THE DEVELOPMENT OF PERCEPTUAL EXPERTISE FOR FACES AND

OBJECTS IN AUTISM SPECTRUM DISORDERS

By

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CHAPTER I

INTRODUCTION

The human brain has the ability to develop specialized mechanisms dedicated to the efficient processing of a particular class of stimuli. The development of expertise with human faces is perhaps the best example of such specialization (Gauthier & Nelson, 2001). Although most adults have acquired a nearly unparalleled expertise for perceiving and processing faces, this skill is not universal. Many individuals with autism spectrum disorders (ASD) have not developed perceptual expertise with faces (Grelotti, Gauthier, & Schultz, 2002).

In recent years, a closer examination of the processes involved in acquiring perceptual expertise has generated a potential framework for understanding the lack of face expertise in autism (Diamond & Carey, 1986; Gauthier & Tarr, 1997; Gauthier, Skudlarski, Gore, & Anderson, 2000). According to this line of research, the neural and behavioural correlates of face expertise can also be observed during the processing of non-face objects of expertise in typically developing adults (Diamond & Carey, 1986; Gauthier & Tarr, 1997; Rossion et al., 2000). For example, individuals who have developed perceptual expertise with non-face objects are able to identify these objects on a subordinate level of categorization quickly and accurately (Tanaka & Taylor, 1991) and may even engage neural networks previously associated with face processing expertise in the processing of these objects (Gauthier & Tarr, 1997; Rossion et al., 2000). In line with these observations, there is also significant evidence that experts with non-face objects show perceptual specialization for the upright

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forms of these objects (Busey & Vanderkolk, 2005; Diamond & Carey, 1986; Gauthier et al., 1998; Moore et al., 2006).

Interestingly, both neural and behavioral markers of expertise have been found to be absent when individuals with ASD perceive faces (Gauthier, Klaiman, & Schultz, 2009; Hubl et al., 2003; Hobson, Ouston, & Lee, 1988; Langdell, 1978; McPartland, Dawson, Webb, Panagiotides, & Carver, 2004; Teunisse & de Gelder, 2003). Rather, they seem to be 'face novices' (Grelotti, Gauthier, & Schultz, 2002). Previous research indicates that this impairment may emerge in early infancy (Osterling & Dawson, 1994) and persist through adulthood (Ashwin, Baron-Cohen, Wheelwright, O'Riordan, & Bullmore, 2007; Blair, Frith, Smith, Abell, & Cipolotti, 2002; Golan, Baron-Cohen, & Hill, 2006). In addition to an impairment in face processing ability, individuals with ASD tend to employ qualitatively different perceptual strategies in the processing of faces (Hobson et al., 1988; Joseph & Tanaka, 2003; Langdell, 1978; Tantam et al., 1989). Further, regions of the brains that are associated with both face and expertise processing are known to be structurally and functionally different in ASD (Critchley et al., 2000; Pierce et al., 2001; Schultz et al., 2000; Van Kooten et al., 2008; Wang et al., 2004). Yet, a case study of an adolescent with ASD who developed expertise with a particular object raises the possibility that markers of expertise may be observed when individuals with ASD process non-face objects of expertise. Specifically, Grelotti and colleagues (2005) found that this individual recruited areas of the brain typically associated with face expertise when processing his particular object of expertise and, yet, did not recruit these neural structures when processing faces.

Although the term 'expertise' has been defined in many different ways in previous research, for the sake of clarity, expertise will be defined here as a level of

ability at which the recognition of upright instances of an object can occur quickly and accurately. Because it is difficult to define what constitutes quick and accurate recognition across individuals, expertise in the current study will be behaviourally defined as the level of proficiency when recognition of a stimulus on the level of an individual exemplar (e.g, 'Lassie') is equivalent or superior to the ability to recognize the broader category of objects (e.g., 'dog') (Tanaka & Taylor, 1991).

For most typically developing adults, this level of ability is achieved through the development of a perceptual strategy referred to as 'holistic processing'. Although there is currently no consensus on the definition of this term (Maurer, Le Grand, & Mondloch, 2002), we will use 'holistic processing' to refer to the automatic perception of the whole image or gestalt which involves the simultaneous perception of individual parts as well as the spatial relations among parts (Bartlett & Searcy, 1993; Tanaka & Farah, 1993). It is important to note that expertise could also be achieved through 'local processing'. Local processing involves the examination of individual features or parts of an object separately. Although the development of holistic processing is often associated with the acquisition of expertise and it is often assumed that holistic processing strategies are essential to achieving a level of expert ability (Tanaka & Gauthier, 1997), these assumptions have yet to be empirically validated. Accordingly, the current study will allow for the possibility that expertise may be achieved through holistic *or* local strategies by examining expertise and processing strategy independently.

One approach for measuring the extent to which an individual employs holistic versus local strategies is to quantify the degree to which an individual demonstrates an inversion effect. The inversion effect is measured by comparing performance on upright versus inverted stimuli. Inversion of an object

disproportionately disrupts the extraction of holistic information (Farah, Tanaka, & Drain, 1995; Freire, Lee, & Symons, 2000; Leder & Bruce, 2000), while local information remains relatively intact (Bruyer & Coget, 1987; Freire et al., 2000). Although the inversion effect is typically measured with faces, an inversion effect has also been observed with non-face objects of expertise (Busey & Vanderkolk, 2005; Diamond & Carey, 1986; Gauthier et al., 1998; Moore et al., 2006).

In line with evidence that individuals with ASD tend to employ local processing strategies over holistic processing strategies (Behrmann et al., 2006; Jolliffe & Baron-Cohen, 1997), there is significant evidence that adults with ASD lack a face inversion effect (Hobson et al., 1988; Langdell, 1978; Tantam Monaghan, Nicholson, & Stirling, 1989). Yet, several more recent studies have found that individuals with ASD may, in fact, have an intact face inversion effect (Lahaie et al., 2006; Nishimura, Rutherford, & Maurer, 2007; Scherf, Behrmann, Minshew, & Luna, 2008; Teunisse & de Gelder, 2003). These conflicting results suggest that further investigation on this topic is needed, particularly studies which compare the face inversion effect to inversion effects with other types of complex objects of expertise.

Despite these inconsistent findings regarding the inversion effect, it is clear that in most tasks and across most real-life situations face processing in ASD is atypical and impaired relative to controls (Behrmann et al., 2006; Sasson, 2006). This observation raises an important theoretical question: do individuals with ASD lack the ability to develop perceptual expertise with any complex object, or is this impairment specific to faces? In other words, with sufficient motivation, are individuals with ASD capable of developing face expertise to the level of their typically developing peers, or does a more general cognitive/perceptual deficit involved in the actual process of gaining expertise prevent them from doing so? Furthermore, if individuals with ASD

are able to acquire expertise with a non-face object, what type of processing strategies will they employ as experts?

Hypotheses related to the lack of face expertise in ASD can be broadly categorized as domain-general or face-specific hypotheses. The former set of hypotheses, which we will refer to as domain-general hypotheses, contends that a pervasive underlying cognitive or perceptual deficit (or deficits) disrupts the acquisition of expertise (Behrmann et al., 2006; Davies, Bishop, Manstead, & Tantam, 1994; Happé & Frith, 2006). According to this view, this deficit is not face-specific, but rather is most evident with faces, as faces are highly complex and often require rapid identification. Alternatively, a second set of hypotheses, which will be referred to as face-specific hypotheses, purport that individuals with ASD have the basic cognitive and perceptual skills necessary for developing perceptual expertise, yet simply lack the social motivation to develop such a skill with faces (Dawson, Carver, Meltzoff, Panagiotides, McPartland, & Webb 2002; Grelotti et al., 2002). Supporting this view, the case study reported by Grelotti and colleagues (2005) suggests that, with sufficient motivation, it is possible for an individual with ASD to achieve expertise with non-face objects.

The primary aim of the current study is to shed light on the nature of the face processing deficit in ASD by examining the extent to which it is attributable to a lack of expertise with faces specifically or to a more general perceptual or cognitive atypicality. By examining perceptual expertise with a non-face object, this experimental paradigm effectively controls for the possible group differences in the quality and quantity of experience with the object of expertise (whether face or non-face) and the reward value associated with the object.

The more specific objectives of the study are: (1) To investigate the extent to which individuals with ASD can develop perceptual expertise with non-face objects, in relation to controls, in order to determine if the process of developing expertise is atypical in ASD; (2) To examine the underlying mechanisms and strategies employed with objects of expertise in individuals with and without ASD.

To address these aims, two specific hypotheses will be tested. First, we predict that individuals with ASD will develop perceptual expertise with Greebles to the same extent and at the same rate as typical individuals. This prediction is based on previous work involving Greeble training in individuals with prosopagnosia, which indicates that perceptual expertise can develop in the absence of a face processing expertise (Duchaine, Dingle, Butterworth, & Nakayama, 2004). Secondly, we predict that individuals with ASD will rely on different strategies than the control group to reach this level of expertise. That is, individuals with ASD will not demonstrate an inversion effect to the same extent as controls do when processing objects of expertise. We base this hypothesis on previous research indicating that individuals with ASD show a general tendency to process the local details or parts of an object rather than perceiving the image as a whole (Happe, 1999; Lopez, Donnelly, Hadwin, & Leekam, 2004).

CHAPTER II

METHODS

Participants

The participants enrolled in this study originally included 18 adults with a diagnosis of an ASD and 20 control adults without a family history of ASD. All participants gave informed consent prior to study participation. All participants with ASD were recruited via a database compiled by the Autism Research Centre, composed of individuals who have volunteered via the Autism Research Centre website (www.autismresearchcentre.com) to receive information about opportunities for research participation. The control participants were recruited through either the Autism Research Centre database or printed advertisements placed in the community. Inclusion criteria required that participants in both groups were between the ages of 18 to 60 years, reported normal or corrected-to-normal vision, and received IQ scores of 85 or above. In order to assess IQ, all participants were given the Wechsler Abbreviated Scale of Intelligence (WASI; Wechsler, 1999), except one participant in the ASD group. Exclusion criteria for both groups included history of psychosis, epilepsy, or traumatic brain injury.

For the ASD group, all participants were required to have received a clinical diagnosis of either autism or Asperger syndrome (AS) from a licensed clinical psychologist or physician based upon standard DSM-IV criteria (DSM-IV, APA 1994). Of the participants included in the final analysis, nine were diagnosed with AS and three were diagnosed with autism. As expected, the ASD group differed significantly from the typical group in Autism Spectrum Quotient (AQ) scores, *t* (22)

= -7.77, $p < .001$. The mean, standard deviations, and range of scores on the AQ for each group are displayed in Table 1.

Because the final ASD group included seven males and five females (while the control included six males and six females), independent t-tests were conducted to determine the potential effect of gender on outcome measures. These tests revealed that males and females for both groups combined did not show significantly different performance on the either response time ($p > .10$) or accuracy for the inversion effect task ($p > .10$). Furthermore, independent t-tests between males and females within each diagnostic group revealed no effect of gender within either group for response time ($p > .10$) or accuracy outcome measures ($p > .10$).

Over the course of the two-week training period, six individuals with ASD and six controls withdrew from the study. Most participants cited the high time demands of the study as the reason for withdrawal. No significant differences between individuals who completed the study and those who withdrew were detected for either response time (RT) ($p > .10$) or accuracy measures on the pre-training inversion effect task ($p > .10$). Additionally, neither age nor FIQ scores were significantly correlated with response time ($p > .10$) or accuracy measures on the inversion effect task either before or after training ($p > .10$). Additionally, two individuals in the control group did not meet pre-specified criterion for expertise and were therefore excluded from analysis. The participants included in the final analysis were 12 individuals with ASD and 12 individuals without ASD. The two groups did not differ significantly in age, full-scale IQ, verbal IQ, or performance IQ scores ($p > .10$; see Table 1).

Table 1.Participant Information for Control and ASD groups

	Group	
	Control Group (n= 12)	**ASD Group (n= 12)**
	[Mean (± SD)]	**[Mean (± SD)]**
Age (years)	28.92 (± 6.42)	28.83 (± 9.29)
	(Range: 18 - 39)	(Range: 19 - 53)
Sex	6 females	5 females
	6 males	7 males
Full Scale IQ	117.67 (± 8.28)	114.82 (± 12.48)
	(Range: 101 - 129)	(Range: 91 - 129)
Verbal IQ	115.42 (± 8.91)	117.18 (±13.50)
	(Range: 99 - 128)	(Range: 96 - 137)
Performance IQ	115.42 (± 10.24)	109.55 (± 15.94)
	(Range: 101 - 134)	(Range: 81 - 134)
Autism Spectrum	16.25 (± 4.82)[*]	35.75 (± 8.52)[*]
Quotient (AQ)	(Range: 7 - 24)	(Range: 27 - 46)

[*]$p < .001$

Measures

Autism Spectrum Quotient (AQ). The Autism Spectrum Quotient (AQ) is self-report measure of autistic traits (Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001). Because autistic traits are likely to be on a continuum (Baron-Cohen, 1995; Frith, 1991; Wing, 1988), this questionnaire measures these traits in populations

with and without a diagnosis of ASD. The AQ consists of 50 items with 10 items each measuring: social skills, communication, imagination, attention to detail, and attentional switching. Items are in a forced-choice format and require participants to read a statement and choose one of the following: 'strongly agree', 'slightly agree', 'slightly disagree', or 'strongly disagree'. Questionnaires were completed on our website before beginning the Greeble Training program. Possible scores on this measure range from 0 to 50, with higher scores indicating a greater number of traits associated with ASD.

Wechsler Abbreviated Scale of Intelligence. The Wechsler Abbreviated Scale of Intelligence (WASI) is a brief assessment of intelligence that consists of four subtests: Vocabulary, Matrix Reasoning, Similarities, and Block Design (Wechsler, 1999). The WASI can be administered to individuals from 6 to 89 years. The WASI yields the following standard scores with a mean of 100 and a standard deviation of 15: Full-Scale Intelligence Quotient (FSIQ), Verbal Intelligence Quotient (VIQ), and Performance Intelligence Quotient (PIQ).

Materials

The stimuli used in this study consisted of 40 unfamiliar faces and 40 unfamiliar non-face objects (Greebles). All images were color photographs converted to greyscale and presented on a black background. Twenty images from each class of stimuli were presented in the session before expertise training and then used in the training program, while the remaining twenty images from each class were presented in the session after expertise training.

Greebles are a set of novel objects consisting of a central body with four appendages (see Figure 1) (Gauthier & Tarr, 1997; Gauthier et al., 1998). Because it

has been argued that Greebles' face-like appearance facilitates the recruitment of face processing mechanisms (Kanwisher, 2000), we chose to use asymmetric Greebles for this particular study, as this set of stimuli do not have a part configuration resembling faces (Rossion et al., 2004). Like faces, however, these stimuli, are a set of homogenous objects with the same first-order relationships among parts. Furthermore, with extensive experience, participants can develop sensitivity to configural alterations of Greeble parts (Gauthier & Tarr, 1997). The 40 Greeble stimuli in this experiment were obtained from Michael J. Tarr at Brown University (http://www.tarrlab.org/). Greebles can be categorized on the 'family' level, according to the shape of their main body, or on the 'individual' level according to the shape and positioning of their appendages. Each individual Greeble was assigned a unique nonsense word name (e.g., 'pimo') (see Figure 1 for the distinction between family and individual level categorization). The 40 Greebles used in this experiment were from five different 'families' and two distinct 'genders'.

The 40 faces in this experiment were obtained from the Max-Planck Institute for Biological Cybernetics in Tuebingen, Germany (Troje & Bülthoff, 1996). The faces were cropped into an oval shape to remove the hairline, neck and ears and then converted to greyscale. Although the oval crop was largely determined by the size and shape of the individual faces in order to prevent distortion, the images were also adjusted in order to minimize differences in size and luminance. The faces were then retouched using Adobe Photoshop ® CS3 software to remove any salient features on the surface of the face. The faces included 20 females and 20 males, each with a neutral facial expression. Faces were rotated horizontally at 30˚ angles from the frontal face view (20 faced to the right and 20 faced to the left), with eye gaze oriented in the same direction as the head. Rotated faces were chosen for this study, in

order to control for symmetry between faces and Greebles. Importantly, there is evidence that rotation does not significantly affect holistic or featural processing (McKone, 2008). All faces were scaled to be approximately the same size as the Greebles. Face stimuli were presented at a visual angle of 7.5° (height) x 3.9° (width). The Greeble stimuli subtended 7.2° x 3.9°.
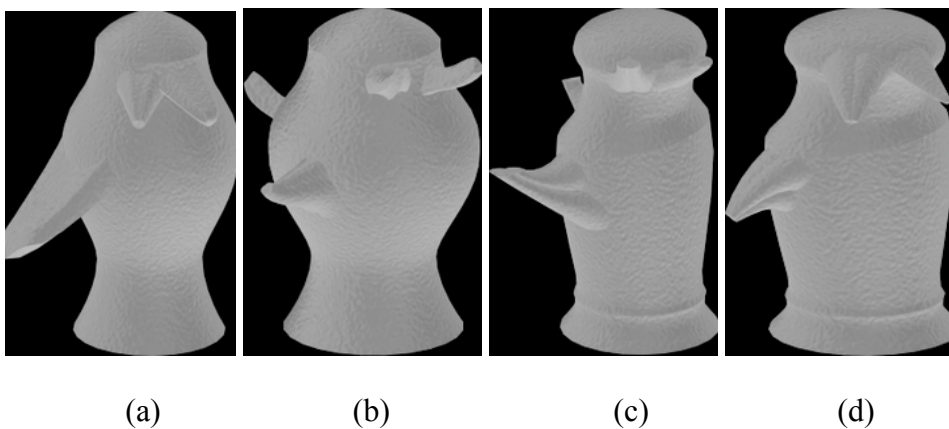

(a) (b) (c) (d)

Figure 1. Examples of individual Greebles used in the training program and laboratory sessions. From right to left: Biff (from the Nalli family), Harga (from the Nalli family), Zadra (from the Yuju family), and Uster (from the Yuju family). Greebles (a) and (b) are members of the same family and Greebles (c) and (d) are members of a different family and, consequently, each of these pairs have the same central body shape. Greebles (a) and (d) are members of the same gender and Greebles (b) and (c) are members of a different gender and, consequently, each of these pairs have the same orientation of for their appendages (either all appendages are facing up or all appendages are facing down). The shape and configuration of the appendages is different for each individual Greeble.

Procedure

This study was approved by the University of Cambridge Psychology Research Ethics Committee. Informed consent was obtained from all participants before participation in the study. The procedure of this experiment was adapted from the procedures of Gauthier and colleagues (1998), Gauthier & Tarr (2002), and Rossion and colleagues (2002), in order to compare our results to previous studies in

the typical population. Accordingly, this experiment was comprised of three parts: an initial inversion effect task in the laboratory before expertise training, ten sessions of expertise training, and a second inversion effect task after participants completed the training.

Pre-training inversion effect task. In the initial laboratory session, all participants performed a computerized inversion effect task with faces and Greebles. After a block of 20 practice trials, participants completed 12 blocks of 40 trials each (480 trials in total). The sequence of each trial was as follows: a centered fixation cross for 200 ms, a blank screen for 550 ms, the first stimulus of a pair for 1000 ms, a perceptual mask for 250 ms, and the second stimulus for 1000 ms (Figure 2). A perceptual mask, which consisted of a scrambled face or Greeble, was presented between the two stimuli to prevent retinal persistence in matching the two stimuli. A blank screen followed the second stimulus for 1800 ms, at which point, participants were asked to indicate whether the stimuli were the same or different by pressing a labelled key on the keyboard. The location of the keys for 'same' and 'different' was counterbalanced across participants.

Of the twenty faces and the twenty Greebles in the session, each stimulus appeared at least once during each block (either in upright or inverted orientation). Within the 40 trials of each block, there were 20 trials with each class of stimuli (faces and Greebles), half of which were in the upright orientation and half in the inverted orientation. In each of these conditions, half of the trials were with female faces or Greebles and half of the trials were with male faces or Greebles. Accordingly, each condition (e.g., 'upright male Greeble') occurred exactly five times in each block. The entire session took participants 45-60 minutes to complete.

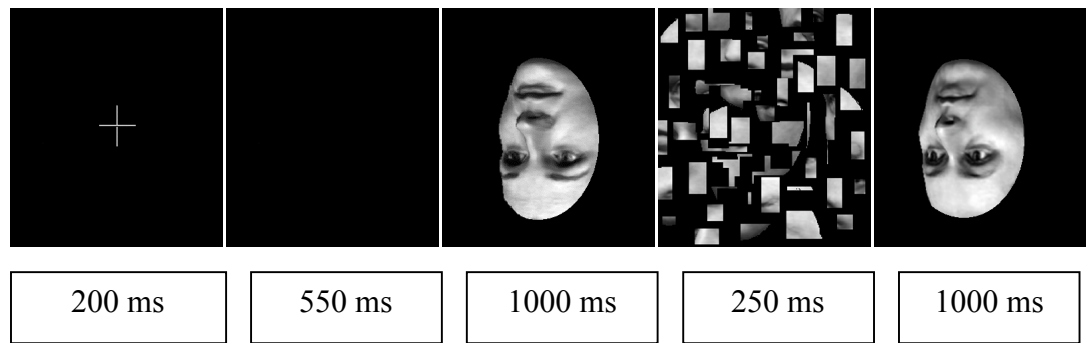| 200 ms | 550 ms | 1000 ms | 250 ms | 1000 ms |

Figure 2. Example of the inversion effect task sequence.

Greeble training program. The Greeble training program consisted of ten sessions completed online over the course of two weeks. The sessions were completed using a personal computer, a work computer, or a computer at the library. The training focused on teaching participants to categorize a set of Greeble stimuli on both the family level and the individual level. Participants were instructed to complete all ten sessions in two weeks and to complete no more than one session per day. As sufficient motivation may be the driving force behind the development of expertise (Grelotti et al., 2002), participants were offered a cash bonus if they were one of the three participants in each group with the highest level of accuracy for upright Greebles in the post-training inversion effect task.

An internet-based training program was developed for this study in order to make participation possible for participants with ASD who did not live near our laboratory. The program was accessed via the Autism Research Centre website (www.autismresearchcentre.com). Participants' progress in the training program could be monitored daily, as their activity in the training program was loaded onto a database. However, it is important to note that internet-based training likely introduces more variance in both the training experience and in the response time data compared to a standardized training program conducted in a laboratory. Such variance

may be unrelated to behaviour, but instead due to the processor speed, the type of operating system, the bandwidth of internet connection, the number of different programs running simultaneously, and the integration of keyboard input (McGraw, Tew, & Williams, 2000; Reips, 2000). The training experience of each participant may also be slightly different, as stimulus presentation varies according to different display settings (Krantz, 2000). Differences among computing systems which may affect perception of the stimuli can include screen dimensions (height and width), operating system type and edition, browser type and edition, and display settings, such as colour quality and screen resolution (Reips, 2002).

Several precautions were taken to minimize these potentially confounding factors. First, all images were downloaded to the participants' computers before the start of the training. Although the loading time may vary substantially according to the bandwidth of the Internet connection, preloading the stimuli virtually eliminates any timing differences due to bandwidth differences (McGraw et al., 2000). Additionally, all participants were given clear written instructions for logging on to the website and asked to contact the researcher if the training instructions were unclear in any way or if they had any questions about the tasks in the sessions. Before beginning the session, participants were instructed to close all other programs running simultaneously. Participants were also asked to use the same computer throughout the training and to use Internet Explorer if available. Information was also collected regarding the computer, the operating system, and the Internet connection that each participant used throughout training. Participants were also required to use a computer less than 10 years old with an operating system of Windows 2000, Mac OS X, or another equivalent or more advanced system. Additionally, because the main variable of interest (the point at which response time on the individual level was equivalent or

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significantly faster than response time on the family level) was first calculated within each individual subject before comparisons were made across individuals or groups, any source of stable variability among computers, operating systems, or internet bandwidth in this variable was controlled for to some extent.

Over the course of training, participants were introduced to five Greeble families with four individual Greebles in each family. The five different family names were introduced in the first session. In this session, all exemplars in the training set were assigned a family name and all Greebles were presented with their family name for participants to study. Participants practiced categorization by family name throughout the training. Because family categorization depends upon only one feature of the Greeble (the main body shape), this judgement should be equally difficult for novices as for experts as soon as the association between name and body shape has been learned. On the other hand, discrimination on the individual level should be more difficult for novices than for experts. The individual names were introduced over the course of the first four sessions, with five new Greebles being presented in each session. Both family names and individual names used in the training were nonsense words (e.g., 'plok', 'camar', 'snodi'). After the first five sessions, participants practiced with all Greeble family and individual names for the remaining five sessions.

Each training session took about an hour to complete and included a combination of seven tasks designed by Gauthier and colleagues (1998) (see Appendix A). These tasks tested participants' ability to recognize and identify upright Greebles both with and without corrective feedback. Two of these tasks required participants to passively study Greebles paired with their family or individual names. Another task asked participants to categorize the Greebles on the family level with

corrective feedback. This feedback consisted of a 'beep' following an incorrect reply and the task did not continue until participants had responded correctly. In addition to the family names, three tasks were completed to learn the individual names. In the first task, participants were presented with the Greeble and its individual name and asked to press the key that corresponded to the Greeble's name. The second task also required participants to categorize Greebles according to individual name but without the name available. Corrective feedback was provided in this task as participants heard a 'beep' for an incorrect reply and were required to try again until they chose the correct answer. The third task for individual names required participants to name Greebles without corrective feedback. In every session, tasks to learn both family and individual names were completed.

In each training session, participants were tested with a verification task (Gauthier & Tarr, 2002). Each instance of the verification task tested participants on the identification of all Greeble family and individual names that had been learned at that point in the training. In the first four sessions, unnamed Greebles were also included in this task. The correct pairing for an unnamed Greeble was a 'NIL' label. For example, if an unnamed Greeble was matched with a 'NIL' label, participants should have indicated that this pair was correct. In this task, either a family name or an individual name was presented for 1000 ms and then a Greeble followed that either matched or did not match the label. The Greeble remained onscreen until the participant made a response. Participants were asked to press the 'C' key if the label correctly matched the Greeble and the 'I' key if the label was incorrect. The first session included two blocks of the verification task. Every remaining session included four blocks of the verification task per session. Each block of the verification task included 120 trials with each Greeble being presented three times during the task.

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Participants were not given feedback on their answers and were not given the opportunity to correct themselves after providing a response.

In order to remove the influence of trials in which participants were not engaged in the task, response times less than 100 ms or greater than 5000 ms were not included in the analysis. Furthermore, for any instance of the task in which the accuracy was less than chance, that particular block was excluded from analysis. The main variables of interest were the mean response time in identifying Greebles on the family level and the mean response time in identifying Greebles on the individual level. Response time was measured as the time (in ms) from the presentation of the Greeble until a response was made. Accuracy over the entire session was also measured to determine whether or not participants were attending to the task so that response time could be interpreted as a meaningful representation of the participants' knowledge of Greeble names. Accuracy was measured as the percentage of trials that were correct in each block of the verification task for both family level and individual level categorization. Percentage correct scores were calculated by determining the percent of Greebles correctly identified on both the family level and individual level in each block of the verification task and then averaging these blocks for all participants in a group to determine overall accuracy for each group. However, in line with previous studies of expertise (e.g., Gauthier et al., 1998), accuracy measures from this task were not used to determine participants' level of expertise.

Post-training inversion effect task. When participants had completed all sessions of the training program, they returned to complete a post-training inversion effect task. Participants completed this session approximately two weeks after completion of the first laboratory session. The procedure of this session was nearly

identical to the first, but with a new, unfamiliar set of stimuli (20 new faces and 20 new Greebles).

Analytic Approach

Due to the complexity of this study design, all variables of interest for this study are listed in Table 2, along with definitions for each variable and how the variable was used in the analyses.

Table 2. Variables of Interest

	Training Data		
Variable Name	**Description**	**Computational Definition**	**How Used in Analyses**
Family Level Categorization	Mean response time (ms) for indicating whether a family name is 'correct' or 'incorrect' for a Greeble in the verification task of the training program	Mean Response Time= (Sum of response times in each trial of the verification task in a block/120 total trials)	Compared to individual level categorization with pairwise *t*-tests for each individual in each block of the verification task to determine point of expertise
Individual Level Categorization	Mean response time (ms) for indicating whether an individual name is 'correct' or 'incorrect' for a Greeble in the verification task of the training program	Mean Response Time= (Sum of response times in each trial of the verification task in a block/120 total trials)	Compared to family level categorization with pair-wise *t*-tests for each individual in each block of the task
Point of Expertise	The average block of the verification task in which the mean response time for the individual categorization of a Greeble was either not significantly different or was significantly faster than the mean response time for the family categorization for each individual	Mean Point of Expertise = (Sum of the blocks in which each participant reaches expertise for each group)/ number of participants in each group	The blocks in which each individual achieved expertise were averaged for each group, then submitted to independent *t*-tests to determine if the average blocks were different between groups
Accuracy	The percentage of trials that were correct in each block of the verification task for both family level and individual level categorization combined	The mean percent correct (percent correct for each individual =number of correct trials in a block /120 trials total) averaged across each group	Accuracy across the entire training program was averaged across each individual and across each group, then independent *t*-tests were conducted to compare mean accuracy between the ASD and control groups

Table 2. Variables of Interest (continued).

Inversion Effect Task (Both Pre- and Post- Training)			
Face Inversion Effect (FIE)	The difference between the response time (or percent correct) for an upright face and the response time (or percent correct) for an inverted face both before and after training	FIE before training = Statistical significance of the difference between upright face before and inverted face before FIE after training= Statistical significance of the difference between upright face after and inverted face after	Measured within each group using pairwise t-tests to compare upright to inverted faces; also pairwise t-tests were conducted within each group to determine if the FIE was different before vs. after training
Greeble Inversion Effect (GIE)	The difference between the response time (or percent correct) for an upright Greeble and the response time (or percent correct) for an inverted Greeble both before and after training	GIE before training = Statistical significance of the difference between upright Greeble before and inverted Greeble before GIE after training= Statistical significance of the difference between upright Greeble after and inverted Greeble after	Measured within each group using pairwise t-tests; also pairwise t-tests were conducted within each group to determine if the FIE was different before vs. after training
Change in performance for Upright/Inverted Faces/Greebles	A measure of how the processing of each stimulus category (upright face, upright Greeble, inverted face, inverted Greeble) changed as a result of training	Statistical significance of the difference before versus after training for upright and inverted faces and Greebles	Pairwise t-tests were conducted to compare response time or accuracy before training to after training for each stimulus category
FIE Treatment Effect	The extent to which the face inversion effect changed as result of training (difference score of the FIE before training and the FIE after training)	FIE treatment effect = [FIE After (Upright Face After – Inverted Face After)] – [FIE Before (Upright Face Before – Inverted Face Before)]	Independent t-tests were conducted to compare ASC and control groups on this measure
GIE Treatment Effect	The extent to which the Greeble inversion effect changed as result of training (difference score of the GIE before training	GIE treatment effect = [GIE After (Upright Greeble After – Inverted Greeble After)] – [GIE Before (Upright Greeble Before – Inverted Greeble After)]	Independent t-tests were conducted to compare ASD and control groups on this measure

In order to address the first hypothesis that individuals with ASD would develop expertise with Greebles in the same time period as the control group, the point of expertise was calculated for each individual participant. As in previous studies of perceptual expertise, the point of expertise was calculated by conducting pairwise *t*-tests to measure differences between the mean response time for family level identification and the mean response time for individual level identification in each block of the verification task for a particular session (Gauthier & Tarr, 1997). The mean response times for both individual and family level categorization were calculated by averaging response times for each type of categorization across all trials of a block (120 trials total) for each individual participant. Pairwise *t*-tests were then conducted on these mean response times for each participant on each block of the verification task. The 'point of expertise' was defined as the block of the verification task in which the mean response time for the individual categorization of a Greeble was either not significantly different ($p > .05$) or was significantly faster than the mean response time for the family categorization ($p < .05$). In order for a participant to be considered an 'expert' for the current study, the point of expertise had to be achieved in at least two blocks of the verification task in a single session. The point of expertise was marked as the first block in which the participant reached the criterion for expertise.

Only training sessions occurring after all Greebles had been introduced were examined in order to determine the point of expertise. Because all Greebles were introduced by session four, only sessions four to ten were included in this analysis to determine the point of expertise (and the first three sessions were not examined). As sessions four through ten each had four blocks of the verification task, each block in a session was designated as a fraction of the session number for analysis. For session

five, for example, the four blocks were designated as 5.0, 5.25, 5.5, and 5.75 for the first, second, third, and fourth blocks, respectively. These more precise measurements of the point of expertise for each participant were then averaged separately for the ASD and control groups to determine the mean point of expertise within each group. Independent *t*-tests were then conducted to determine if the mean point of expertise was different between the two groups. Independent *t*-tests were also conducted on the mean accuracy scores for each group in order to ensure that these results were not attributable to group differences in the speed-accuracy trade-off.

To address the second hypothesis that participants with ASD would employ different perceptual strategies than control participants, the results of the inversion effect were analyzed using both between-group and within-group statistical tests to examine how response time and accuracy data for faces and Greebles changed for each diagnostic group as a result of training. Both response time and accuracy data were collected from the inversion effect task. The variables of interest for this task were mean response time and percentage correct in identifying faces and Greebles in the upright and inverted orientations. In analyzing response time data, response times occurring after the subsequent trial began (i.e., any response times greater than 2800 ms) and incorrect responses were excluded from analysis. Because most responses were correct (i.e., the average percent correct scores were above 80% for all conditions in both groups) and response times over 2800 ms occurred less than 5% of the time, nearly all of the data collected was included in the analysis.

Because the development of an inversion effect would ideally be measured by examining the interactions among several variables from the inversion effect task (particularly the session x group x type of stimulus x orientation interaction), an ANOVA involving all of these factors was initially planned. However, exploratory

analyses of the response time and accuracy data from the inversion effect task indicated that several variables that would be included in an omnibus ANOVA (the Greeble inversion effect in RT before training, the face inversion effect in RT after training and the accuracy measures for inverted Greebles and upright faces) violated the homogeneity of variance assumption for parametric tests (Levene's test for Equality of Variance, $p < .05$). Accordingly, a single ANOVA was not conducted to examine interactions among inversion effect task variables. Although a non-parametric approach was considered, this approach was not taken, as the independent t-test has been found to be more powerful than its nonparametric alternative (the Mann-Whitney U-test) when sample sizes are equal (Zimmerman, 1987). Consequently, between-group differences were examined through separate independent t-tests for the face inversion effect and Greeble inversion effect and within-group differences were examined through multiple pairwise t-tests. Both response time and accuracy data from the inversion effect task were analyzed, first, for differences between diagnostic groups using independent t-tests with variables that did not violate the homogeneity of variance assumption and, second, within-group differences were examined using pairwise t-tests with variables that may have contributed to any significant between-group differences detected by independent t-tests for either the face inversion effect or Greeble inversion effect.

In line with previous studies of the inversion effect (Carey & Diamond, 1994; Mondloch, Le Grand, & Maurer, 2002), the face inversion effect (FIE) was defined as a difference score of the response time (or percent correct) for an upright face minus the response time (or percent correct) for an inverted face. Similarly, the Greeble inversion effect (GIE) was defined as the response time (or percent correct) for an upright Greeble minus the response time (or percent correct) for an inverted Greeble.

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To examine between-group differences, the two groups were compared on a measure referred to as the FIE treatment effect and the GIE treatment effect. These treatment effects were defined as the extent to which the face and Greeble inversion effects changed as result of training (by subtracting the inversion effect before training from the inversion effect after training), as this measure did not violate the homogeneity of variance assumption of the independent t-test (Levene's Test for Equality of Variance, $p > .05$). Both the FIE and GIE treatment effects were examined for response time and accuracy data. The FIE and GIE treatment effects were calculated as follows for both response time and accuracy measures:

Face Inversion effect (FIE) treatment effect = [FIE After (Upright Face After – Inverted Face After)] – [FIE Before (Upright Face Before – Inverted Face Before)]

Greeble Inversion Effect (GIE) treatment effect = [GIE After (Upright Greeble After – Inverted Greeble After)] – [GIE Before (Upright Greeble Before – Inverted Greeble After)]

If a between-group difference was detected in either the FIE or the GIE treatment effect for response time or accuracy data, pairwise t-tests were then conducted within each group to determine the source of this difference. These pairwise tests were only conducted when a significant between-group difference was detected with a particular class of stimuli and only involved variables that may have contributed to the between-group difference. In other words, if a significant effect of training was detected with the response times for the Greeble inversion effect, pairwise t-tests were conducted to examine the relations among upright and inverted

Greebles before and after training in the response time data only, as all of these variables may have contributed to the between-group difference. Similarly, if a between-group difference was found in the FIE treatment effect, pairwise tests were conducted to examine the relations among upright and inverted faces before and after training. These tests were performed to determine if the between-group difference reflected a change in the presence or absence of an inversion effect or simply a change in performance with either upright or inverted stimuli as a result of training. Accordingly, these comparisons included: tests to determine whether an inversion effect was present before training [upright face or Greeble (before) and inverted face or Greeble (before)] or after training [upright face or Greeble (before) and inverted face or Greeble (after)], along with before and after comparisons to determine if there was a change as a result of training for upright [upright face or Greeble (before) and upright face or Greeble (after)] and inverted faces or Greebles [inverted face or Greeble (before) and inverted face or Greeble (after)]. For these tests, a Bonferroni correction for multiple comparisons was applied to reduce the chance of a Type I error, adjusting the alpha to $p = .0125$ (.05/4).

Finally, to further substantiate the findings of the pairwise comparisons above, additional pairwise t-tests were also conducted when between-group differences were detected in the FIE or GIE. As with the pairwise tests described above, these tests were conducted with face inversion effects only when a between-group difference was detected with either the FIE treatment effect or with Greeble inversion effects only when a between-group difference was found in the GIE treatment effect. In other words, only the inversion effects that may have contributed to the between-group difference in treatment effect were examined. These tests were performed to confirm that the face or Greeble inversion effect significantly changed as a result of training.

Thus, if a significant between-group effect was detected with the GIE treatment effect, pairwise *t*-tests were conducted to compare the Greeble inversion effect before training to the Greeble inversion effect after training in each group. Similarly, if a between-group difference was detected in the FIE treatment effect, pairwise *t*-tests were conducted to compare the face inversion effect before training to the face inversion effect after training in each group.

CHAPTER III

RESULTS

Training Results

        Response time and accuracy data from the verification task of the training

program were used to measure level of expertise during the program (Figure 3). Of

the 24 participants who achieved expertise, two control participants had incomplete

data from the first three sessions due to a website error. These data points were not

included in the analyses. Independent *t*-tests indicated that the mean point of expertise

was not significantly different between the ASD and the control group, $t (22) = -1.08$,

$p = .29$. In the ASD group, the expertise criterion (the 'point of expertise') was

reached after a mean of 5.33 sessions (range = 4.25- 9.75, $SD = 1.87$), while the

control group reached this criterion after a mean of 4.71 sessions (range = 4.25- 6.75,

$SD = 0.73$). Expertise was also maintained across sessions in both groups, as the mean

response time for family level categorization was not significantly faster than the

mean response time for individual level categorization after the point of achieving

expertise, $t (22) = -0.26$, $p= .80$. Further, Independent *t*-tests revealed that the mean

accuracy (percent correct) in naming Greebles during the verification task for the

ASD group ($M = 91.57$, $SD = 11.75$) was not significantly different from the mean

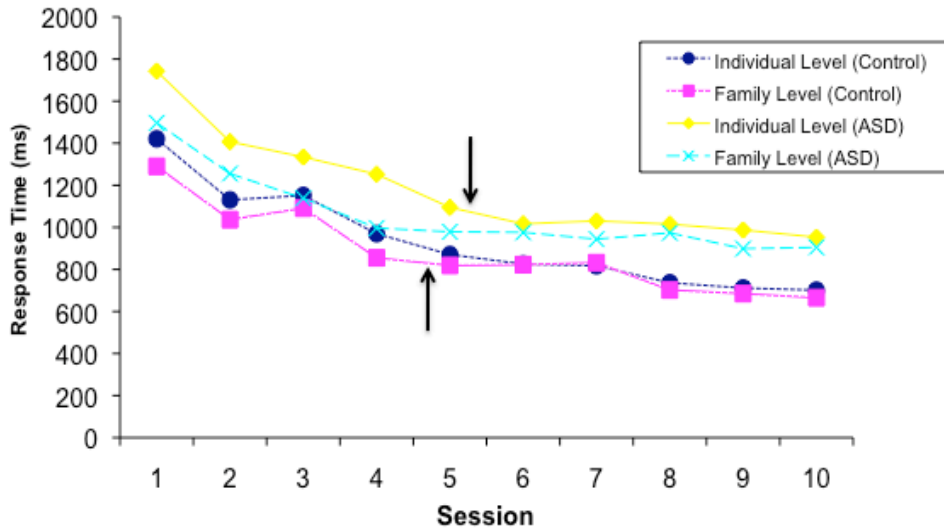accuracy of the control group ($M = 90.47$, $SD = 10.79$), $p >.10$.

Figure 3. Performance during the expertise training program over the course of ten sessions for participants with and without ASD. The point where the mean response time for family level categorization meets the mean response time for individual level categorization is the 'point of expertise' (when expertise with Greebles is acquired). Arrows indicate the point of expertise for each group.

Inversion Effect Task: Response Time

The mean response times (and standard deviations) for each stimulus condition involved in the inversion effect task are listed in Table 3. For response time data, independent *t*-tests (two-tailed) indicated that, while there was no between-group difference in how the FIE changed as a result of training (FIE treatment effect), t (22) = 0.46, p = .65, a nearly significant difference was found in the GIE treatment effect, t (22) = -2.02, p= .056. Because this test may have been underpowered due to the small sample size, pairwise *t*-tests (two-tailed) were conducted to better understand why the group difference in the GIE treatment effect might have trended towards significance.

Table 3. Mean Response Times and Standard Deviations (in milliseconds) for Upright and Inverted Faces and Greebles

		Control Group		ASD Group	
		Before Training	After Training	Before Training	After Training
Type	Orientation	[Mean (± SD)]		[Mean (± SD)]	
Faces	Upright	704.69 (± 106.33)	644.46 (± 118.27)	768.28 (± 218.82)	686.94 (±203.14)
	Inverted	762.89 (±114.66)	708.62 (± 114.68)	818.21 (± 202.23)	736.69 (± 201.77)
Greebles	Upright	749.33 (±110.17)	680.68* (± 132.01)	806.99 (± 219.36)	710.95 (± 208.53)
	Inverted	755.99 (± 114.73)	706.84* (±140.98)	837.55 (± 247.81)	747.67 (± 237.42)

* Variables that contribute to significant inversion effects, $p < .0125$

Four pairwise *t*-tests were conducted for each diagnostic group, in order to understand the effect of training on the GIE. As expected, the control group was not found to have a significant Greeble inversion effect before training, $t(11) = -1.90$ $p = .30$. However, a significant Greeble inversion effect was found after training in the control group, $t(11) = -4.09$, $p = .002$, as significantly faster response times for upright Greebles ($M = 680.68$, $SD = 132.01$) compared to inverted Greebles ($M = 706.84$, $SD = 140.98$) were found after training (see Figure 4). When response times with upright Greebles was compared before versus after training, this difference did not reach significance given the alpha level set by the Bonferroni correction, yet it did show a trend towards significance, $t(11) = 2.54$, $p = .029$. A significant difference in response times, was also not detected with inverted Greebles before versus after training, $t(11) = 1.75$, $p = .11$.
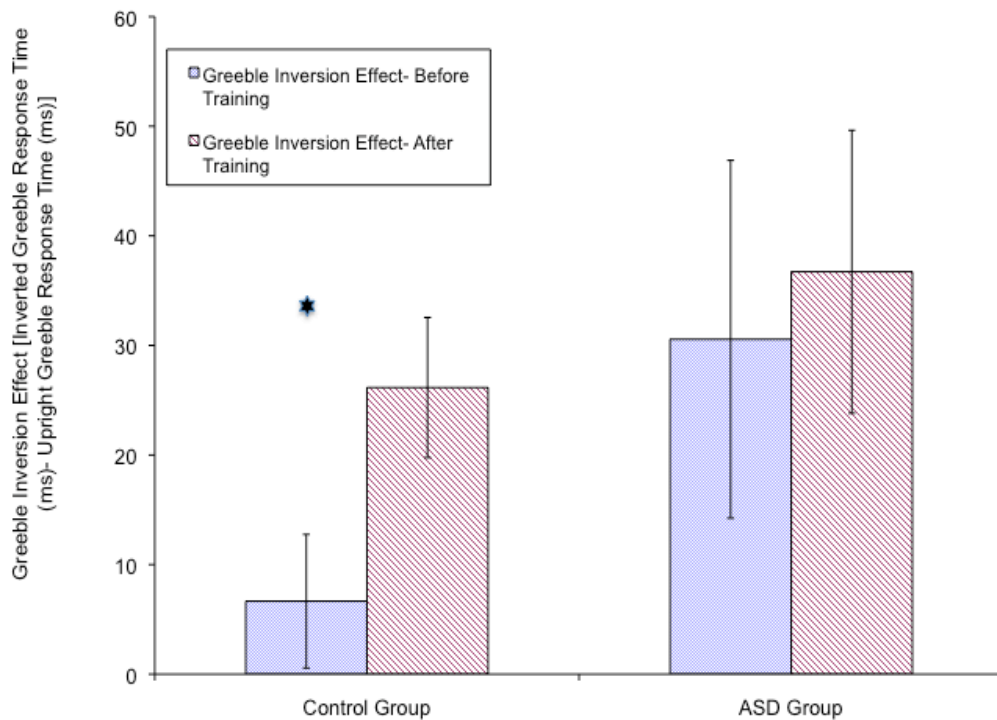
Figure 4. Changes in the Greeble inversion effect (GIE) as a result of expertise training for individuals with and without ASD. The GIE is calculated by subtracting the mean response time for upright Greebles from the mean response time for inverted Greebles. Error bars represent standard error.

For the ASD group, no significant inversion effects were detected for Greebles, yet trends towards significance were detected both before, t (11) = -1.87, p = .09, and after training t (11) = 2.85, p = .02 (see Figure 4). Additionally, a significant effect of training was found for both upright Greebles, t (11) = 4.33, p = .001, *and* inverted Greebles, t (11) = 3.10, p = .010. These differences reflect significantly faster response times for upright Greebles after training (M = 710.95, SD = 208.53) compared to before training (M = 806.99, SD = 219.36) and significantly faster response times for inverted Greebles after training (M = 747.67, SD = 237.41) than before training (M = 837.55, SD = 247.81).

In order to further substantiate these findings, pairwise t-tests (two-tailed) were conducted to examine the effect of training on the GIE in both the control group

and the ASD group. These tests found that, in the control group, the Greeble inversion effect was significantly greater after training than before training, $t(11) = -2.45$, $p = .03$, while, in the ASD group, there was no difference in the GIE as a result of training, $t(11) = -0.46$, $p = .65$.

Inversion Effect Task: Accuracy

The mean percentage correct scores (and standard deviations) for the inversion effect task are reported in Table 4. For accuracy data, independent *t*-tests (two-tailed) detected a significant between-group difference in the FIE treatment effect, $t(22) = 2.30$, $p = .03$, but not in the GIE treatment effect, $t(22) = 0.81$, $p = .42$. These results suggest that, for accuracy measures, the effect of training on the FIE is different in control group compared to the ASD group, while the effect of training on the GIE is not different across groups.

Table 4

Mean Percentage Correct Scores and Standard Deviations for Upright and Inverted Faces and Greebles

Type	Orientation	Control Group		ASD Group	
		Before Training	**After Training**	**Before Training**	**After Training**
		[Mean (± SD)]		[Mean (± SD)]	
Faces	**Upright**	91.32*	95.97*	87.64	87.57
		(± 6.92)	(± 2.53)	(± 13.04)	(±16.04)
	Inverted	84.79*	83.68*	80.97	82.15
		(±9.02)	(± 7.40)	(± 9.91)	(± 10.30)
Greebles	**Upright**	83.75	89.72	82.50	87.78
		(±8.61)	(± 5.93)	(± 12.51)	(± 9.34)
	Inverted	83.26	91.11	73.98	88.33
		(± 7.23)	(± 6.77)	(± 12.71)	(± 11.22)

* Variables that contribute to significant inversion effects, $p < .0125$

To examine how the FIE may have differed across groups, four pairwise *t*-tests (two-tailed) were conducted to investigate differences in accuracy for upright and inverted faces. For the control group, a significant face inversion effect was detected before training, $t (11) = 3.56$, $p = .004$, and after training, $t (11) = 6.70$, $p < .001$. Before training, the average percent correct score for upright faces was 91.32 % ($SD = 6.92$), while the average percentage for inverted faces was 84.79 % ($SD = 9.02$). Similarly, after training, the average percentage correct score was greater for upright faces ($M = 95.97$, $SD = 2.53$) compared to inverted faces ($M = 83.68$, $SD = 7.40$) after training. However, no significant effects of training were found for upright faces, $t (11) = -2.17$, $p = .05$, or inverted faces, $t (11) = 0.40$, $p = .70$, when accuracy was compared for each of these categories before training versus after training

For the ASD group, a face inversion effect was not detected either before training, t (11) = 2.30, p = .04, or after training, t (11) = 1.55, p = .15. However, the face inversion effect before training did show a trend towards significance. No significant changes in accuracy with upright faces, t (11) = 0.30, p = .98, or inverted faces t (11) = -0.94, p = .37, were detected as a result of training. Figure 5 illustrates these findings.
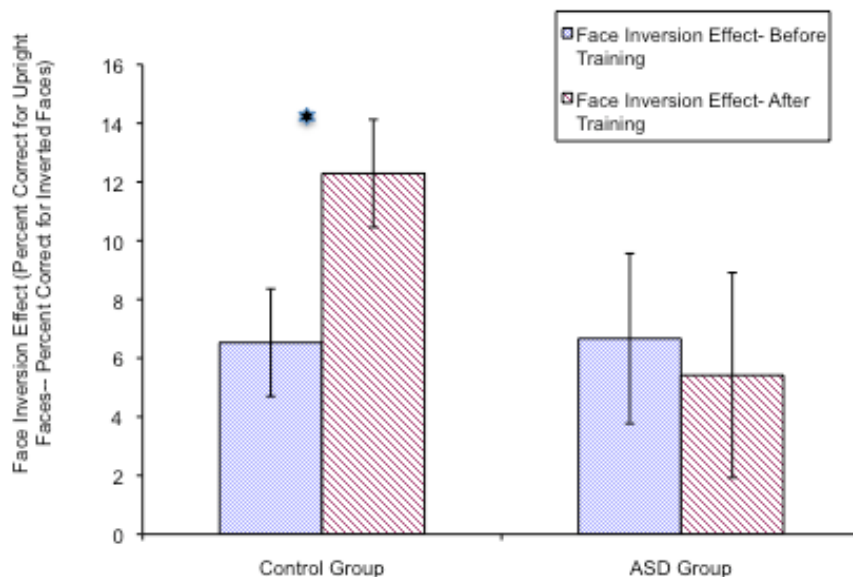

Figure 5. Changes in the face inversion effect (FIE) as a result of training for individuals with and without ASD. FIE is calculated by subtracting the average percent correct score for inverted faces from the average percent correct score for upright faces. Error bars represent standard error.

To provide further support for these results, pairwise t-tests (two-tailed) were conducted to compare the FIE before training to the FIE after training within each group. These tests indicated that, while there was no difference in the FIE before versus after training in the ASD group, t (11) = 0.48, p = .64, the FIE in the control

group was significantly greater after training than before training, $t(11) = -3.69$, $p =$

.004.

CHAPTER IV

DISCUSSION

The findings of the current study indicate that, when provided with sufficient experience, individuals with ASD are indeed capable of developing perceptual expertise with complex objects. The acquisition of expertise with Greebles is evident in the qualitative shift that occurs in the recognition of Greebles on an individual level in individuals with and without ASD. As illustrated by Figure 3, individuals with ASD achieved this expertise criterion after approximately the same quality and quantity of experience as the control group.

However, these findings also suggest that individuals with ASD employ qualitatively different perceptual strategies as experts when compared to the control group. To summarize the findings from the inversion effect task, significant between-group differences were detected in the GIE treatment effect for response time measures and in the FIE treatment effect for accuracy measures. For the control group, expertise training resulted in an enhanced GIE (as evidenced by a speed advantage for upright Greebles) and an enhanced FIE (as evidenced by an accuracy advantage for upright faces). On the other hand, neither the GIE nor the FIE were observed in the ASD group either before or after training. However, individuals with ASD did show significantly enhanced performance with upright and inverted Greebles following training (as evidenced by faster RT).

More broadly, the results of the inversion effect task suggest that the control group processed objects of expertise through specialized holistic processing strategies and unfamiliar objects through local processing strategies. In contrast to the ASD

group, the control group's strategy for objects of expertise could be clearly differentiated from their strategy for unfamiliar Greebles, as a face inversion effect was observed both before and after training and a Greeble inversion effect was observed after training only. The development of a Greeble inversion effect indicates that controls acquired the ability to employ holistic processing mechanisms after achieving expertise, supporting previous studies of perceptual expertise in control populations (Gauthier et al., 1998; Moore, Cohen, & Ranganath, 2007; Rossion et al., 2002). The enhanced face inversion effect in the control group following training further suggests that controls were practicing holistic processing strategies during the training program. Because expertise training involves extensive practice of perceptual strategies used in expertise processing, the process that is practiced is likely to become more efficient as a result of training, resulting in enhanced holistic processing of Greebles and faces in the post-training inversion effect task. Surprisingly, the control group did not show the expected improved performance with upright Greebles as a result of training. Yet, although neither response time nor percent correct was significantly different after training versus before training, a trend towards improvement with upright Greebles after training was found, as controls were 68.65 ms faster after training and 5.97% more accurate after training (see Table 3 and Table 4). The lack of a significant improvement with upright Greebles may be attributable to the change in task from the training program to the inversion effect task or to the introduction of a new set of Greeble stimuli in the inversion effect task.

Yet, despite statistically equivalent performance throughout training, individuals with ASD clearly employed different perceptual strategies after achieving expertise. These different strategies were evident in the lack of a Greeble inversion effect in the ASD group. However, because the ASD group achieved expertise within

the same time period as the control group, this different perceptual style cannot be associated with a decrement in performance. Rather, these results should be interpreted as further evidence that individuals with ASD often use a different perceptual or cognitive style to accomplish tasks (Happé, 1999).

This different perceptual style may confer distinct advantages and disadvantages in expertise processing. The first striking aspect of this cognitive style is that individuals with ASD approach faces and objects of expertise with the same perceptual strategy as entirely novel objects (Greebles). Accordingly, individuals with ASD not only failed to show an inversion effect for unfamiliar Greeble stimuli, but also showed no evidence of an inversion effect with Greebles even *after* achieving expertise. In other words, individuals with ASD did not acquire perceptual specialization for the upright form of an object even after extensive training. Instead, they employ the same basic perceptual strategy regardless of experience with an object. This strategy likely involves a focus on the local parts of an object, as the perception of parts is not affected by orientation. Further supporting this assertion, individuals with ASD showed significantly faster response times for both upright *and* inverted Greebles following training, even though the training program involved exclusively upright Greebles. These results suggests that individuals with ASD likely acquired a local processing strategy during training, as the strategy they employed was equally effective for upright Greebles as for inverted Greebles.

The use of a different perceptual strategy in ASD may reflect a different set of goals in how individuals with ASD approach the perception of objects of expertise. For typically developing individuals, expertise perception is often used to accomplish goals of a social nature. In particular, the same processes which underlie the inversion effect have been found to be important in facial identity recognition (McKelvie,

1995), emotional expression discrimination (Durand, Gallay, Seiqneuric, Robichon, & Baudoin, 2007; Fallshore & Bartholow, 2003), visual speech perception (Rosenblum, Yakel, & Green, 2003), and eye gaze processing (Jenkins & Langton, 2003). Consequently, it may be most adaptive for typical adults to approach all tasks of expertise perception with a holistic processing strategy. For individuals with ASD, on the other hand, the immediate detection of social cues from a face may *not* be the most important goal in object recognition. Instead, they may have developed a bias to focus on the local details of an object with the goal of understanding an object's physical nature and how it functions as part of a system. Because following eye gaze and responding to emotional expression are integral parts of social interaction, inconsistent use of holistic processing may underlie some of the social difficulties in ASD.

However, it is important to note, that although no significant inversion effects for faces or Greebles were detected in the ASD group, there were trends towards significant inversion effects for both sets of stimuli (see Figures 4 and 5). Yet, because individuals with ASD also showed a Greeble inversion effect that approached significance *before* expertise training, this trend in the ASD group does not reflect a perceptual specialization for the upright form of a stimulus as a result of extensive experience. Rather, this trend may simply reflect a greater sensitivity to the physical properties of a stimulus. This tendency could be attributable to a superior understanding of physical causality or 'folk physics' in individuals with ASD (Baron-Cohen, 1997). Because of this sensitivity individuals with ASD may be more aware that the rounded top half of a Greeble (and a face) could not serve as a stable base. Accordingly, individuals with ASD may find physically impossible (inverted) stimuli more difficult to process regardless of experience with the object. This finding is

particularly relevant in light of recent studies that have reported an intact face inversion effect in ASD (Joseph & Tanaka, 2003; Nishimura, Rutherford, & Maurer, 2007; Scherf et al., 2008; Teunisse & de Gelder, 2003), as many of these studies did not compare the face inversion effect to an inversion effect with a novel non-face object.

Interestingly, despite the different perceptual mechanisms employed by individuals with ASD, both groups achieved expert level processing with Greebles. In order to perform at levels comparable to typical individuals, it is likely that individuals with ASD are employing very efficient compensatory strategies, such as enhanced local processing. Yet, it is important to note that, even with such highly effective compensatory strategies, a preference for local processing over holistic processing may cause individuals with ASD to miss many of the subtle cues of identity and emotion that are embedded in the configuration of a face.

A more general aim of the current study was to address possible hypotheses regarding the nature of the face processing deficit in ASD by examining the extent to which face processing deficits are face-specific or attributable to a more general cognitive/perceptual deficit. To address these hypotheses, it will be important to distinguish face processing ability from face processing strategy. First, because individuals with ASD were found to successfully acquire Greeble expertise in the current study and previous research has shown that individuals with ASD are impaired in face recognition (Blair et al., 2002; Boucher & Lewis, 1992; Davies et al., 1994), this distinction suggests that the deficit found in the ability to discriminate and recognize faces may be face-specific to some extent. Yet, because individuals with ASD employ a different processing strategy with objects of expertise and faces, this finding suggests that differences in face processing strategy may reflect a more

pervasive cognitive or perceptual atypicality. In sum, our findings suggest that face-specific explanations may be appropriate for understanding impairments in face processing abilities in ASD, while domain-general hypotheses may account for atypical face processing strategy. However, it is also possible that atypical face processing in ASD may require a more complex explanation than the one outlined above. Investigation into the development of perceptual expertise in infants and young children is clearly needed before these explanations can be confirmed.

Although the current study is one of the first experimental studies of perceptual expertise in ASD, one clear limitation of this study is the small sample size. Another potential limitation of this study is the use of laboratory-trained objects of expertise, as it is unclear the extent to which expertise with Greebles relates to real-life expertise. Although these two types of expertise have been equated theoretically, they are different on many levels, including the participants' intrinsic motivation to acquire expertise and their total of history of experience with the object. Because individuals with ASD may have different motivational and attentional biases in achieving expertise, laboratory-trained expertise was chosen for the current study in order to control for these potential group differences.

The study of perceptual expertise has broader implications for the development of novel face processing interventions for individuals with ASD. Because Greeble expertise can be achieved in less than ten hours, the development of expertise with Greebles provides a feasible model for the development of face expertise. Evidence from the current study suggests that a training program involving subordinate level processing may have some success for individuals with ASD. However, because holistic processing strategies do not develop naturally in

individuals with ASD, it may be that more explicit instruction is required in order to encourage the development of compensatory strategies.

In summary, the current study suggests that, with sufficient motivation, individuals with ASD may show significant gains through expertise training programs. However, these gains may be limited by general perceptual biases that cannot be remediated even with an extensive amount of experience. Future face processing interventions for individuals with ASD should focus on both giving individuals with ASD more experience with faces and on enhancing compensatory strategies to overcome perceptual biases, which may be detrimental to the development of face processing abilities and more general social functioning.

Appendix A

Greeble Training Procedure

1) Family Inspect: Participants see a Greeble image above a family name
   (Camar, Nalli, Masio, Vomsi, or Yuju), with at least two examples from every
   family given each time the task is run. Greebles are presented one at a time
   (except in the first trial of the first session where ten Greebles are presented at
   once). The image and the label remain onscreen for 3 seconds with no
   response needed from participants. All 20 Greebles are included in this task
   (including Greebles who have not yet been assigned an individual name).
   a. Text shown before the task begins:

      "Please study the Greebles with their family names. You do not need
      to make any response."

2) Family Categorization: Participants see Greeble without label and must
   respond by pressing the first letter of the family name (C, N, M, V, or Y). If
   they respond incorrectly, they hear a 'beep'. At least six examples of each
   family are presented whenever this task is run Greeble remains onscreen until
   participants press a button. This task includes all 20 Greebles in all sessions.
   a. "Please name the Greeble's family by pressing the key for the first
      letter of the family name (example: press 'C' if the Greeble belongs to
      the family Camar)"

3) Individual Inspect: A Greeble with an individual name (e.g., pimo) underneath
   it comes onscreen and remains onscreen for 3 seconds. Participants do not
   need to make a response. Five new Greebles are introduced in this task in each

of the first four sessions. This task only includes the new Greebles introduced

in that particular session. The order in which the Greebles are introduced is

random for each participant.

   a. "You will now be introduced to five new Greebles. Please study them

      carefully and remember which Greeble belongs with which name. You

      will be tested on this later in training."

4) <u>Naming with Response:</u> Participants see a Greeble with an individual name

   beneath it and then press a key for the first letter of that name. The purpose of

   this task is to practice associating a particular key with a particular Greeble

   name. Participants hear a 'beep' if their response is incorrect. The Greeble

   remains onscreen until the participant has pressed the correct button. This task

   only includes new Greebles introduced in that session for sessions 1 to 4, but

   includes all 20 Greebles in sessions 5 to 10.

   a. "Next you will see a Greeble with an individual name underneath it.

      Please study the Greeble with the name and then press the key of the

      first letter of the Greeble's name (example: press 'W' if you see a

      Greeble named Wobbi)"

5) <u>Naming with Feedback:</u> A Greeble without a label comes onscreen and

   participants must press the key for the first letter of the Greeble's name. The

   Greeble remains onscreen until the participant presses a key. If they respond

   incorrectly, they hear a 'beep' and see the Greeble again with correct name.

   The Greeble with the correct name remains onscreen for one second. This task

   only includes new Greebles introduced in that session for sessions 1 to 4, but

   includes all 20 Greebles in sessions 5 to 10.

a. "You will see a Greeble without a name and you should name the Greeble as quickly as you can, by pressing the first key of the Greeble's name (example: press 'S' as quickly as you can when you see the Greeble 'Snodi'). If you are incorrect, it's okay since we will then show you the correct answer."

6) <u>Naming Test</u>: Participants first see the word 'Name?' or 'Family?' for one second and then see Greeble without label and must press the key for Greeble's family or individual name. In this task, all twenty Greebles are presented, including named and unnamed Greebles. If it is an unfamiliar Greeble, the correct response is to press space bar. The Greeble remains present until the participant attempts to name the Greeble. No feedback is provided for this task. Each task consists of 60 trials.

a. "In this task, you will have to give the Greeble family name or individual name. You will first be told if it is the individual name ('Name?') or the family name ('Family?'). You will then see a Greeble and then you will have to press the key of the first letter of that Greeble's family or individual name. We will not be timing you for this test, so please take as long as you need to get the answer right. If the Greeble that you see is unfamiliar to you (if you believe that you have not learned the name of this Greeble yet), please press the SPACE BAR. This will be a test of your expertise so please try and do your best. You will be given as much time as you want to answer, so take your time and try to get the name correct. You will not be told if you are right or wrong after you respond."

7) <u>Verification test</u>: Participants see either a family name or an individual name for 1000 ms, then a blank screen for 200 ms, followed by a Greeble. Participants must press the 'c' key if the label is correct or press the 'i' key if the label is incorrect. The Greeble remains onscreen until the participant presses a key and no feedback is provided for this task. This task will also include unnamed Greebles, with the correct pairing for an unnamed Greeble being the 'NIL' label. This test will include 120 trials in every block, so each Greeble will be tested 6 times for this task

   a. "In this task, you will first see either a family name or an individual name. You will next see a Greeble. If the Greeble you see is matched with the right family or if the Greeble is matched with the right name, then press the key 'C' for 'correct'. If the Greeble you see does not match the family name you see or if it is not matched with the right name, then press the key 'I' for 'incorrect'. If it is a Greeble you have never seen before and it is paired with the word 'NIL', this answer is correct ('c'). If an unknown Greeble is paired with any other name or if 'NIL' is paired with a Greeble that already has an assigned name, this answer is incorrect ('I'). Please keep your fingers on the 'C' and 'I' keys throughout this test. For this task you will be timed, so please answer as quickly and accurately as possible. This task will also test your expertise of Greebles, so please try your best. Remember we will be timing your response!"

<u>Session One</u>

This should be displayed at the beginning of this session:

"In these training sessions, you will learn the family and individual names of 20 Greebles. You will have a few different exercises in each session to practice and you will be given instructions before the exercise begins. You will learn five new Greebles every session for the first four sessions. In the first half of this session, you will learn family names and then you will practice categorizing Greebles into their families. In the second half of this session, you will the Greebles' individual names. At the very end of the session, you will be tested on this knowledge, so please study the Greebles and their names carefully. Remember if you are one of the top Greeble experts, you will receive a prize of £5!"

1) Family Inspect- (10 Greebles at once, each with a family label underneath it, 2 Greebles selected randomly from each family- one male and one female— male means the parts are pointing up and female means the parts are pointing down)- 1 trial

2) Family Inspect- 10 trials (one Greeble per trial this time and every other time)

3) Family Categorization- 30 trials

4) Individual Inspect- 10 trials (*Five new greebles introduced*)

5) Naming with Response- 10 trials (new Greebles)

6) Naming with Feedback- 15 trials (all Greebles)

7) Naming- 60 trials (all Greebles included for the rest of the session)

8) Verification- 120 trials

9) Family Categorization- 30 trials

10) Naming with Response- 10 trials

11) Naming- 60 trials

12) Verification- 120 trials

Total trials= 476

Session Two

At the beginning of sessions 2, 3, and 4 other session:

"Welcome back to Greeble training! In this session, you will first practice the family and individual names you learned in the last session. You will then be introduced to five new Greebles. After practicing these new names, you will be tested on all of the Greebles you know so far. Please try your best to learn the Greeble names, because your performance at the end of the session will determine when you become a Greeble expert. Remember that the top Greeble experts will receive a cash reward!"

1) Family Inspect- 10 trials

2) Naming with Response- 10 trials (with Greebles from previous session)

3) Verification- 120 trials (with old Greebles)

4) Individual Inspect (five new Greebles with names introduced)

5) Naming with Response- 10 trials (new Greebles)

6) Naming with Feedback- 15 trials (all Greebles)

7) Naming- 60 trials (all Greebles included for the rest of the session)

8) Verification- 120 trials

9) Naming - 60 trials

10) Verification - 120 trials

11) Naming - 60 trials

12) Verification- 120 trials

Total trials= 736

<u>**Session Three**</u>

1) Family Inspect- 10 trials

2) Naming with Response- 40 trials (old Greebles)

3) Verification- 120 trials (old Greebles)

4) Individual Inspect- 10 trials (5 new Greebles introduced)

5) Naming with Response- 10 trials (new Greebles only)

6) Naming with Feedback- 45 trials (all Greebles included)

7) Naming- 60 trials (all Greebles included for the rest of the session)

8) Verification- 120 trials

9) Naming - 60 trials

10) Verification- 120 trials

11) Naming - 60 trials

12) Verification- 120 trials

Total Trials = 771

<u>**Session Four**</u>

1) Family Inspect- 6 trials

2) Naming with Response- 60 trials (only old Greebles)

3) Verification- 120 trials

4) Individual Inspect- 10 trials (only new Greebles)

5) Naming with Response- 10 trials (only new Greebles)

6) Naming with Feedback- 60 trials (all Greebles included for the rest of the session)

7) Naming- 60 trials

8) Verification- 120 trials

9) Naming - 60 trials

10) Verification- 120 trials

11) Naming - 60 trials

12) Verification- 120 trials

Total Trials = 806

<u>Session Five</u>

At the beginning of sessions 5,6,7,8, and 9:

"Welcome back to Greeble training! You have now been introduced to all 20 Greebles and you are well on your way to becoming an expert! Keep up the good work and you could win a cash prize for being one of the top Greeble experts!"

(All twenty Greebles will be included for the rest of the training)

1) Naming with Response- 40 trials

2) Naming- 60 trials

3) Verification- 120 trials

4) Naming - 60 trials

5) Verification - 120 trials

6) Naming - 60 trials

7) Verification- 120 trials

8) Naming - 60 trials

9) Verification- 120 trials

Total Trials = 760 trials

Session Six

1) Naming with Response- 40 trials

2) Naming- 60 trials

3) Verification- 120 trials

4) Naming - 60 trials

5) Verification - 120 trials

6) Naming - 60 trials

7) Verification- 120 trials

8) Naming - 60 trials

9) Verification- 120 trials

Total Trials = 760 trials

Session Seven

10) Naming with Response- 40 trials

11) Naming- 60 trials

12) Verification- 120 trials

13) Naming - 60 trials

14) Verification - 120 trials

15) Naming - 60 trials

16) Verification- 120 trials

17) Naming - 60 trials

18) Verification- 120 trials

Total Trials = 760 trials

<u>Session Eight</u>

10) Naming with Response- 40 trials

11) Naming- 60 trials

12) Verification- 120 trials

13) Naming - 60 trials

14) Verification - 120 trials

15) Naming - 60 trials

16) Verification- 120 trials

17) Naming - 60 trials

18) Verification- 120 trials

Total Trials = 760 trials

<u>Session Nine</u>

1) Naming with Response- 40 trials

2) Naming- 60 trials

3) Verification- 120 trials

4) Naming - 60 trials

5) Verification - 120 trials

6) Naming - 60 trials

7) Verification- 120 trials

8) Naming - 60 trials

9) Verification- 120 trials

Total Trials = 760 trials

At the end of every session except session ten:

"You have now completed this Greeble training session! Thank you for your help and keep up the good work!"

Session Ten

10) Naming with Response- 40 trials

11) Naming- 60 trials

12) Verification- 120 trials

13) Naming - 60 trials

14) Verification - 120 trials

15) Naming - 60 trials

16) Verification- 120 trials

17) Naming - 60 trials

18) Verification- 120 trials

Total Trials = 760 trials

At the end of session ten:

"You have now completed Greeble training. Thank you so very much for all of your time and effort! Please call or email the researcher immediately so you can schedule your second session."

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