conducted on median reaction times on correct trials revealed only a main effect of test ($F_{1,28} = 27.98$, $p < 0.01$), indicating that all observers responded faster on the post-tests than the pre-tests. *t*-Tests, with

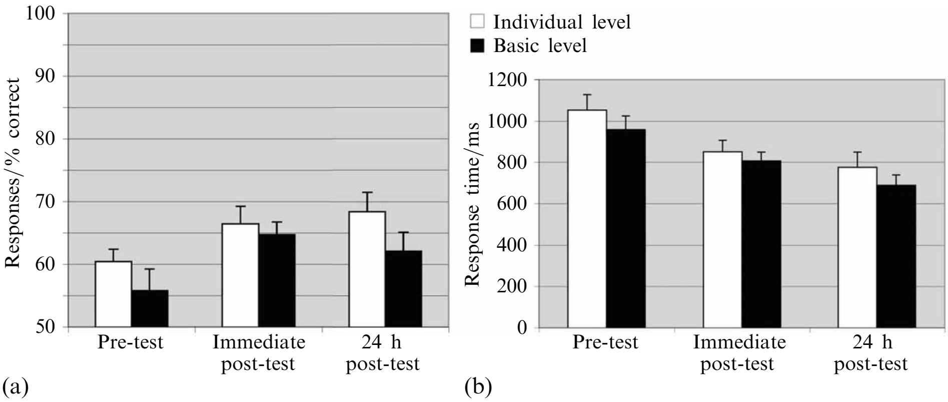

Figure 4. Experiment 1. (a) Mean accuracies (+ one standard error; 50% correct = at chance). (b) Mean reaction times (+ one standard error) on correct trials on pre-test, immediate post-test, and post-test 24 h later by the ILTG and BLTG.

a Bonferroni correction, indicated that reaction times decreased monotonically across tests (all ps < 0.01). The main effect of group ($F_{1,28} = 1.0$, $p = 0.33$) and the group $\times$ test interaction ($F_{1,28} = 0.27$, $p = 0.76$) were not significant (see figure 4b).

2.2.3 *Matched observers.* Although the group difference in accuracy was not significant, a closer examination of the raw data revealed that some of the individuals in the ILTG had not learned the Bobos well during training (performance on the last training block ranged from 62.5% to 93.75%). Therefore, we re-analysed the results including only those individuals who obtained a score of more than 75% correct on the last training block ($n = 11$). There was also great variability in pre-test performance, with 4/15 participants in the BLTG, but none in the ILTG, performing significantly below chance (44% correct, $p < 0.05$). Therefore, we matched participants in the ILTG to participants in the BLTG with similar pre-test accuracy (within ± 1 correct trial), such that the mean accuracy was 60.02% for the ILTG and 58.51% for the BLTG. Median reaction times on correct trials also did not differ between observers in the two groups ($t_{16} = 0.96$, $p = 0.35$).

2.2.4 *Training.* A comparison of the training data from the matched observers ($n = 9$ matched pairs) again revealed that the accuracy on the last training block was higher for the BLTG (M = 98.3%, SE = 1.1%) than the ILTG (M = 90.3%, SE = 2.5%) ($t_{16} = 2.98$, $p < 0.01$). As would be expected, the task of learning to identify the stimuli only at the basic level of categorisation was easier than the task of also learning to identify some stimuli at the individual level. This finding was also confirmed with a comparison of median reaction times on correct trials, with the BLTG (M = 377 ms, SE = 28 ms) responding faster than the ILTG (M = 662 ms, SE = 56 ms) on the last training block ($t_{16} = 4.55$, $p < 0.01$).

2.2.5 *Post-tests.* When the immediate post-test scores of the two groups were compared with the d' analysis, the ILTG was significantly more accurate than the BLTG ($t_{16} = 2.38$, $p < 0.05$).[1] However, this group difference was not observed 24 h later ($t_{16} = 1.02$, $p = 0.32$) (see figure 5a). Reaction times were also not significantly different between the two groups on the immediate post-test ($t_{16} = 0.45$, $p = 0.66$) or the post-test 24 h later ($t_{16} = 0.43$, $p = 0.67$) (see figure 5b).

[1] Because variance on the pre-test was constrained by matching the performance of the two training groups, we did not do an ANOVA including pre-test and post-test as a within-subjects factor.

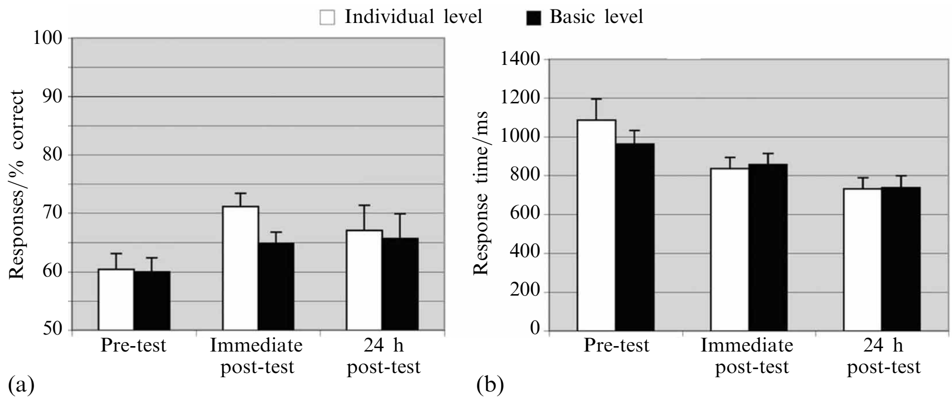

Figure 5. Experiment 1. (a) Mean accuracies (+ one standard error; 50% correct = at chance). (b) Mean reaction times (+ one standard error) on correct trials in pre-test, immediate post-test, and post-test 24 h later by paired observers in the ILTG and BLTG matched on pre-test sensitivity to second-order relations (on an individual basis) and restricted to observers in the ILTG group who showed evidence of learning (>75% correct in last training block).

2.3 *Discussion*

Within a single training session involving only 144 trials (24 Bobo discrimination trials × 6 blocks), observers in the ILTG learned to identify 4-blob images (Bobos) that differed only in second-order relations. Furthermore, there was some evidence that this learning transferred to a different set of Bobos from the ones used during training. When groups were matched on accuracy during the pre-test, observers who had learned to identify Bobos at the individual level of categorisation were better able to discriminate a different set of Bobos than observers who had learned to identify only these images at the basic level of categorisation, as predicted. This finding suggests that the level of categorisation at which learning takes place influences sensitivity to second-order relations of an object, and that this effect can be observed after only 144 trials of training lasting approximately 45 min. The absence of a group difference in reaction times rules out a speed – accuracy tradeoff. However, this difference was not significant when the performance of observers was not matched based on pre-test sensitivity to second-order relations.

When the whole group is considered, the observers in the ILTG appeared to learn the Bobos well (M = 86.0% on block 6). However, 4/15 observers were less than 75% correct in identifying the Bobos, even after 6 blocks of training. Therefore, for some participants, 144 trials with feedback may not be sufficient for learning to discriminate very similar visual stimuli. Moreover, the group difference was not observed 24 h later, a result suggesting that the learning benefit demonstrated by the ILTG was temporary and indicating no evidence of the benefit of sleep in memory consolidation that has been reported with other perceptual tasks (eg Mednick et al 2002, 2003).

Although these results suggest that learning to identify objects at the individual level of categorisation may lead to greater sensitivity to changes in second-order relations that are relevant to correct identification, this interpretation must be tempered because the variability in learning and in the pre-test performance made it necessary to exclude twelve participants from the final analysis (six participants from each of the ILTG and BLTG). Therefore, we attempted to replicate the findings in experiment 2 with a matched yoked design such that the pre-test performance of the observers in the BLTG and ILTG would be matched.

3 Experiment 2

In experiment 2, we used a matched yoked training paradigm and re-examined the influence of the level of categorisation on sensitivity to second-order relations. In order to decrease the amount of variability in the performance of the ILTG we trained participants to criterion. The procedure was the same as in experiment 1 except that participants in the ILTG were required to continue training until their accuracy during a block exceeded 80% correct. Each participant in the BLTG was matched to a participant in the ILTG on the basis of his/her pre-test score, and was then given as many training blocks as his/her matched counterpart required, in order to reach 80% accuracy. Therefore, although amount of training and exposure to the stimuli varied across individuals, every matched pair across the two groups completed the same number of training trials. We also added a fourth Bobo stimulus to be learned by the ILTG to further promote general learning. Additionally, we included a control group to aid interpretation of the small improvement in the BLTG between the pre-test and post-test that was revealed by the main effect of test in experiment 1, in the analyses involving the unmatched groups. This effect may reflect a practice effect or some improvement in sensitivity to second-order relations even though this group was not required to differentiate among the Bobos during training, as has sometimes been found in the perceptual learning literature (eg Cox et al 2005; Fiser and Aslin 2001). To differentiate these possibilities, in experiment 2 we included a control group that performed a visual discrimination task unrelated to face or object processing (motion discrimination of sinusoidal gratings) between the pre-tests and post-tests. Unlike experiment 1, there was no post-test 24 h later.

3.1 *Method*

3.1.1 *Participants.* Participants were seventy-five undergraduate students ($n = 25$ per group) enrolled in either a first-year psychology course or a second-year cognitive psychology course (mean age = 19.24 years; twenty-three males). Participants were randomly assigned to the control group or an experimental group (ILTG versus BLTG). The pre-test scores determined the placement of participants in the two experimental groups so that each participant in the ILTG had a matched counterpart in the BLTG with the same pre-test score (±1 correct trial). Two additional participants in the ILTG failed to reach the learning criterion of 80% correct within the allotted time (45 min), and therefore their data were excluded from the analyses. Two additional individuals were tested as part of the control group, but their data were not analysed because there were no matches for their pre-test scores in the experimental groups.

3.1.2 *Stimuli.* The pre-test and post-test stimuli were identical to those used in experiment 1. The training stimuli were the same except for the addition of one Bobo stimulus (Bobo 4) and two basic-level stimuli (Kiki with 9 blobs and Lula with 10 blobs), which were added to promote greater learning by making the training task more challenging (Ahissar and Hochstein 1997). Participants in both the ILTG and the BLTG were required to learn the five category names (Bobo, Jiji, Lula, Tika, and Kiki). In addition, the ILTG was required to learn the 4 individual Bobos (Bobos 1, 2, 3, and 4; see figure 6).

3.1.3 *Pre-test.* The pre-tests and post-tests were the same as in experiment 1.

3.1.4 *Training.* The training blocks were constructed in the same way as those used in experiment 1. Observers in the ILTG completed a minimum of four training blocks, and then continued training to the criterion of at least 80% correct on individual-level identification trials within a single block (24 trials). Performance was monitored on every block starting with the fourth block and additional blocks were presented until the participant reached criterion (see figure 7a).

Later participants were assigned to one of the experimental groups depending on the pre-test score. If pre-test accuracy matched the score of an earlier participant in the ILTG, that observer was placed in the BLTG, and underwent as many training blocks as his/her matched counterpart (see figure 7a). If there was no match, he/she was

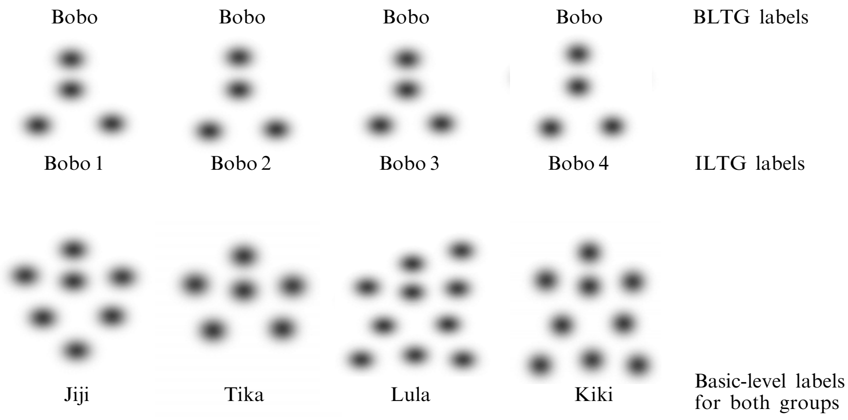

Figure 6. Training stimuli for experiment 2.

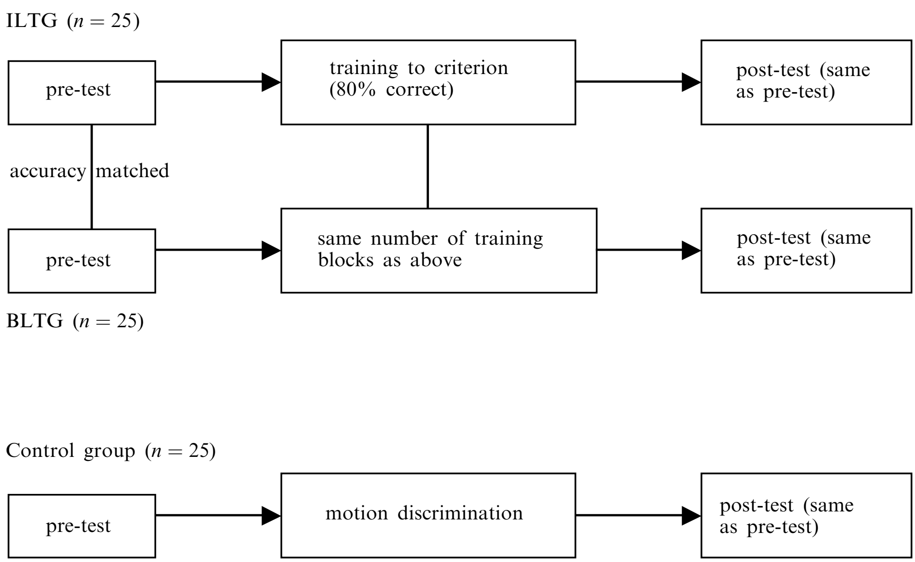

Figure 7. (a) Flow-chart of the procedure for participants in the ILTG and BLTG. Pairs of individual participants were matched on pre-test accuracy and underwent the same number of training blocks. (b) Flow-chart of the procedure for participants randomly assigned to the control group.

placed in the ILTG (and trained to criterion). As in experiment 1, observers in both the ILTG and the BLTG saw the same Bobos. The only difference was that all names presented to the BLTG were at the basic level of categorisation, whereas Bobos were labeled individually for the ILTG. Those participants who were randomly assigned to the control group completed the pre-test, followed by a motion-discrimination task using vertical gratings that lasted roughly 30 min (training with the blob stimuli took 15–45 min; figure 7b).

3.1.5 *Post-test.* Following the training or control blocks, all participants completed the post-test. Unlike in experiment 1, observers did not return for a second post-test 24 h later.

3.2 *Results*

3.2.1 *Pre-test.* The pre-test scores of observers in the ILTG (M = 62.1%), BLTG (M = 61.6%), and control group (M = 61.5%) were well matched.

3.2.2 *Training.* On average, participants in the ILTG required 6.3 blocks of training (range: 4 – 13 blocks) in order to reach the criterion of 80% correct on a block of individual-level identification trials. Participants in the BLTG completed the same number of training blocks (ie M = 6.3 blocks) because the training protocols of the participants in the BLTG were yoked to the participants in the ILTG, on the basis of pre-test performance. The BLTG (M = 98.0%, SD = 2.8%) performed better on their last training block than the ILTG (M = 91.2%, SD = 3.5%) ($t_{48} = 7.52$, $p < 0.01$), indicating that it was easier to learn to identify these images at the basic level than at the individual level of categorisation. Median reaction times on correct trials also revealed that observers in the BLTG (M = 457 ms, SE = 26 ms) were faster to respond correctly than those in the ILTG (M = 836 ms, SE = 59 ms) on the last training block ($t_{48} = 5.86$, $p < 0.01$).

3.2.3 *Post-test.* After training,(2) a one-way ANOVA using d' analysis revealed a significant effect of group on the post-test ($F = 5.37$, $p < 0.01$) (figure 8a). In order to determine whether training led to improvements in sensitivity to second-order relations, a posteriori comparisons with Dunnett's t-test were performed against the performance of the control group. The results revealed that the ILTG (M = 73.9%) was significantly better than the control group (M = 63.9%, $p < 0.01$), whereas the BLTG (M = 67.7%) did not differ significantly from the control group ($p = 0.13$).(3) Thus, training at the individual level led to improved sensitivity above any effect of repeat testing, but training at the basic level did not.

Observers' median reaction times on correct trials were compared across the three groups by a repeated-measures ANOVA with group as the between-subjects variable, and test (pre-test versus post-test) as the within-subjects variable. The main effect of group was not significant ($F_{2,72} = 0.19$, $p = 0.83$). There was a main effect of test ($F_{1,72} = 8.56$, $p < 0.01$), indicating that observers in all three groups were faster to respond on the post-test than the pre-test (see figure 8b). The group $\times$ test interaction approached significance ($F_{2,72} = 3.05$, $p = 0.05$). However, a posteriori Dunnett's t-test on the pre-test and post-test did not reveal any significant group differences.

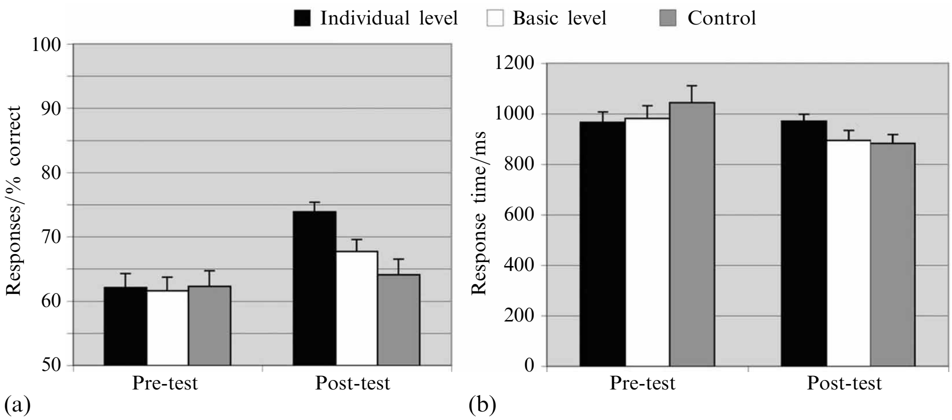

Figure 8. Experiment 2. (a) Mean accuracies (+ one standard error; 50% = at chance). (b) Mean reaction times (+ one standard error) of observers on the pre-test and post-test sensitivity to second-order relations for the ILTG, BLTG, and the no training group (matched on pre-test accuracy on an individual basis).

(2) Because variance on the pre-test was constrained by the yoked design, we did not do an ANOVA including pre-test and post-test as a within-subjects factor.

(3) Unlike in experiment 1, we did not re-test sensitivity to second-order relations 24 h later, and therefore we cannot address the question whether the ILTG would have demonstrated an effect of sleep on memory consolidation in this experiment.

3.3 *Discussion*

Experiment 2, which required observers in the ILTG to continue training until they were 80% correct on the last training block, replicated the results of experiment 1. Adults who learned to identify 4-blob images at the individual level of categorisation were more sensitive to the second-order relations of the blobs in novel exemplars than adults who had seen the images as often but had learned to identify them only at the basic level of categorisation. The results demonstrate that learning to discriminate individual exemplars of an object category can increase sensitivity to second-order relations. Furthermore, the BLTG was no more accurate on the post-test of sensitivity to second-order relations than a group of control subjects who did not receive any training with the 4-blob images. Therefore, exposure to the stimuli without the task demands of individual-level recognition was not sufficient for improving sensitivity to second-order relations. These results are consistent with the hypothesis that the level of categorisation at which objects are identified directly influences how those objects are processed, and therefore acute sensitivity to second-order relations in upright faces may arise, in part, from our experience of identifying faces at the individual level.

4 General discussion

Experiments 1 and 2 demonstrate that after a single training session adults can learn to discriminate individual 4-blob objects that differ only in second-order relations, and that this learning transfers to a different set of 4-blob objects. Furthermore, exposure to the same images without being required to recognise them at the individual level was not sufficient to improve sensitivity to second-order relations. This is the first demonstration that the level of categorisation at which non-face objects are identified can directly influence sensitivity to the second-order relations in those objects. The results are consistent with previous findings showing that learning to identify exemplars at the individual level of categorisation improves discrimination of novel exemplars from the learned category (eg Gauthier and Tarr 1997; Gauthier et al 1998; Scott et al 2006; Tanaka et al 2005).

Observers in this study demonstrated improvements in sensitivity to second-order relations after a single training session, whereas sensitivity to second-order relations in faces is still developing after 14 years of experience (Mondloch et al 2003b). Likely as a result of the short training, the improvement in discriminating Bobos appears temporary (experiment 1), but this temporary process may be the same process underlying the development of sensitivity to second-order relations in upright faces that becomes consolidated with more experience. Experience with faces differs from experience with non-face objects in three important ways: (i) faces are a visually homogenous category because all faces share the same first-order relations (ie the basic configuration of having the eyes above the nose above the mouth); (ii) it is necessary to identify faces at the individual level (eg Bob versus John); and (iii) one reliable cue to discriminating individual faces is second-order relations. Although improvements in basic visual sensitivity are likely also to be involved (Mondloch et al 2006b), our results suggest that learning to identify faces at the individual level of categorisation may contribute to the development of adults' acute sensitivity to second-order relations in faces.

The results are consistent with the hypothesis that sensitivity to second-order relations in faces develops, at least in part, because of our experience of individuating faces. However, Bobos differ from faces in an important way. Individual Bobos can be discriminated only in terms of second-order relations, whereas there are many cues that differentiate the faces we encounter in everyday life (eg hair colour, skin colour, glasses, beards, etc). Sensitivity to second-order relations in faces may develop because other cues to facial identity (eg hair colour, skin colour, feature shapes) are less reliable than second-order relations, as they can change in different contexts (eg different lighting, point of view, make-up, facial expression, etc). In future research it would be interesting to examine whether adult observers can learn to differentiate Bobos when other cues are available, but less reliable, than second-order relations, in order to extend the present findings to a real-world context. It would also be interesting to use this paradigm to study children, who change with age from relying more on salient, but less reliable, feature cues for face identification and being readily fooled by paraphernalia (eg Campbell and Tuck 1995; Campbell et al 1995; Carey and Diamond 1977; Freire and Lee 2001; Freire et al 2000; Mondloch et al 2002, 2006a) to becoming adept at recognising the identity of faces based on second-order relations and through changes in point of view (Mondloch et al 2002, 2003a) and not being fooled by paraphernalia (eg Freire and Lee 2001).

The successful transfer of learning demonstrated by the individual-level training group is most likely attributable to the similar amount and type of variability that existed in the training and test stimuli (Karni and Bertini 1997). The Bobo stimuli used during training and test differed only in second-order relations, and the variations were limited to the variability that naturally exists among faces. Another contributing factor may have been the ease of the task, as shown by the relatively few trials ($M = 151$ trials) needed to reach the criterion of 80% correct in experiment 2 and the fact that 25/27 participants reached the criterion within a single training session lasting at most 45 min. This finding is consistent with previous findings that, with greater task difficulty, the effects of perceptual learning become more specific (Ahissar and Hochstein 1997). Thus, the relative ease with which the individual Bobos were learned may have also contributed to the successful transfer of learning to novel exemplars.

Identifying the neural basis of the improvement observed in the individual-level training group is beyond the scope of the current study; however, previous findings suggest that the locus of the learning effect is in the higher visual areas (Kourtzi and DiCarlo 2006). Ahissar and Hochstein (2004) postulate that in easy tasks with large signal-to-noise ratios, learning can occur at higher areas of the visual stream allowing more generalisation, whereas more difficult tasks may require neural modifications at lower levels where the receptive fields are more specific to retinal position and orientation. This hypothesis is supported by evidence that monkeys trained to categorise a continuous set of digitally morphed stimuli as cats or dogs showed differential activation of the prefrontal cortex to the two trained categories (Freedman et al 2003). Furthermore, monkeys trained to categorise faces on the basis of second-order relations (eye height and eye separation) demonstrated increased neuronal fine-tuning in the inferotemporal cortex for those cues (Sigala and Logothetis 2002). These findings suggest that the locus of the categorisation effect observed in the current study is not likely to be in low-level areas such as the primary visual cortex, but rather in the higher visual areas.

One limitation of the current study is that task difficulty during training was not equated between the individual-level and basic-level training groups. We chose to equate the amount of visual exposure to the blob stimuli in both groups, which necessarily resulted in the task requiring individual-level identifications being more difficult than the task requiring only basic-level identifications. Therefore, the current study cannot separate the effect of differences in the level of categorisation per se from differences in the cognitive demand of the two procedures, such as differences in the amount of attention required. However, these effects are not necessarily mutually exclusive. For example, even newborns orient towards face-like stimuli more than towards non-face stimuli, suggesting that humans are naturally biased to attend to faces (eg Johnson et al 1991; Maurer and Young 1983). Therefore, attention may also play a role in the real-world experience of categorising faces at the individual level but categorising non-face objects at the basic level of categorisation. Nevertheless, future studies should attempt to equate task difficulty by introducing more basic-level categories to be learned only by the basic-level group, or by using a divided attention paradigm to increase attentional load.

The paradigm developed in the current study could be extended in a number of ways to explore the conditions under which increased sensitivity to second-order relations in blob images transfers to sensitivity to second-order relations in other stimuli. In order to expand our understanding of perceptual learning in general, one could test whether observers in the individual-level training group would demonstrate improved sensitivity to second-order relations in one of the basic-level trained categories, such as the Tikas composed of 5 blobs. One could also present individual Tikas simultaneously with the individual Bobos, but only train observers to learn individual Bobos, to determine whether learning generalises to similar objects learned concurrently without an individual-level categorisation task. To better understand the development of face processing, one could continue training with the individual Bobos for thousands of trials over several days. Although 'fast learning' effects (as in the current single-session paradigm) are very task-specific (Karni and Bertini 1997), a recent study using an interference paradigm suggests that the recognition of faces and non-face objects of expertise are functionally related (Gauthier and Curby 2005; but see also Rhodes et al 2004 for lack of FFA activation in response to non-face objects of expertise). It is possible that with 'slow learning' (involving modifications in the neural representation of Bobos—Karni and Bertini 1997), the learning would transfer to improved sensitivity to second-order relations in faces, especially other-race faces. Such a finding would suggest that the greater sensitivity to second-order relations shown for upright faces than inverted faces (eg Mondloch et al 2006b) is not specific to faces per se, but rather to experience discriminating individual exemplars of an object category. Conversely, if extensive training with Bobos does not transfer to the processing of second-order relations in faces, the results would lend support to the hypothesis that faces are processed differently than other objects of expertise.

In summary, in a single training session, adults trained to identify individual objects improved their sensitivity to the second-order relations of those objects, whereas adults trained to identify the same objects at the basic level of categorisation did not. Thus, adults' acute sensitivity to second-order relations in upright faces may develop, at least in part, through our experience identifying faces at the individual level of categorisation.

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