Final report on AOARD grant #064038 'Face recognition and processing in a mini brain'.

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1. Executive summary.

This report covers a 1 year project which evaluated the specific mechanisms that a miniature brain containing less than 1 million neurons (in animal model of the honeybee) uses to learn and subsequently recognize human faces. There were four specific aims (detailed below) to the project, and all of these have been met. The bee brain shows some similarities to newborn human infants in the way in which faces are learnt, and bees appear to bind available information into a configural representation of a face. Different to human face processing, once bees have learnt to build a configural representation, bees do not use piecemeal processing for face recognition (human use both, but place higher weighting on configural processing). Bees that had received conditioning to one particular view of faces (e.g. plane view where faces look straight ahead) and were then presented at a novel view (e.g. 30 degrees rotation) were not able to solve the task (but newborn humans can; pointing towards specialized neural processing in humans for this important task). Comparing between solutions used by both the miniature brain and then human brain allow inferences about likely strategies that might be useful for AI solutions.

2. Specific aims of the project were:

(i) **Capacity to learn faces.** I will evaluate the specific facial features that bees use when initially learning face stimuli. The data will be comparable to existing data sets on how humans learn face stimuli.

(ii) **The extent to which configural or holistic processing contributes to recognition.** In human cognition faces are recognized mainly using a configural (the holistic integration of facial features) visual strategy. I will investigate the extent to which configural processing contributes to the mechanism(s) bees use to discriminate between and recognize human face stimuli.

(iii) **The extent to which feature extraction contributes to recognition.** I will investigate if bees are able to discriminate between and recognize faces using some model of feature extraction where particular facial features are given priority weighting as to their contribution in a recognition process.

(iv) **Ability to recognize faces when the stimulus is rotated in the horizontal plane.** I will investigate the ability of bees to reliably recognize faces when the target training face and the test faces are presented at different angles of rotation.

3. Summary of research findings in relation to specific aims.

Aim (i) The project has been able to identify that the miniature brain of honeybees learns to recognize faces by binding information contained in both the internal (eyes, nose and mouth) and external features (hair, ears and chin) of a human face. The data also shows that reliable recognition of faces only requires relatively low spatial frequency information as bees could be observed scanning both internal and external facial features (e.g. Fig. 1). This finding is remarkably similar to how newborn

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14. ABSTRACT
This report covers a 1 year project which evaluated the specific mechanisms that a miniature brain containing less than 1 million neurons (in animal model of the honeybee) uses to learn and subsequently recognize human faces. There were four specific aims (detailed below) to the project, and all of these have been met. The bee brain shows some similarities to newborn human infants in the way in which faces are learnt, and bees appear to bind available information into a configural representation of a face.

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primate (human) infants first learn faces by mainly weighting attention to outer facial features (Turati *et al*. 2006 *Child Dev* **77** p297). The finding on bee visual learning of faces has been reported in the proceedings of the IBRO World Congress of Neuroscience (Dyer et al. 2007a).

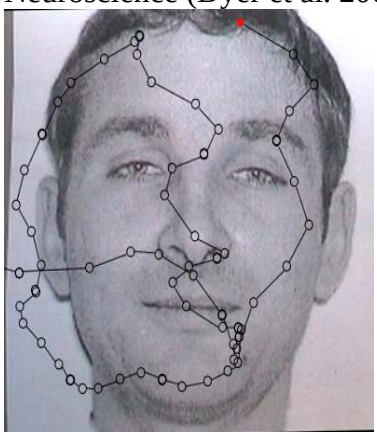

Fig. 1. Bee scanning a face during initial learning; most attention is paid by bees to external features (human babies prefer external, but human adults pay the most attention to inner features including eyes, nose and mouth).

Aim (ii) The project showed that bees conditioned to faces appear to exclusively use a holistic solution to recognize faces. This finding was a surprise and differs from human vision where subjects use a combination of both holistic/ configural (major strategy) and piecemeal/feature extraction processing. The finding suggests that a dual strategy in the primate brain is a useful strategy to promote reliable recognition (especially in demanding situations that confound configural processing). The finding has been accepted for publication in the Proceedings of the Society for Neuroscience meeting in San Diego, USA (Dyer et al. 2007b).

Aim (iii) Data from a variety of experiments in the project consistently indicated that bees do not recognize faces using a single feature extraction model (once bees have received a reasonable amount of experience with stimuli). This was a surprising finding, and indicates that the miniature brain rapidly develops a configural strategy for recognizing faces. The finding will also be reported in the Proceedings of the Society for Neuroscience meeting in San Diego, USA, (Dyer et al. 2007b). However, one experiment did show that bees can use major combinations of features like either outer (combination of hair, ears and chin) or inner (combination of eyes, nose and mouth) to recognize faces (but not with the same accuracy as if all information is present). Bees were unable to use a single feature to recognize faces (humans can do this, although not as reliably as when configural information is available), which might be because bees lack the volitional control of the human mind to switch strategies once configuration has been disrupted.

Aim (iv). Even though bees appear to be able to use a configural strategy (see above), bees were not able to recognize faces if the faces were stretched in one dimension (either horizontal or vertical). This type of image manipulation does not affect human visual processing (pointing to specialized neurons or solutions in the primate brain for solving this task; see Dyer et al. 2007b for details). The finding will also be reported in the Proceedings of the Society for Neuroscience meeting in San Diego, USA, (Dyer et al. 2007b). The project then evaluated if bees can recognize faces if these have been learnt in one particular view (e.g. plane view where faces look straight ahead) and are

then presented at a novel view (e.g. 30 degrees rotation). This is an exciting new approach to this face recognition problem as a recent study (Turati et al. 2007, Cognition, in press) has shown that newborn (< 3 days old) human babies can recognize faces with rotation. I was able to secure the same stimuli set from Dr Turati (Italy) to test bee face processing with rotation. Bees trained on just one view* were not able to recognize faces presented at a novel angle of rotation, suggesting that there is a special mechanism hard wired into the human brain (but not bee brain) for recognizing human faces in novel rotated views.

*Current research that extends the initial face rotation investigation (under AOARD 074080) shows that the miniature brain of bees can be conditioned to learn how to process novel faces by integrating learnt images. Data from aim (iv) will thus form part of a major report (manuscript in preparation) on how bee miniature brains learn to process face rotation with specific conditioning.

4. Further reporting of findings to the wider scientific community.

The data collected to meet aims (i-iii) has been reported in either the Proceedings of the IBRO World Congress of Neuroscience (Dyer et al. 2007a) or will be reported in the Proceedings of the Society for Neuroscience meeting in San Diego, USA, (Dyer et al. 2007b). I have also recently presented the work at a number of meetings/seminars including the Max Planc Institute in Frankfurt, and I recently met with Professor Lars Chittka (London) to discuss the project findings. It is anticipated that manuscripts will be submitted at the end of November (07) following feedback from experts at the Society for Neuroscience meeting in San Diego.

I have also received an invite from the prestigious Scientific American to write a paper on how bees recognize faces. This manuscript is in an advanced stage of preparation after receiving initial feedback (on initial draft) from Scientific American editors. However, I have advised the editors that I will wait until the data is published in a peer reviewed journal prior to allowing it to be made available in Scientific American. This is to ensure that a proper peer review process is conducted on the research findings. Part of that process is the presentation of findings at the two international conferences (Dyer et al. 2007a,b) so that findings are discussed with a broad range of experts in the field of neuroscience.

The findings of the project have also been reported in a seminar to USAF staff and associates at the Remote Biometrics Workshop, WICC (near Wright Patterson Air Force Base), Dayton, USA (13th and 14th March 2007). A copy of that talk is available to appropriate persons via a USAF workshop web site; the contact person for permission for access is Dr Greg Arnold.

5. Conclusion.

This has been a successful project that has been able to meet all specific aims. However, as an interesting footnote to aim (iv), which showed that the bee brain can not recognize faces in a novel view following exposure to the faces in a plane view; I have conducted an additional set of experiments under agreement AOARD 074080

that shows that the bees brain can be conditioned to integrate information from multiple views and then learn to solve novel views. This is a major finding that is a significant extension to aim (iv) in the current report.

Comparisons between bee and human face processing solutions point towards some specific differences in strategies used by the two biological systems, which might be of value for designing AI type solutions. In particular;

5.1 Low spatial frequency information is sufficient for face recognition, and both human and bee visual systems mainly use a configural solution to recognize faces.
5.2 Humans (but not bees) have a secondary system that uses piecemeal processing, which might provide advantages in difficult viewing conditions where configuration is disrupted.
5.3 The human brain easily deals with stretching of a face image, but the bee brain can not (suggesting this is a possible advantage human vision has evolved for this class of visual stimuli). Thus configural processing that can manage image manipulations would appear to be advantageous.
5.4 The human brain (when compared to the bee brain) appears to have special mechanisms for recognizing rotated faces, as bees can not solve the same face rotation task that newborn infants can solve.

6. References

Dyer AG, Reser D, Chittka L, Zhang Y, Rosa MGP (2007a) Miniature brains link inner and outer features. 7th IBRO World Congress of Neuroscience, 12-17 July, p 301. (see Appendix A)

Dyer AG, Reser D, Berg C, Neumeyer C, Rosa MGP (2007b) How do honeybee miniature brains process faces? Proceedings of the Society for Neuroscience, Cognitive Learning and Memory Systems VIII, San Diego Conference Centre (Halls B-H#107804) 7th November 2007 (abstract book in press). (see Appendix B)

Appendix A (Dyer at al. 2007a):

Miniature brains link inner and outer features to recognize faces

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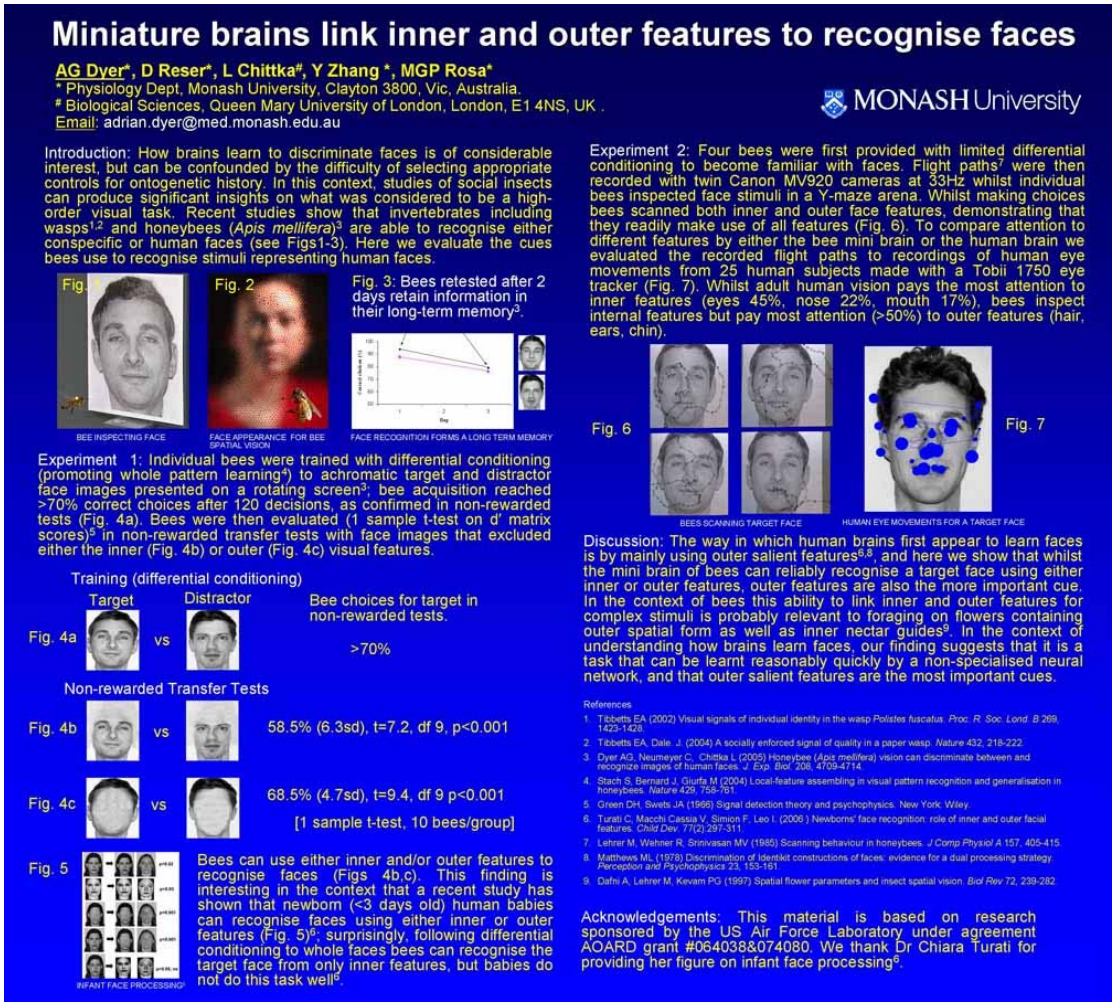
How organisms learn to discriminate faces is of considerable interest, but can be confounded by difficulty selecting appropriate controls for ontogenetic history. In this context, studies of social insects can produce significant insights on what we consider a high-order visual task. We use free flying honeybees (*Apis mellifera*) as a model to understand how a non-mammalian brain learns to recognise human faces. Individual bees were trained with differential conditioning to achromatic target and distractor face images presented on a rotating screen (*J Exp Biol* 2005 v208p4709); bee acquisition reached >70% correct choices after 120 decisions, as confirmed in non-rewarded tests. Bees were then evaluated in non-rewarding transfer tests with face images that excluded either the inner (eyes, nose, mouth) or outer (hair, ears) salient features. For both inner (58.5% ± 6.3 s.d., t=7.2, p<0.001) and outer (68.5% ± 4.7 s.d., t=9.4, p<0.001) transfer test conditions bees were able to continue choosing the target face above chance levels (one sample t-tests, N= 10 bees in each group, d.f. = 9). Flight paths were recorded whilst individual bees inspected face stimuli in a Y-maze arena. Bees scanned both inner and outer face features, demonstrating that they readily make use of all features. However, compared to adult humans, bees spent less time scanning the eyes. In summary, small brains with no previous experience can quickly learn to use both inner and outer features to recognize faces. This finding demonstrates interesting parallels with recent findings that newborn human babies can use inner and outer features to recognize faces (*Child Dev* 2006 v77p297).



Appendix B (Dyer at al. 2007b):

How do honeybee miniature brains process faces?

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Biometric information in a face provides first layer non-invasive identification. Faces viewed in complex scenarios including anamorphic stretching (*Perception* 2002 v31p1221) or contrast variability are processed reliably by the human brain; but current computer based algorithms are comparatively poor in complex environments (*ACM Computing Surveys* 2003 v35p399). To help interpret human biological solutions it is useful to know how 'other' brains process faces. One model that has recently emerged to understand how a non-mammalian brain processes human faces is the honeybee (*J Exp Biol* 2005 v208p4709). Individual free flying honeybees (*Apis mellifera*) were provided with differential conditioning to achromatic target and distractor face images. Bee acquisition reached >70% correct choices after 100 decisions, and bees were then tested in non-rewarded transfer tests. Bees were able to choose target faces when configuration was constant but brightness was inverted (64%, p<01). When face features (hair, eyes, nose, mouth and chin) were scrambled in the vertical plane, a task that disrupts human configural processing whilst still permitting partial recognition (*Perception* 2000 v29p893), bees chose the target stimulus at chance level (51.6%, ns). When faces were stretched by 200% in either a vertical (47.1%, ns) or horizontal (55.0%, ns) plane, which has a minimal effect of human face processing, bee choices dropped to chance level, indicating that while mammalian and bee brains share the capacity to deal with faces presented in certain natural contexts, larger numbers of neurons in the mammalian brain may allow more flexible/ computationally robust strategies to cope with transformed stimuli.