

PLASTICITY OF FACE PROCESSING IN CHILDREN AND ADULTS

PLASTICITY OF FACE PROCESSING IN CHILDREN AND ADULTS

BY
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Abstract

To assess how the plasticity of the face processing system changes with age, we trained 8-year-olds, 10-year-olds, and adults to differentiate 10 chimpanzee faces at the individual level for 3 days by having them watch a child-friendly training video. Their improvement from baseline was compared to that of age- and gender-matched controls who completed the pre- and post-tests, but did not complete training. Improvement did not vary across age: 8-year-olds, 10-year-olds, and adults all showed similar improvement in accuracy at discriminating the 10 chimpanzee faces on which they were trained. This improvement resulted in the reduction of the own-species bias after training. However, the benefits of training did not generalize to novel exemplars. In addition, participants from both the training and control groups showed a practice effect: their accuracy at discriminating both chimpanzee and human faces improved from pre- to post-test. Taken together, these results demonstrate that the face processing system is somewhat plastic between 8 years of age and adulthood and suggest that this plasticity remains stable throughout this period of development.

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Introduction

Adults are experts at recognizing faces: this expertise is evident in their rapid recognition of faces at the individual level. For example, adults can remember and identify hundreds of faces, recognize a familiar one within half a second and, in addition, extract information about an individual's age, gender, expression and direction of gaze from the face (Bahrick, Bahrick, & Wittlinger, 1975; Carey, 1992; see Bruce & Young, 1998, for a review).

This expertise, however, manifests reliably only for face categories with which adults have had a wealth of experience: typically upright human faces of their own age and race. Adults are less accurate at processing faces of another race (for a review, see Meissner & Brigham, 2001), age (Anastasi & Rhodes, 2005; Hills & Lewis, 2011; Kuefner, Macchi Cassia, Picozzi, & Bricolo, 2008; Macchi Cassia, Kuefner, Picozzi, & Vescovo, 2009a; Wright & Stroud, 2002) or species (Dufour, Coleman, Campbell, Petit, & Pascalis, 2004; Mondloch, Maurer, & Ahola, 2006; Pascalis, de Haan, & Nelson, 2002). For example, in a two-alternative-forced-choice recognition task, adults are more accurate at recognizing human faces than monkey faces (Dufour et al., 2004). Similarly, when tested with a visual paired comparison task, adults automatically discriminate between two human faces, but not between two monkey faces (Pascalis & Bachevalier, 1998; Pascalis et al., 2002). More specifically, after being familiarized with an individual human face, adults look longer at a novel human face; however, after being familiarized for the same duration with a monkey face, adults do not look

longer at a novel monkey face (Pascalis & Bachevalier, 1998; Pascalis et al., 2002). In addition, much the same as for inverted faces, the N170 is of larger amplitude and longer latency for upright monkey faces than for upright human faces (de Haan, Pascalis, & Johnson, 2002). This face-specific electrophysiological response is robust for upright human faces relative to non-face objects and is considered a correlate of face detection (for review see Eimer, 2011). Inverted human faces and monkey faces elicit a N170 of larger amplitude and longer latency perhaps because humans have a harder time detecting the facial structure in inverted faces and monkey faces relative to upright human faces.

Although adults' are more accurate at recognizing familiar face categories, the face processing system is initially less specialized. At birth, newborns show no visual preference for human faces when monkey and human face stimuli are equated for all low-level perceptual properties (i.e., luminance, contrast, low spatial frequency) and show evidence of the ability to discriminate a human face from a monkey face (Giorgio, Leo, Pascalis, & Simion, 2011). In addition, newborns are able to match a monkey's facial and vocal gestures. When presented with two videos side-by-side of a monkey producing a coo and the same monkey producing a grunt, along with a vocalization of a coo or a grunt, infants look longer at the video that corresponds to the vocalization, at least in the presence of temporal synchrony (e.g. synchronous onsets and offsets of the monkeys' facial and vocal gestures) (Lewkowicz, Leo, & Simion, 2010). These findings suggest that the face processing system is broadly tuned at birth.

However, within the first year after birth, the face processing system becomes tuned to the types of faces encountered most frequently in the environment, such as faces of an infant's own race and species. Consequently, during this period of perceptual narrowing, infants develop an own-species bias, characterized by a superior ability to discriminate human faces as opposed to faces of another species, and an own-race bias, a superior ability to discriminate own-race as opposed to other-race faces. For example, 6-month-old infants are able to discriminate between both individual human and individual monkey faces, but by 9 months of age, infants only show evidence of the ability to discriminate between human faces (Pascalis et al., 2002). In addition, although younger infants can match primate voices and faces, 6- to 8-months-old infants show no evidence of this ability even when temporal synchrony is a cue (Lewkowicz & Ghazanfar, 2006). Similarly, 3- to 6-month-old infants can discriminate between sheep faces and between other-race faces, but 9- to 11-month-olds no longer show evidence of these abilities (Kelly et al., 2007; Kelly et al., 2009; Simpson, Varga, Frick, & Fragaszy, 2011). The evidence suggests that newborns begin with a broadly tuned face processing system, but with experience in the first few months of life, this system becomes tuned to, and infants get better at processing, familiar face categories (e.g., own-species, own-race), and they simultaneously lose their ability to discriminate between faces of unfamiliar categories (e.g., other-species, other-race). This type of perceptual narrowing may reflect the development of a more precise face prototype. This face prototype, continuously updated with

experience, is a prototypical or average face in reference to which individual faces that we encounter in our environment are thought to be encoded, at least in adults (Nelson, 2001).

The process of perceptual narrowing is not specific to face processing, but rather a domain-general developmental phenomenon (for review see Scott, Pascalis, & Nelson, 2007). At a young age, unlike monolingual adults, infants are able to discriminate speech contrasts that form phonemic categories in another language (e.g., Caucasian infants can discriminate between /Ta/ and /ta/ in Hindi) (Werker, Gilbert, Humphrey, & Tees, 1981). Experience with their native language, and lack of exposure to non-native speech sound categories, results in infants' failure to demonstrate such discrimination at 12 months of age (Werker & Tees, 1984; Werker & Tees, 2005). A similar pattern is seen in the development of the perception of musical rhythms. Unlike North American adults or 12-month-olds, 6-month-old North American infants demonstrate the ability to detect violations in the metrical structure of Balkan folk tunes containing complex meters, which are uncommon in North American music (Hannon & Trehub, 2005a; Hannon & Trehub, 2005b).

Although perceptual narrowing results in the decline of infants' ability to discriminate between faces of unfamiliar face categories, even a modest amount of experience with faces from these categories at a young age can prevent this decline. Six-month-old infants who were exposed to 6 individual monkey faces presented in the context of a picture book for 3 months maintained their ability to

discriminate monkey faces at 9 months (Pascalis et al., 2005). Importantly, in addition to being able to discriminate the 6 monkey faces to which they were exposed, these infants were also able to discriminate novel monkey faces. However, demonstration of this ability is maintained only when infants gain experience with individuated monkey faces as opposed to when the same faces are presented categorically or when the infants are merely exposed to them (i.e. without an individual or categorical label) (Scott and Monesson, 2009). Therefore, it is the quality of exposure rather than the quantity that is important. Similarly, exposure to Chinese faces at the individual level between 6 and 9 months leads to good discrimination between both Chinese and Caucasian faces at 9 months in Caucasian infants (Heron-Delaney et al., 2011; for similar results in the auditory domain see Kuhl, Tsao, & Liu, 2003) and similar exposure between 8 and 10 months can reverse the manifestation of perceptual narrowing for other-race faces (Anzures et al., 2012; for similar results in auditory processing of music see Hannon and Trehub, 2005b). These findings suggest that early experience with faces from unfamiliar face categories at the individual level can prevent or even reverse the manifestation of perceptual narrowing.

Few studies have examined to what degree the face processing system remains plastic after infancy and after this period of perceptual narrowing. Evidence that the face processing system remains flexible during early childhood comes from a study that found that adults of Korean origin who were adopted between 3 and 9 years of age by Caucasian families showed another-race bias

(i.e., superior ability to recognize Caucasian faces as opposed to own-race faces) unlike control Korean participants who showed the classic own-race bias (Sangrigoli, Pallier, Argenti, Ventureyra, & Schonon, 2005). Studies with adults suggest that visual experience with faces in adulthood can still shape the face processing system to some extent. For example, unlike control adults who show an own-age bias, trainee teachers (mean experience: 16.5 months) are equally accurate at recognizing child (8-11 years) and adult faces, and are actually faster at recognizing children's faces (Harrison & Hole, 2009). Similarly, while control adults process adult faces more holistically (i.e., as a whole; holistic processing is a hallmark of expert human face processing) than child faces, preschool teachers process adult and child (4- to 6-year-old) faces holistically to a similar extent (de Heering & Roisson, 2008). This suggests that experience in adulthood results in quantitative and qualitative changes in face processing. A similar study found that maternity-ward nurses (mean experience: 16.4 years) showed a smaller own-age bias (i.e., mean accuracy for upright adult faces - mean accuracy for upright newborn faces) than novices and, unlike novices, showed an inversion cost (better accuracy for upright than inverted faces; a hallmark of expertise) for newborn faces (Macchi Cassia, Picozzi, Kuefner, & Casati, 2009b; but for negative results in a similar study, see Yovel et al., 2012).

Although the studies of teachers and nurses suggest that there may be some plasticity during adulthood, the authors did not control for previous intermittent exposure to the unfamiliar face category (i.e., newborn or child

faces). For example, Macchi Cassia and collaborators (2009b) tested nurses who had a minimum of 2 years experience working in a maternity ward. However, the researchers did not take into account the participants' possible previous contact with newborns. This is important because the authors conclude that their results can be accounted for by experience gained with newborn faces exclusively in *adulthood*. Conversely, it is possible that the group differences in recognition of newborn faces found can be explained by contact with this face category acquired by the experienced group at an *earlier age*. While growing up, the maternity ward nurses may have had more contact with, or motivation to interact with, infants. This possible experience and interest may have even contributed to their choice of career.

An alternative approach to investigate the plasticity of the face processing system is to use monkey faces, since it is easier to establish participants' prior exposure to this category of stimuli. In a recent study, Dufour & Petit (2010) found that a group of primatologists and caretakers with an average of 8 years of experience were more accurate at discriminating monkey faces, and were more affected by the inversion of these stimuli, than a control group. Both of these findings suggest that experience with faces at the individual level can still shape the face processing system in adulthood. However, while both groups demonstrated automatic discrimination between human faces in a visual paired comparison task by looking longer at a novel face after familiarization with an individual human face, neither experts nor non-experts showed the same evidence

of automatic discrimination of monkey faces. Therefore, although experience with monkey faces acquired in adulthood does result in the improved recognition of these stimuli, it does not appear to result in the automatic discrimination of these faces that is seen for human faces.

A third approach to measuring the flexibility of the face processing system in adults is to control exposure by training participants in the laboratory on the unfamiliar category. The best-known study of this kind involved training adults to discriminate novel objects, called "Greebles", that could be classified at the individual, subordinate, and basic levels (Gauthier & Tarr, 1997). Unlike novices, trained adults more quickly recognized Greeble parts in trained Greeble configurations than untrained configurations. The authors related trained participants' sensitivity to configural cues in Greebles to expert face processing, which is characterized by a greater sensitivity to the relation between features of the face than to the relation between features of objects (Diamond & Carey, 1986). Subsequent studies have trained adults to discriminate birds (Tanaka, Curran, & Sheinberg, 2005), cars (Scott, Tanaka, Sheinberg, & Curran, 2008), and novel objects called "Ziggerins" (Wong, Palmeri, & Gauthier, 2009). These studies do not find improvement after categorization training. However, after individuation training, adults exhibit improved discrimination of both trained and novel exemplars of the trained object category (Scott et al., 2008; Tanaka et al., 2005), as well as increased holistic processing (i.e. processing an object as a whole; a hallmark of expert human face processing) (Wong et al., 2009). In a

similar study, Tanaka and Pierce (2009) trained Caucasian adults to discriminate Hispanic (or African American) faces at the individual level (e.g., Joe, Bob, etc.) and African American (or Hispanic) faces at the categorical level (e.g., African American or Hispanic). Only individuation training led to improved discrimination of novel face exemplars of the trained race. Similarly, in a more recent study, adults were trained to individuate faces of one of two novel races and categorize faces of the other race. The Thutmosians and the Guansians, the two novel races, varied in either eye or mouth information and were used because researchers could ensure that participants had had no previous experience with them. Adults who completed the individuation training showed improved face recognition abilities for novel face exemplars of the race that they were trained to individuate but not for the race they were trained to categorize (Tanaka, Webster, Gordon, & Meixner, 2012).

Results from face adaptation studies also provide evidence that experience in adulthood can still shape adults' face processing system and suggest a possible mechanism for the plasticity. It has been proposed that adults mentally represent faces by coding them as deviations from the norm or average face in a hypothetical multi-dimensional 'face space', the dimensions of which code for features that reliably co-vary among individuals (Valentine, 1991). In line with this theory is the finding that after being adapted to a distorted face, for example a contracted face, adults' perception of subsequent faces will be biased in the opposite direction relative to the norm, for example they will perceive a normal

face to be expanded. This is referred to as a figural distortion after-effect (for a review, see Rhodes & Leopold, 2011). Similarly, adaptation to a specific identity (e.g., Dan, who has a large chin and small lips) causes a similar shift in the norm and results in the perception of an average face as more similar to the opposite identity (i.e., the average is perceived to have a smaller-than-average chin and larger-than-average lips). This identity after-effect is larger for computationally opposite identities that are located on opposite ends of an axis in ‘face space’ that passes through the norm, than for computationally non-opposite identities located on an axis that does not pass through the norm (refer to Figure 1) (Rhodes & Jeffrey, 2006). A larger after-effect for opposite identities is evidence that faces are processed relative to a norm. These after-effects have been taken as evidence that the norm is constantly being updated based on an individual’s diet of faces or experience and that this mental representation of faces is malleable even in adulthood.

By 6-8 years of age, children also show evidence of coding faces relative to an average face (Anzures, Mondloch, & Lackner, 2009; Jeffery et al., 2010; Nishimura, Jeffrey, Pellicano, & Rhodes, 2008). Certain studies have directly compared after-effects in children and adults in an effort to compare the plasticity of the face processing system at different periods of development. Identity after-effects in children do not deviate systematically in magnitude from those of adults

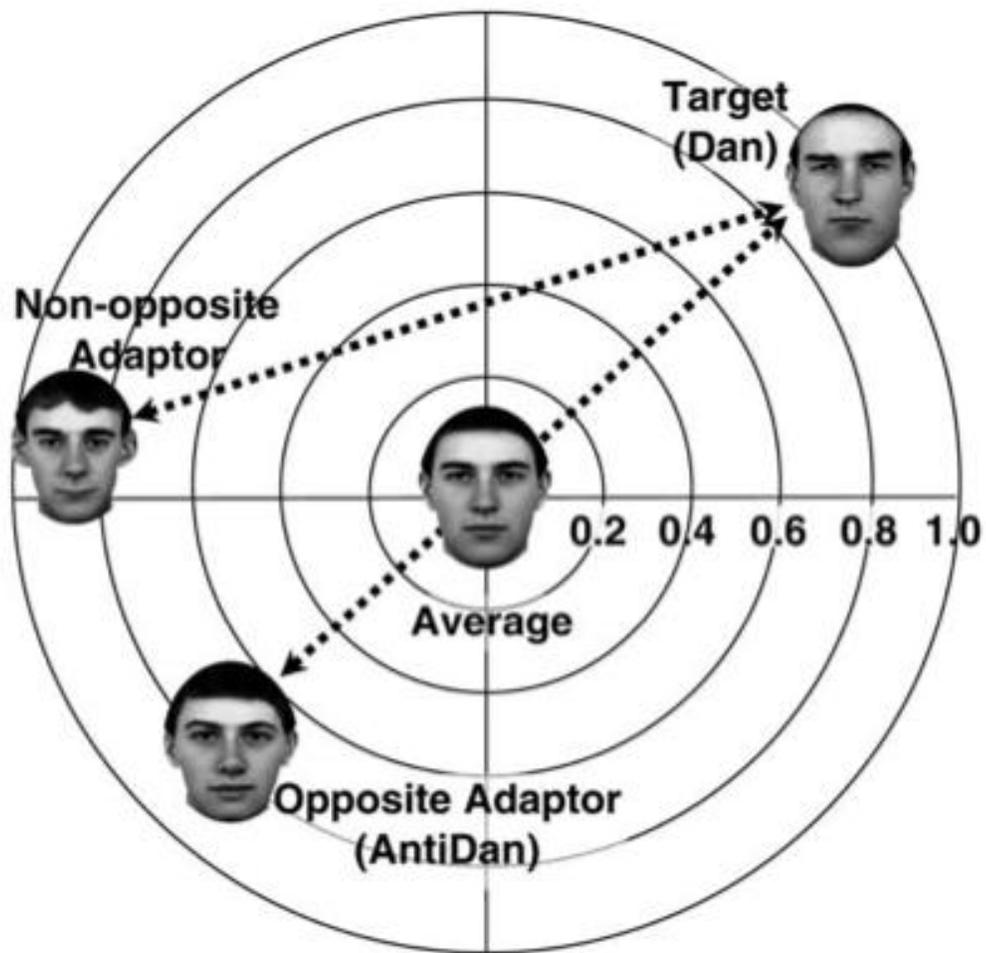


Figure 1. An example of an opposite (anti-face, face) and non-opposite adapt-test pair used by Rhodes and Jeffrey (2006).

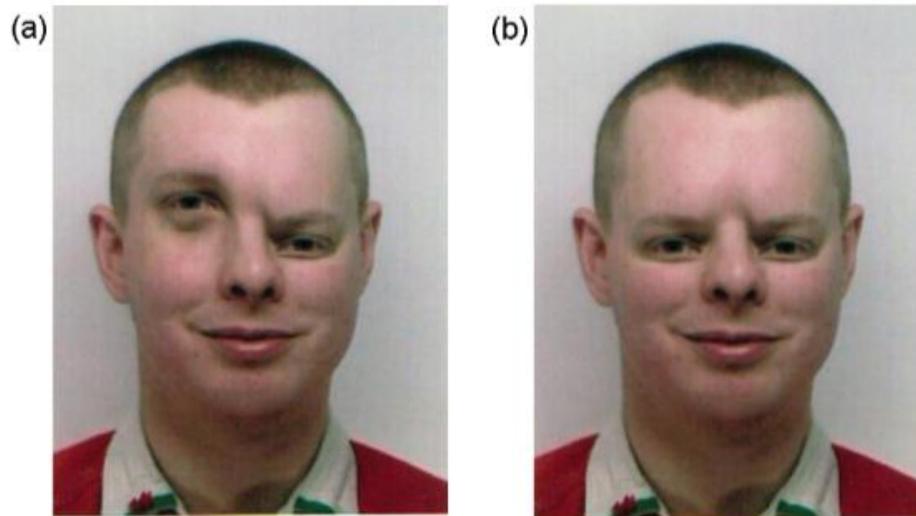


Figure 2. An example of (a) an asymmetrical distortion (left eye +20 pixels, right eye -20 pixels) and (b) a symmetrical distortion (both eyes -20 pixels) used by Hills et al. (2010) for adaptation in their study comparing figural distortion after-effects in children and adults.

when the adapting stimulus preserves the normal arrangement of facial features, a configuration that is used to detect that a stimulus is a face and not an object (Nishimura, Jeffrey, Pellicano, & Rhodes, 2008; Nishimura, Robertson, & Maurer, 2011; Pimperton, Pellicano, Jeffrey, & Rhodes, 2009). However, when adapting stimuli have symmetrical and asymmetrical eye distortions (Figure 2), children (6-12 years of age) show larger figural distortion after-effects than adolescents (13-18 years of age) (Hills, Holland, & Lewis, 2010). Children also show after-effects for both asymmetrical and symmetrical distortions, whereas adolescents only show after-effects for symmetrical distortions. These results suggest that older adolescents might not represent faces with asymmetrical distortions in face-space, whereas younger children are more tolerant of such distortions.

Another approach to investigating how plasticity may change over the course of development is to investigate how more natural and long-term exposure affects children and adults' face recognition abilities. To our knowledge, only one previous study has examined whether the plasticity of the face processing system changes with age in response to everyday exposure. Macchi Cassia and collaborators (2009a) tested both 3-year-olds and adults, with different histories of exposure to infant faces, on their ability to recognize upright and inverted infant and adult faces. Unlike 3-year-olds without a younger sibling, who were more accurate at discriminating adult faces than infant faces and who showed an inversion effect only for adult faces, those with a younger infant sibling were

equally accurate at recognizing upright adult and infant faces and exhibited inversion effects for both face categories. In contrast, exposure to an individual infant face for a similar period of time (i.e. approximately 1 year) in adulthood was not enough to modulate the adults' face processing system. Unlike children with a younger sibling, first-time mothers were more accurate at discriminating adult faces than infant faces and showed an inversion effect for adult, but not newborn faces. The contrast in 3-year-olds' and adults' abilities to discriminate infant faces after similar exposure suggests that there is a decline in plasticity between 3 years of age and adulthood. However, first-time mothers with a younger sibling, who were therefore exposed to an individual infant face at a young age, showed an inversion effect for infant faces. Combined, the data suggest that the effects of early experience with other-age faces can be reactivated with re-exposure in adulthood and imply that the face processing system is plastic during development, but becomes less plastic with age. However, Macchi Cassia and collaborators (2009a) did not measure the amount of exposure child and adult participants had had with other infant faces. In addition, 3-year-olds in their study had an average of 15 months of exposure to an individual infant whereas adults had an average of 9 months of exposure. Such differences in duration of exposure could potentially explain the age differences in recognition of infant faces.

The present study will examine in a systematic way the effect of exposure to chimpanzee faces (an unfamiliar face category) at different stages of development between childhood and adulthood. By using chimpanzee faces (*Pan*

troglydytes), we can be confident that neither children nor adults have had significant exposure prior to the study. In addition, participants from all age groups will gain the same exposure for the same duration of time. More specifically, we will train 8-year-olds, 10-year-olds, and adults to recognize 10 chimpanzee faces at the individual level (e.g. Edwin, Stan, etc.) for 3 days by having them watch a child-friendly training video and will compare their ability to discriminate both human and chimpanzee faces before and after the training period. We will compare the training groups' improvement in recognition of the chimpanzee faces on which they were trained as well as novel face exemplars to that of a group of age- and gender-matched controls who will not receive training between the pretest and posttest.

Eight-year-olds and 10-year-olds are particularly interesting ages to test, since Sangrigoli and collaborators (2005) showed in their adoption study that the face processing system remains plastic for other-race faces until at least the age of 9 years, the age of the oldest adoptees. In addition, face recognition follows a long developmental trajectory, and on certain tasks children do not exhibit adult-like performance until early adolescence (e.g. Carey & Diamond, 1977; Carey, Diamond, & Woods, 1980; de Heering, Roisson, & Maurer, 2012; Mondloch, Le Grand, & Maurer, 2002). For example, in the Benton task, in which participants have to match unfamiliar faces presented from different viewpoints, children steadily improve in accuracy for upright faces between 6 and 12 years of age (de Heering et al., 2012). The fact that the face processing system is still immature at

8 and 10 years of age may mean that it is still quite plastic, and more easily influenced by experience with faces.

By keeping the onset and amount of exposure to the unfamiliar face category constant, we will be able to draw conclusions about the degree of plasticity of the face processing system at different ages. Greater improvement in the ability to recognize chimpanzee faces after training in the training groups compared to the control groups would be evidence of a plastic face processing system. Furthermore, differences in relative improvement across different age groups will provide evidence on how the flexibility of the system changes with age. We will also test the efficacy of the training by measuring its effect on the participants' own-species bias (i.e. calculated by comparing their mean accuracy on human faces to their mean accuracy on chimpanzee faces). If training is effective and participants improve in their ability to recognize chimpanzee faces, we would expect to see a decrease in their bias for human faces after training. The extent to which the bias may be reduced may also differ across ages. Together, these results will provide a better understanding of how and to what degree experience can shape face processing at different stages of development.

Methods

Design

The study was a 5-day experiment that required participants to come into the laboratory on Days 1 and 5 to complete a face recognition test (refer to Figure

3). The pre- and post-training tests were identical and consisted of a delayed matching-to-sample task that measured participants' ability to discriminate chimpanzee faces (both ones that the participants would be/were trained on and novel ones) and human faces, despite variation in viewpoint. Eight criterion trials with an easier task that required participants to match images of chimpanzee faces that included colour cues, external features and no change of viewpoint preceded both the pre- and post-training tests to verify that participants understood the task. In addition, to assess attentiveness, 20 catch trials, for which participants had to press the correct key as quickly as possible when they spotted a cartoon bug, were intermixed in the test trials.

On Days 2-4 of the experiment, the participants in the training group watched a training video at home about 10 individual chimpanzees, whose faces varied in point of view, size and expression. After watching the video each day, they completed a recognition test with the trained chimpanzee faces. Two sets of training stimuli were used; the face set was counterbalanced across participants in each age group. Face Set A was designated arbitrarily as the trained set for half the control participants and Face Set B for the other half. Participants in the control group were tested on Days 1 and 5, but did not complete training on Days 2-4.

Training protocol for 10 chimpanzee faces

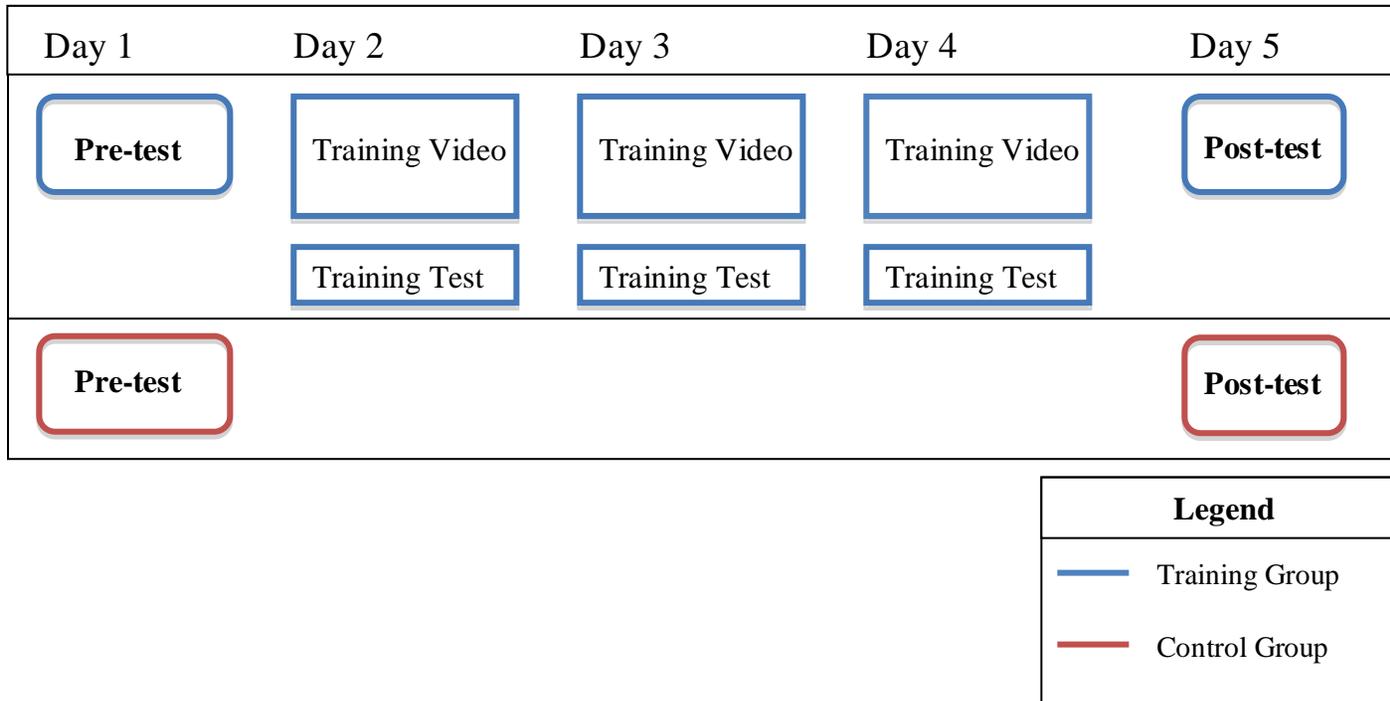


Figure 3. The training protocol included a pre-training test, 3 days of training with 10 chimpanzee faces and a post-training test.

Participants

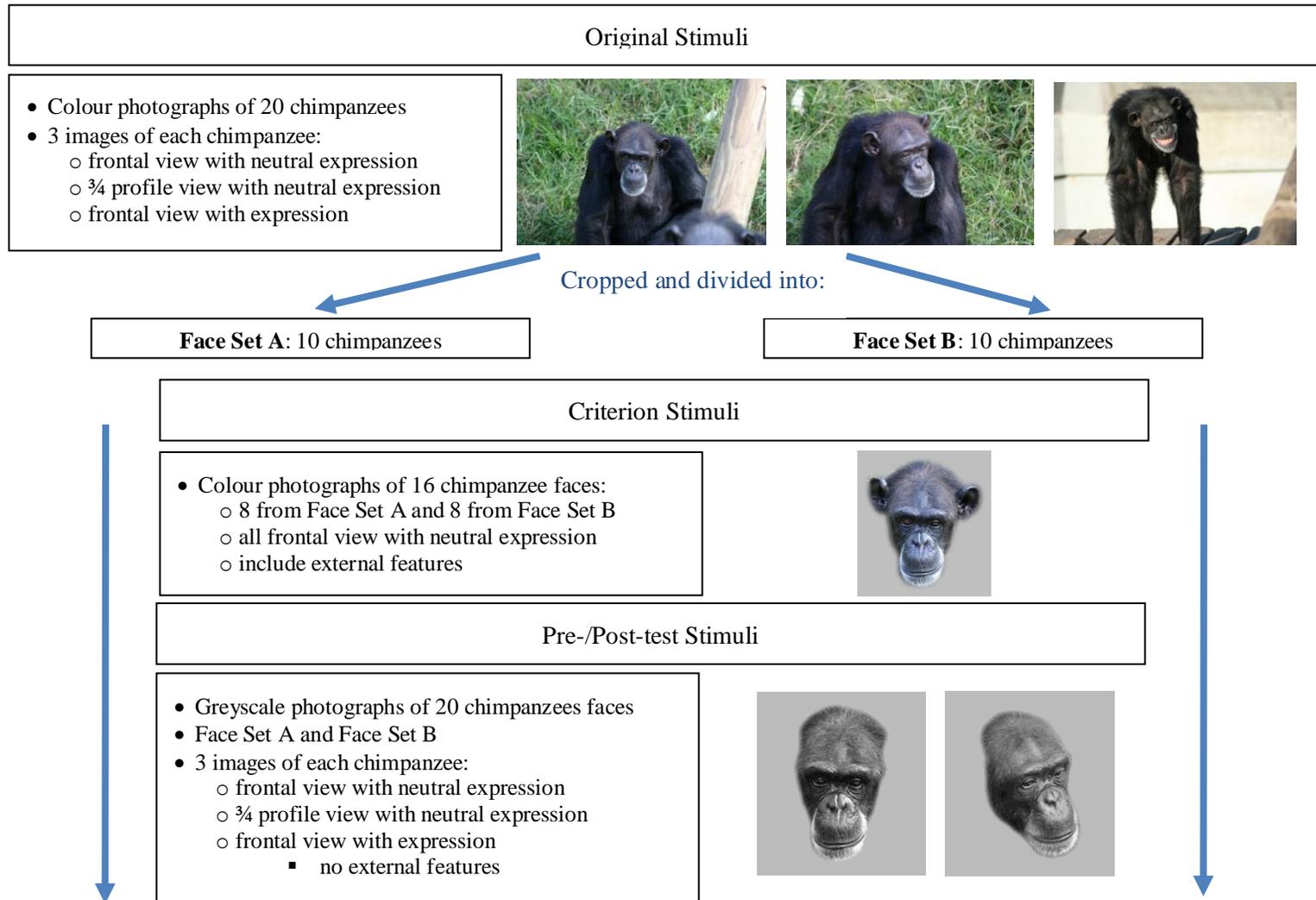
Three groups of participants completed the training paradigm: twenty 8-year-olds (± 3 months; 10 females), sixteen 10-year-olds (± 3 months; 9 females) and twenty adults (aged 18-24; 10 females). In addition, fifty-six age- and gender-matched controls, who completed the pre- and post-tests but did not receive training, also participated in this study. All participants had normal or corrected-to-normal vision. Specifically, participants had linear letter acuity (Lighthouse Visual Acuity Chart) of at least 20/20 in each eye with a maximum of -2 dioptres of optical correction (to rule out nearsightedness greater than 2 dioptres, which would reduce vision at our testing distance of 50 cm). In addition, they had worse acuity with a +3 dioptre add (to rule out farsightedness greater than 3 dioptres), fusion at near on the Worth 4-dot test, and stereoacuity of at least 40 arcsec on the Randot Stereotest. From the training group, an additional four 8-year-olds, three 10-year-olds and two adults were tested, but four were excluded because they failed vision screening, three others because they did not complete the training procedure properly, one because he did not return for the follow-up session, and the last because she was out of the age range. From the control group, four additional 8-year-olds, and two adults were also tested, but three were excluded because they did not return on Day 5 to complete the post-test, one because she failed visual screening, another because she was inattentive and the last for experimenter error.

Children were recruited from a database of mothers who, at the time of their child's birth, had volunteered their child to participate in developmental studies. Adults were McMaster University undergraduate and graduate students who received either course credit or \$30 for their participation.

Materials

Chimpanzee Face Stimuli

The chimpanzee stimuli consisted of two sets of colour digital photographs of 10 chimpanzees, taken with a Canon D50 camera, from different viewpoints and with varying facial expression: frontal view with neutral expression, frontal view with expression, and a nearly $\frac{3}{4}$ profile view with neutral expression (i.e. a total of 60 different photographs of 20 individual chimpanzees). These images were taken from a database of photographs of chimpanzees from the Yerkes National Primate Research Center, and provided to us by Dr. Lisa Parr. In Adobe Photoshop, the backgrounds of the photographs were cropped out to capture only the faces of the chimpanzees with their external features. These images were manipulated in different ways to create the final stimuli for the criterion trials, the pre- and post-tests, the training video and the training recognition test (refer to Figure 4).



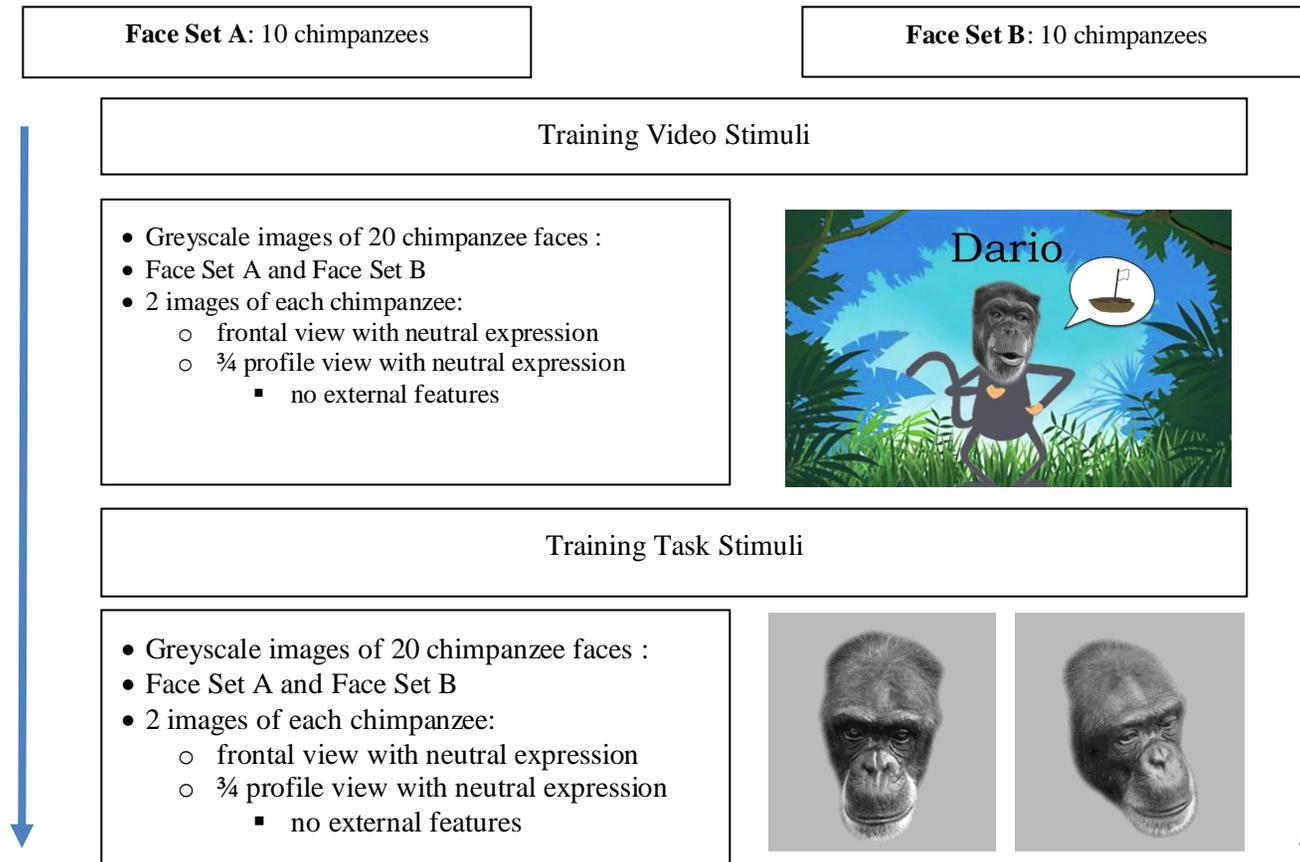


Figure 4. A flowchart outlining the chimpanzee stimuli used in the criterion trials, the pre- and post-tests, the training video and the training tasks.



Figure 5. Example of chimpanzee face stimuli used in the criterion trials. The faces were frontal view with neutral expression, presented in colour and had their external features.

Test Stimuli

Criterion Stimuli. Stimuli for the criterion trials consisted of colour digital photographs of 16 chimpanzee faces with their external features. The face stimuli were all frontal-view and with neutral expression (see Figure 5). Using Photoshop, the distance between the top of the eyebrow and bottom of the mouth was equated across faces to measure 160 pixels. Next, all faces were centred on a uniform 15.2 cm x 16.5 cm grey background and subtended 17.3° by 18.8° of visual angle when viewed from the testing distance of 50 cm.

Pre-test/Post-test Stimuli. Test stimuli used in the chimpanzee face condition of the pre- and post-tests consisted of two sets of greyscale digital photographs of 10 chimpanzees with neutral expression and from different viewpoints: frontal view and in a nearly ¾ profile view (see Figure 6a). In Photoshop, the external features (i.e., fur, ears, neck) were cropped out in order to encourage processing of the internal features of the face and overall luminance was matched.

Test stimuli used in the human face condition of the pre- and post-tests consisted of a set of greyscale digital photographs of 20 Caucasian female faces, aged 17 to 25 years, from three different viewpoints: frontal, turned 45° to the left, and turned 45° to the right (see Figure 6b). All human models had minimal make-up and neutral expressions. These images were obtained from the database in the Visual Development Laboratory at McMaster University, with the permission of Dr. Daphne Maurer. Using Photoshop, the external features (i.e., hair, ears, neck)

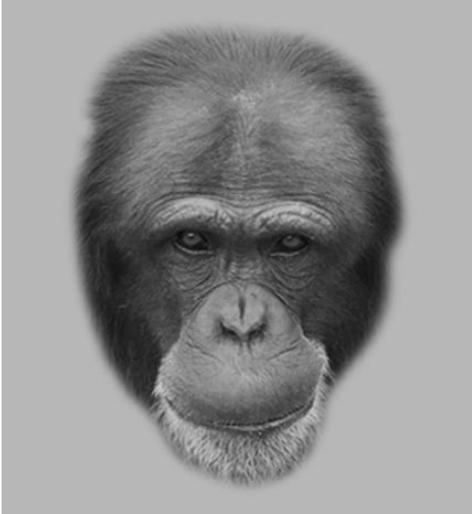
were cropped out. In Photoshop, the distance between the top of the eyebrow and bottom of the mouth was equated across all the chimpanzee and human faces to measure 160 pixels. All faces were centred on a uniform 15.2 cm x 16.5 cm grey background and subtended 17.3° by 18.8° of visual angle when viewed from the testing distance of 50 cm.

Catch Trial Stimuli. To create the stimuli for the catch trials, images of cartoon bugs found online were superimposed onto various parts of 10 human probe faces (frontal-view) and 10 chimpanzee probe (frontal-view) faces in Photoshop (see Figure 7).

Training Stimuli

To familiarize participants with the faces of 10 individual chimpanzees (*Pan troglodytes*) (i.e., *Koko*, *Edwin*, *Stan*, *Walter*, *Fred*, *Max*, *Albert*, *Lucky*, *Dario*, and *Brian*), we created a 16-minute training video that followed 10 chimpanzees on their *Quest for the Golden Banana*. The video began by presenting each chimpanzee individually, introducing his/her name and describing a special ability that he/she possesses (e.g., *Walter is the best swimmer in the jungle*). To reach the end of their quest, the chimpanzees first had to pass five obstacles, and at each one, two of them had to use their special abilities to get past the obstacle (e.g., crossing a river). Two training videos were created, each with a different set of 10 chimpanzee faces, but both with the same storyline.

(a)



(b)

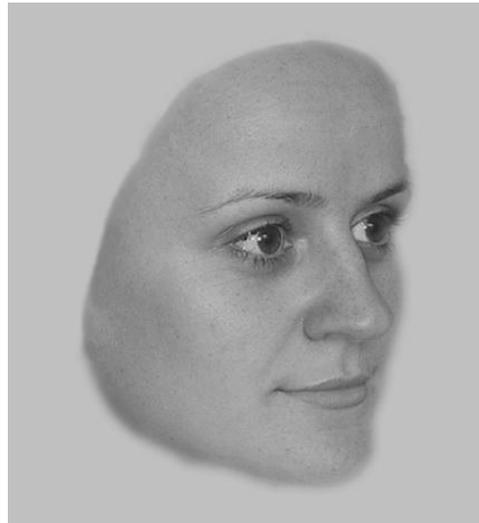
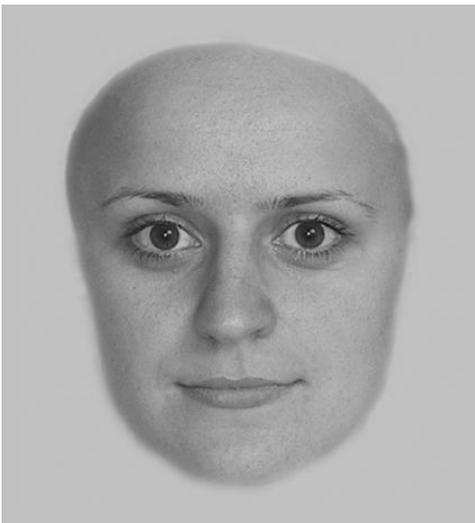
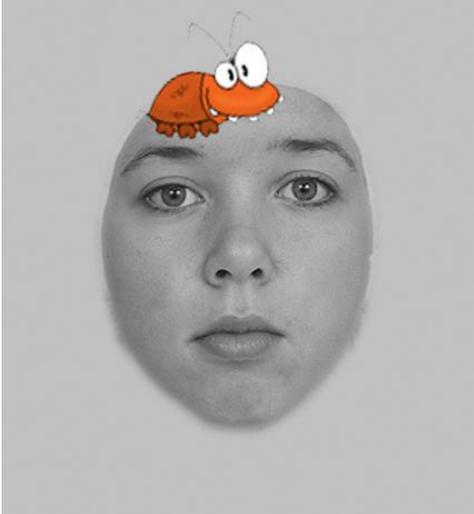


Figure 6. Example of (a) chimpanzee and (b) human face stimuli used in the test trials. The faces were frontal view or $\frac{3}{4}$ profile view with neutral expression.

(a)



(b)

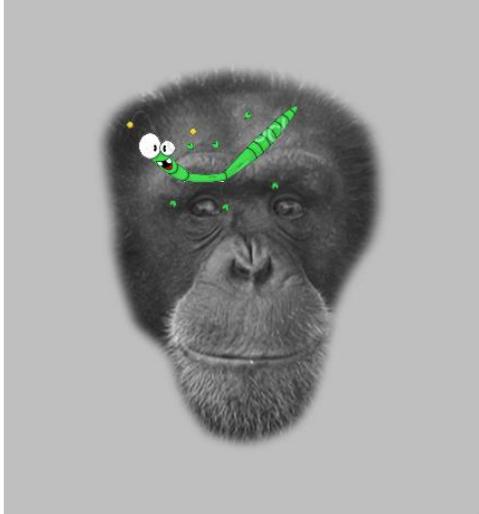


Figure 7. Example of catch trials in the (a) human block and the (b) chimpanzee block.

Each frame (1440 pixels wide by 864 pixels high) of the video sequence was created in Adobe Photoshop. Cartoon images found online were edited and compiled together in Photoshop to create the backgrounds. The training face stimuli consisted of two sets of greyscale digital images of 10 chimpanzees taken from different viewpoints and with varying facial expression: frontal view with neutral expression, frontal view with expression, and a nearly $\frac{3}{4}$ profile view with neutral expression (see Figure 8). In Photoshop, the external features (i.e., fur, ears, neck) were cropped out in order to encourage processing of the internal features of the face and overall luminance was matched. The distance between the top of the eyebrow and bottom of the mouth was equated across faces to measure 80 pixels and then again to measure 160 pixels, to create two image sizes for the training video. In Photoshop, the final faces were superimposed onto cartoon bodies and onto backgrounds in the frames, which were then compiled into a video using iMovie (version 8.0.6) and an audio recording of a male voice narrating the story (see Appendix A) was added to make the final training video. Each chimpanzee was presented in the video for an average of 114.65 seconds (range = 93.5s - 141s).

In addition to the training video, we created a training recognition task in Adobe Flash Player. The stimuli consisted of the same stimuli used in the pre- and post-tests (refer to *Pre-test/Post-test* stimuli). Specifically, greyscale digital images of two sets of 10 chimpanzee faces in frontal-view and $\frac{3}{4}$ -profile-view with neutral expression were used. These faces were centred on a uniform 15.2



Figure 8. Example of chimpanzee stimuli used in the training video.

cm x 16.5 cm grey background and subtended 17.3° by 18.8° of visual angle when viewed from the viewing distance of 50 cm.

Apparatus

The test stimuli were presented on a Dell Trinitron P1330 monitor (screen size = 40.0 cm x 30.0 cm; 43.60° x 33.40° of visual angle from a viewing distance of 50 cm), controlled by a Macintosh Mini running in Mac OS X Version 10.4.2, using Cedrus Superlab software (version 4.0.7b). The training stimuli were viewed at home on participants' personal computers.

Procedure

This study received ethics clearance from the Research Ethics Board of McMaster University. After a brief explanation of the study was provided, written consent was obtained from the adult participants and a parent of the children, as well as assent from the children themselves.

Pre-test.

On Day 1, prior to training, participants came into the laboratory and completed a delayed matching-to-sample task that measured their ability to discriminate between chimpanzee and between human faces. Trials were blocked by the species and at each age group, half of the participants in the training group and half in the control group were tested with chimpanzee faces first. Within the chimpanzee block, half of the trials consisted of faces to be used in training and

the other half consisted of untrained faces, and the presentation order of these trials was randomized. The order of the blocks was the same at pretest and posttest for each individual participant.

Before beginning the task, participants were seated in a darkened room approximately 50 cm from the computer monitor. The experimenter began by saying: *“Today we are going to play a game in the jungle. The jungle is full of tropical trees and monkeys. There are also people in the jungle, and all of the monkeys and people have twins; a brother or a sister who looks exactly like them. Yesterday, there was a big party in the jungle and everyone got mixed up and lost their twin. They need your help to find them! Remember, twins have the exact same face, so when I show you a face, all you have to do is match it to the other face that is the exact same”*. This cover-story was used to make the task engaging for children.

Before proceeding to the first test block, the experimenter showed the participant a demonstration trial, which was followed by 8 criterion trials with chimpanzee faces (in colour, with external features and in frontal view) presented sequentially. The criterion trials were included in the design to verify that the participants understood the task. Each trial began with a fixation cross that was presented until the participant pressed the spacebar on the keyboard, at which point the target face appeared. The target face was presented for 500 ms, and then following a 250 ms delay, the matching and distractor faces appeared side-by-side and remained on the screen until the participant’s response. Participants were

instructed to press the “c” key on the keyboard, which was labelled with an “L”, if the face on the left was the matching face or the “.” key, which was labelled with an “R”, if the face on the right was the correct answer. No feedback was provided, and participants had three chances to get at least 6 out of the 8 trials correct. If the participant met this criterion, the experimenter moved on to the first test block. All participants met this criterion on their first attempt.

Both test blocks began with four practice trials, followed by 100 randomized test trials. As with the criterion trials, each test trial began with a fixation cross, which was followed by the 500 ms presentation of the target face (3/4 profile), and after a 250 ms delay, the presentation of the matching and distractor faces (frontal), which remained on the screen until the participant responded. The task was to indicate whether the face on the left or on the right had the same identity as the target face, with the correct side counterbalanced across trials. Participants were instructed to press the “c” key on the keyboard, which was labelled with an “L”, if the face on the left was the matching face or the “.” key, which was labelled with an “R”, if the face on the right was the correct answer. To ensure that participants were paying attention throughout the experiment, ten additional catch trials were intermixed in each test block. Participants were told that anytime they saw a bug on one of the faces, they would need to swat it away by pressing the “n” key on the keyboard which was labelled with a picture of a butterfly. If participants responded incorrectly on more than 3 catch trials in any one test block, their data were excluded from the main analysis.

One 8-year-old participant's data were not included in our analysis because she failed to meet this criterion. Participants were given as many breaks as necessary and all participants completed the testing protocol in less than 1 hour. Accuracy and reaction times were recorded.

Training

At the end of Day 1, after completing the pre-test, participants were given instructions on how to complete the training procedure at home on Days 2-4. Each participant was provided with access online via Dropbox to a training video about 10 individual chimpanzees and 3 short training tests. They were instructed to watch the same 16-minute training video once per day over the following 3 consecutive days, and following the video, to complete a different training test on each day. All training tests consisted of 10 trials, each of which presented a target chimpanzee face (3/4 profile) for 5 seconds, followed by the presentation of the matching and distractor faces (frontal), which remained on the screen until the participant recorded their response on a response sheet and then clicked on a red button on the computer screen with their mouse to move on to the next trial. As in the pretest, the task was to indicate whether the face on the left or the right had the same identity as the target face.

Post-test

Following the training sessions, participants returned to the laboratory on Day 5 to complete the post-test, which was identical to the pre-test. Specifically,

their ability to discriminate the chimpanzee faces that they were trained on, untrained chimpanzee faces and human faces was assessed. Control participants also returned to the laboratory on Day 5 to complete the post-test.

Results

Training Task

Participants in the training group completed a test with the trained chimpanzee faces at the end of each training day. We calculated accuracy for each participant for each day. To assess how training affected accuracy, we conducted a repeated measures analysis of variance (ANOVA) on participants' accuracy, with *day* (Day 1 vs. Day 2 vs. Day 3) as the within-subjects factor and *age* as the between-subjects factor.

The ANOVA revealed a marginally significant main effect of *day* ($F(2, 106) = 2.88, p = .061$). As shown in Figure 9, there was a trend for accuracy to improve across days. Notably there was no main effect of *age* ($p > .1$) or interaction between *day* and *age* ($p > .1$).

Results of Training

For each participant, we calculated four scores based on accuracy with trained chimpanzee faces and untrained chimpanzee faces prior to and post training (see Figure 10). Face Set A was designated arbitrarily as the trained set for half the control participants and Face Set B for the other half. To assess how performance was affected by training and compare how improvement may have

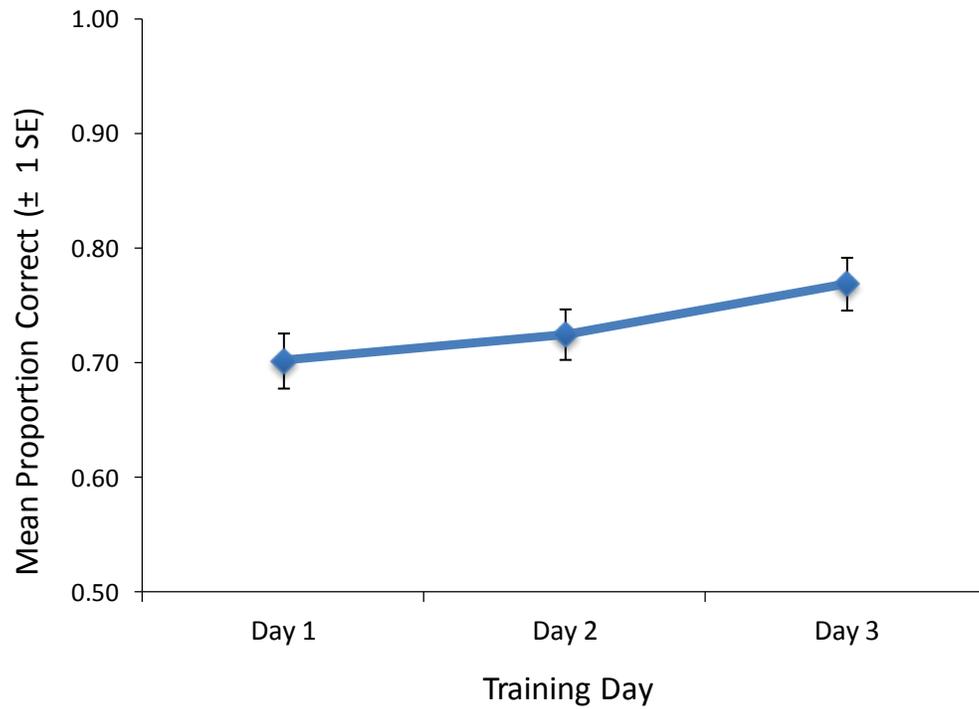


Figure 9. Training group's mean proportion of correct responses (± 1 s.e.) on the test completed after watching the training video on Day 1, Day 2, and Day 3 of training, collapsed across age.

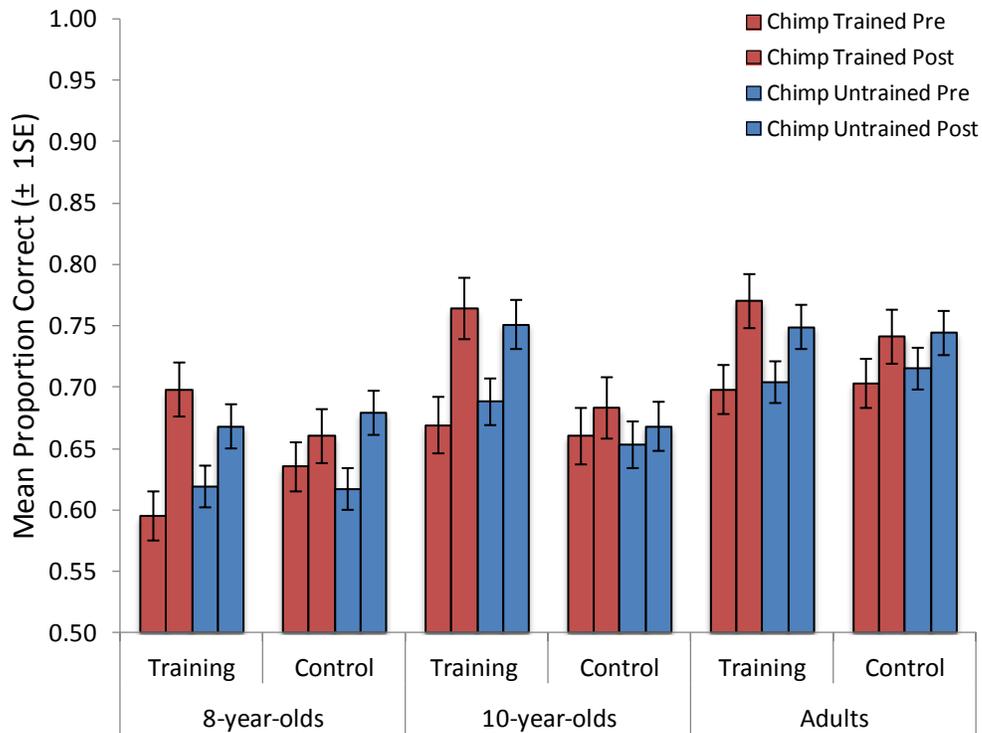


Figure 10. Training group's and control group's mean proportion of correct responses (\pm 1 s.e.) on trained chimpanzee faces and untrained chimpanzee faces at pre-test and post-test.

differed in the training group and the control group, we performed a repeated measures analysis of variance (ANOVA) on participants' accuracy, with *time* (pre- vs. post-test) and *condition* (trained chimpanzee faces vs. untrained chimpanzee faces) as within-subjects factors and *group* (training vs. control) and *age* (8-year-olds vs. 10-year-olds vs. adults) as the between-subjects factors.

The ANOVA revealed a main effect of *time* ($F(1, 106) = 59.93, p < .0001$); participants were more accurate on the post-test ($M = 71\%$; $SD = 8.06$) than on the pre-test ($M = 66\%$, $SD = 7.48$). There was also a significant main effect of *age* ($F(2, 106) = 19.04, p < .0001$). The follow-up Dunnett's *t*-test showed that for chimpanzee faces both 8-year-olds ($M = 65\%$, $SD = 8.01$) and 10-year-olds ($M = 70\%$, $SD = 7.00$) made more errors than adults ($M = 73\%$, $SD = 7.20$) ($ps < .05$). The main ANOVA also revealed a significant interaction between *time* and *group* ($F(1, 106) = 8.72, p < .01$), as well as between *time*, *condition*, and *group*, ($F(1, 106) = 4.78, p < .05$). Critically, there was no interaction between *time*, *group*, and *age*, a pattern that suggests that all age groups showed similar patterns of improvement. To analyze the three-way interaction, we conducted separate repeated measures ANOVAs for the trained and untrained chimpanzee face conditions, with *time* as the within-subjects factor and *group* as the between-subjects factor.

The follow-up ANOVA for the trained chimpanzee face trials revealed a main effect of *time* ($F(1, 110) = 48.94, p < .001$); participants were more accurate on the post-test ($M = 72\%$; $SD = 10.53$) than on the pre-test ($M = 66\%$, $SD =$

9.70). There was also a significant interaction between *time* and *group* ($F(1, 110) = 12.83, p < .01$). As shown in Figure 11, at pretest the training and control groups did not differ in accuracy, but at posttest the training group was significantly more accurate than the control group. Separate follow-up one-way ANOVAs for accuracy at pretest and posttest revealed that at pretest there were no significant main effects or interactions ($p > .05$), however at post-test there was a significant effect of *group* ($F(1, 111) = 5.86, p = .017$). The training group demonstrated an effect of training, and improved more than the control group for the chimpanzee faces that they were exposed to in the training video.

The follow-up ANOVA for the untrained chimpanzee face trials revealed a main effect of *time* ($F(1, 110) = 48.94, p < .001$); participants were more accurate on the post-test ($M = 71\%$; $SD = 8.72$) than on the pre-test ($M = 67\%$, $SD = 8.57$). Critically, unlike for the trained chimpanzee face condition, the interaction between *time* and *group* failed to reach significance ($p > .05$) (see Figure 12). The training group did not improve more in this condition than the control group. Therefore, the training group's improvement was specific to the trained face exemplars and we found no evidence for generalization of training to novel exemplars.

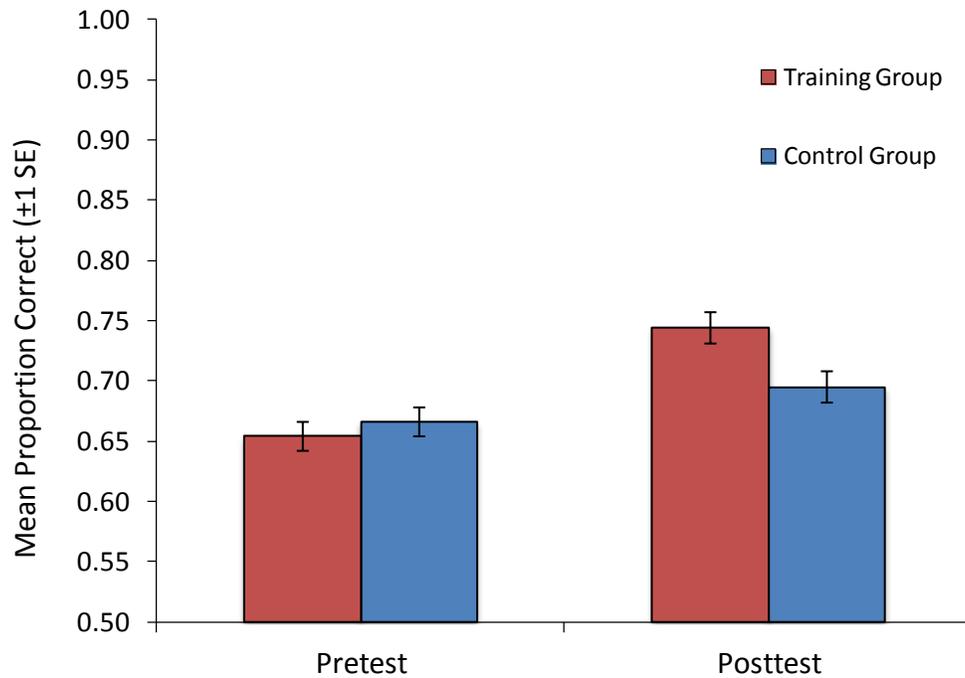


Figure 11. The training and control groups' mean proportion of correct responses (± 1 s.e.) on the pre- and post-tests for the trained chimpanzee faces, collapsed across age.

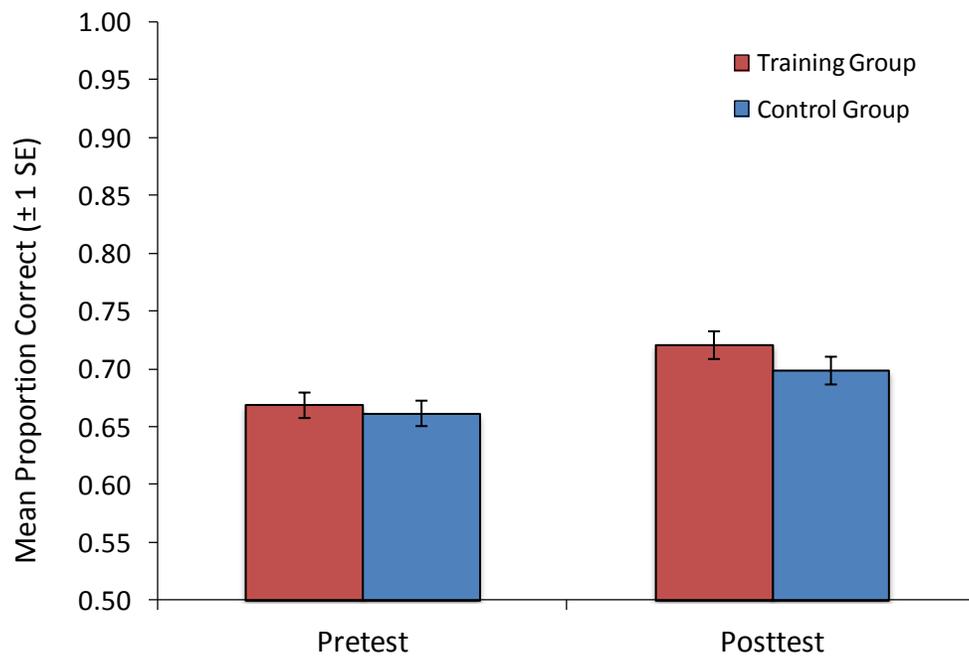


Figure 12. The training and control groups' mean proportion of correct responses (± 1 s.e.) on the pre- and post-tests for the untrained chimpanzee faces, collapsed across age.

Own-Species Bias

For each participant, we calculated the own-species bias prior to and post training. The own-species bias was defined as the difference in mean accuracy for recognizing human versus chimpanzee faces (with the data for trained and untrained chimpanzee faces combined). To assess how the own-species bias was affected by training, we performed a repeated measures analysis of variance (ANOVA) on participants' own-species bias scores, with *time* (pre- vs. post-test) as the within-subjects factor and *group* (training vs. control) and *age* (8-year-olds vs. 10-year-olds vs. adults) as the between-subjects factors.

The results of the ANOVA revealed main effects of *time* ($F(1, 106) = 15.59, p < .0001$) and *age* ($F(2, 106) = 11.66, p < .0001$). The follow-up Dunnett's *t*-test showed that the own-species bias was smaller for both 8-year-olds ($M = .13, SD = .10$) and 10-year-olds ($M = .15, SD = .08$) than adults ($M = .20, SD = .07$) ($ps < .01$). The main ANOVA also revealed a significant interaction between *time* and *group* ($F(1, 106) = 8.36, p < .01$). To analyze this interaction, we conducted separate one-way ANOVAs at pre- and post-test, with *group* as the between-subjects factor. As shown in Figure 13, at pre-test the training and control groups did not differ significantly in regards to their own-species bias ($p > .7$), however at post-test the training group ($M = .13, SD = .09$) exhibited a significantly smaller own-species bias than the control group ($M = .17, SD = .09$) ($F(1, 111) = 5.88, p = .02$).

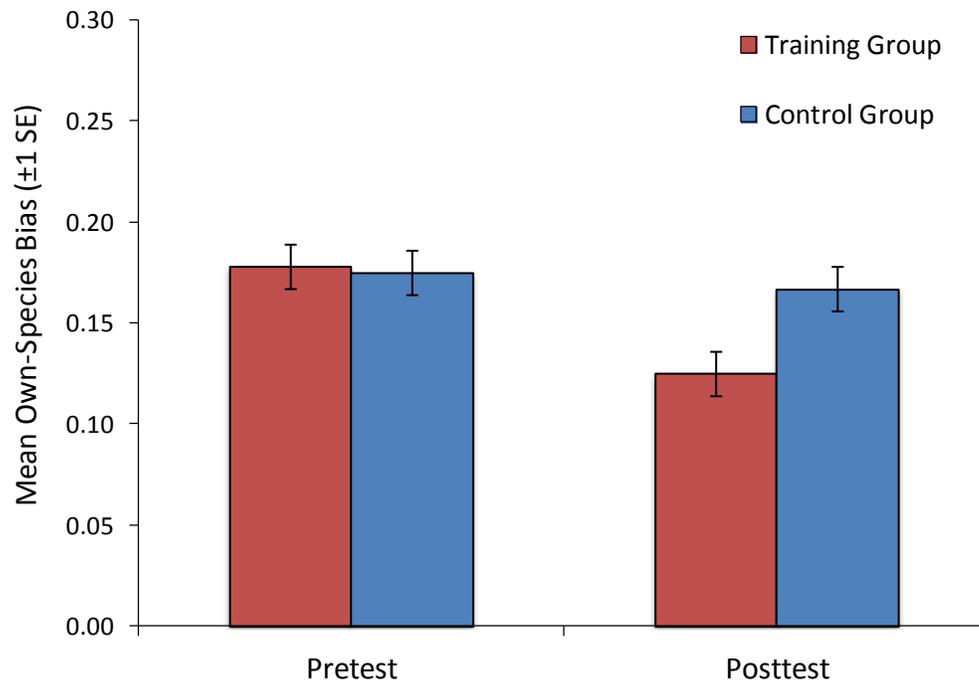


Figure 13. The training and control groups' mean own-species bias scores (± 1 s.e.) on the pre- and post-test, collapsed across age.

Human Faces

To dissect the decline in the own-species bias, we checked whether training with chimpanzee faces might have caused a decline in accuracy for human faces. Therefore, we conducted a repeated measures analysis of variance (ANOVA) on participants' accuracy for human faces, with *time* (pre- vs. post-test) as the within-subjects factor and *group* (training vs. control) and *age* (8-year-olds vs. 10-year-olds vs. adults) as the between-subjects factors (see Figure 14).

The results revealed a main effect of *time* ($F(1, 106) = 13.52, p < .0001$); participants were more accurate on the post-test ($M = 86\%$, $SD = 10.13$) than on the pre-test ($M = 84\%$, $SD = 10.00$). In addition, there was a main effect of *age* ($F(2, 106) = 49.24, p < .0001$). The follow-up Dunnett's *t*-test revealed that both 8-year-olds ($M = 78\%$, $SD = 9.38$) and 10-year-olds ($M = 84\%$, $SD = 8.28$) were less accurate than adults ($M = 93\%$, $SD = 4.52$) ($ps < .0001$). Notably, there was no significant effect of group or interaction between *time* and *group* ($ps > .3$), a pattern that suggests that there was no effect of training on participants' accuracy for human faces.

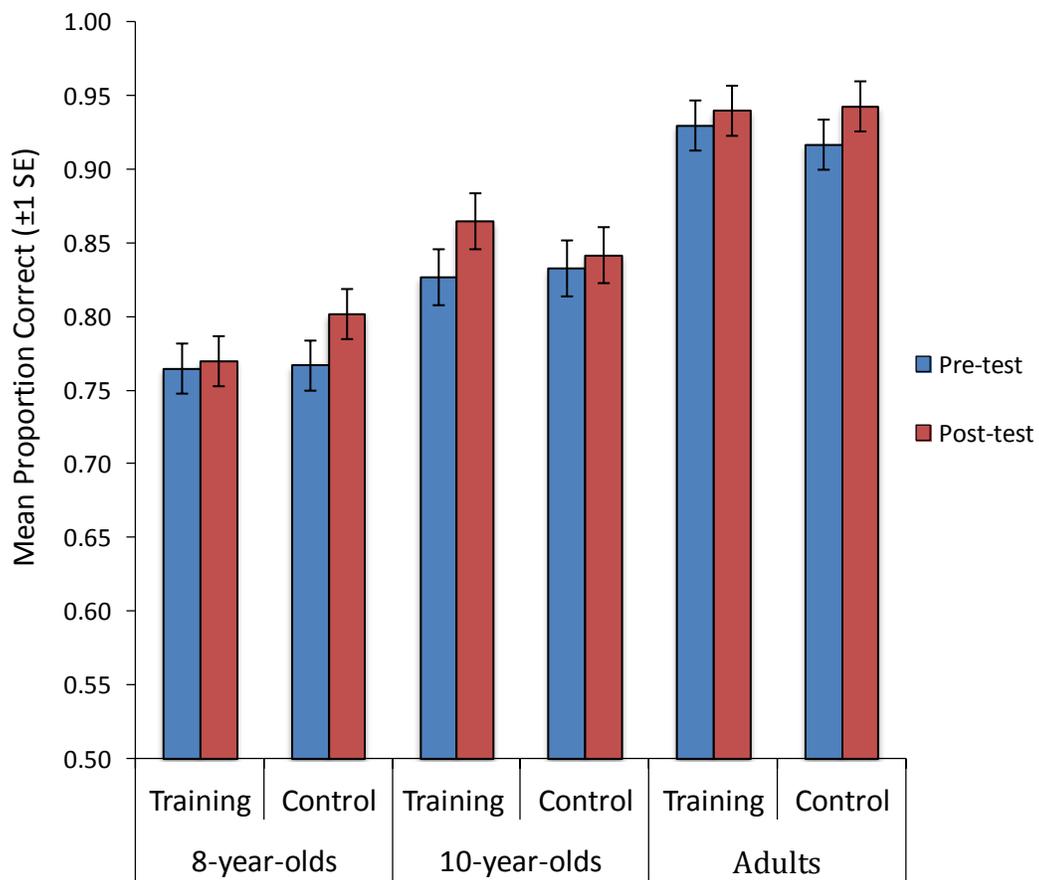


Figure 14. Training group's and control group's mean proportion of correct responses (± 1 s.e.) for human faces at pre-test and post-test.

Discussion

In the present study, we examined how the plasticity of the face processing system may change over the course of development. In order to do this, we trained 8-year-old, 10-year-old and adult participants to discriminate 10 chimpanzee faces by having them watch a child-friendly training video over three consecutive days. We compared the participants' accuracy at discriminating chimpanzee and human faces before and after training. To be able to attribute improvement after training to the training paradigm itself rather than to exposure to the pre- and post-training sessions, we also tested a group of age- and gender-matched controls who completed the pre- and post-tests but who did not watch the training video.

Training Effects

Children and adults in the training groups demonstrated a training effect: their accuracy improved more than that of the control group from pre-test to post-test for the 10 chimpanzee faces on which they were trained. Three other findings support our interpretation that this group difference in improvement for trained chimpanzee faces resulted from training. First, on the training test completed after watching the video on each day of training, there was a trend for accuracy to improve across days. Second, unlike for chimpanzee faces, the training group and the control group showed a similar pattern of improvement for human faces. Both groups improved in their accuracy at discriminating human faces, but, critically,

the training group did not improve more than the control group. Third, the training group demonstrated a greater reduction in their own-species bias (i.e. the difference between mean accuracy on human faces and mean accuracy on chimpanzee faces) after the training phase. While this finding is consistent with previous studies that have shown that the own-race bias is reduced in individuals who have more contact with other-race faces (e.g., Hancock & Rhodes, 2008), it is important to note that this reduction in the training group's own-species bias came about mainly as a result of their improvement for trained chimpanzee faces since the training and control groups did not differentially improve for untrained chimpanzee faces.

To our knowledge, no previous study has attempted to train participants to discriminate chimpanzee faces. However, in line with our results, Dufour & Petit (2010) demonstrated that adults with extensive experience individuating monkey faces are more accurate at discriminating this category of stimuli than controls. In addition, our findings are consistent with previous perceptual learning studies with adults that found improved recognition of other-race, other-age, and inverted faces even after only a modest amount of training in individuating these faces (Hussain et al., 2009; McGugin et al., 2011; Tanaka & Pierce, 2009; Yovel et al., 2012). Similar training paradigms have rarely been used with children. However, Macchi Cassia et al. (2009a) found that unlike control participants, 3-year-olds with more contact with an unfamiliar face category, such as infant faces, show an inversion effect for this face category. Our findings add to a large body of

literature that suggests that even after the period of perceptual narrowing that occurs in infancy, experience can still modulate the face processing system.

We can only speculate about what attributes of our training paradigm made it effective in improving accuracy for the trained faces. Previous studies suggest that exposure to faces or objects at the individual level is necessary for the acquisition of expert-like skills in face and object recognition (Gauthier & Tarr, 1997; McGugin et al., 2011; Scott et al., 2008; Tanaka et al., 2005; Tanaka & Pierce, 2009; Tanaka et al., 2012; Wong et al., 2009). These studies found that unlike individuation, neither mere exposure nor categorization resulted in improved discrimination at the individual level, even when attentional demands were equated to those involved in individuation training (e.g. McGugin et al., 2011; Wong et al., 2009). Therefore, it is the quality, and not only the quantity, of exposure that is important in inducing improvements in a relatively novel face or object category. In the present study, we exposed participants to 10 chimpanzee faces at the individual level (e.g., Max, Dario, Koko). To further emphasize individuality, we also assigned to each chimpanzee his own name and unique characteristic (e.g., Walter is the best swimmer in the jungle). In addition, the training stimuli were presented in the context of a video, which was designed to be entertaining for children and to motivate them to attend to the individual faces. Also, likely important is the fact that the chimpanzee faces used in training were presented from different viewpoints and with different facial expressions. This forced participants to pick up on the identity-relevant cues despite variation in

other cues and hence encouraged learning of the faces rather than of specific image characteristics. Overall, we hypothesize that the nature of participants' exposure to 10 individual chimpanzee faces over the course of three days was likely critical to their improved accuracy at discriminating between those faces during the post-test.

Lack of Generalization

Although three days of training or approximately 60 minutes of exposure to 10 individual chimpanzee faces was sufficient to yield a training effect, it was not sufficient to yield generalized improvement to exemplars not included in the training. Our results are consistent with those of Hussain, Sekuler, & Bennett (2009), who trained adults to identify upright and inverted human faces in two one-hour training sessions, and found improvement that was highly exemplar- and orientation-specific. However, they contrast with several training studies with other-race and other-age faces in adults that have found that improvement generalized to novel exemplars of the trained category even after only three days of training (McGugin, Tanaka, Lebrecht, Tarr, & Gauthier, 2011; Tanaka & Pierce, 2009; Tanaka et al., 2012; Yovel et al., 2012).

The inconsistency of generalization of improvement to novel-exemplars of the trained face category likely results from differences in training paradigm. Studies that have been successful in yielding generalized improvement have, unlike Hussain and collaborators (2009), involved training participants to

associate each face used in training to a name. This association is usually reinforced with tasks that require participants to identify the faces by providing the correct label or to judge whether a name and a face match. Second, although 3 days of training is sufficient to result in improvement of the recognition of other-race and other-age faces that generalizes to novel exemplars, longer training may be required to find similar generalization of improvement for other species. For example, Tanaka and collaborators (2005) trained adults to classify owls at the subordinate level (i.e. classify the species of owl) over 7 days and found improvement that generalized to novel exemplars and novel species categories. In addition, all of these training paradigms gave feedback (including the Hussain et al. (2009) study that failed to find generalization after training with upright or inverted faces). Learning without external feedback is possible and can result in improvement; however, improvement is usually slower compared to paradigms that use feedback (Fahle & Poggio, 2002). The lack of feedback may have been especially limiting because the face category was unfamiliar and the training was limited in duration.

In the current study, participants were also trained to associate each chimpanzee face with a name and in addition, to certain unique qualities over the course of only 3 days. However, participants were not tested on their accuracy in labeling the chimpanzee faces with their names. Such a task might be critical after infancy in promoting individuation and therefore improvement that generalizes to novel exemplars. In addition, participants were not provided with any feedback. A

follow-up study could adjust the training paradigm used in the current study to be longer and to include tasks with feedback that train participants to actively associate the training faces with labels in order to assess whether these components of training are required to yield generalized improvement.

Practice Effects

Participants from both the training and control groups improved in recognizing both chimpanzee and human faces from pre- to post-test, even when there had been no training (i.e., human faces for the training group and all face categories for the control group). In addition there were no age differences in the size of the practice effects. These practice effects may have resulted from perceptual learning, improvement on a perceptual task through practice that is typically specific to the stimuli used in training and facilitated by external feedback (Ball & Sekuler, 1987; Fahle & Poggio, 2002; Gibson, 1963; Hussain, Sekuler, & Bennett, 2009). Alternatively, it may have resulted from task-general learning from practice with the two-alternative matching-to-sample. It is not possible to distinguish between these two types of learning without comparing performance at baseline to a novel stimulus category or novel exemplars of the same category after training. If improvement generalized to a novel stimulus category to the same extent as for the categories participants gained practice with on the pre-test, we could conclude that this improvement is a task-general improvement. Unfortunately, such a condition was not included at post-test as this

was an unexpected incidental finding that does not pertain to the main research question.

Age at Training

The most surprising finding was that 8-year-olds, 10-year-olds and adults all showed similar improvement in their accuracy at discriminating trained chimpanzee faces. The results revealed a significant interaction between time, group and condition. However, neither the critical time by group by age interaction nor the time by group by condition by age interaction was significant. Taken together, these results suggest that the face processing system is plastic in late childhood and remains flexible into young adulthood, and that there is no decline in plasticity during this period of development. Macchi Cassia and collaborators (2009a) found that after approximately 12 months of exposure to an individual infant face, 3-year-olds, but not adults, showed evidence of improved recognition of infant faces. It is possible that, as Macchi Cassia and collaborators (2009a) suggest, there is a decline in plasticity with age, but that this decline stabilizes by 8 years of age and, as our results suggest, the face processing system remains, perhaps to a lesser degree, flexible into early adulthood. For example, the same training might induce generalized improvements in younger children, but only improvements for the specific trained faces in older children and adults. Studies from the auditory and speech domain have also found a decline in plasticity. More specifically, they demonstrated that infants who are at an age

when adult-like perceptual biases have recently formed learn more readily than adults (e.g. Hannon & Trehub, 2005b; Werker & Tees, 2005). For example, after daily exposure to Balkan folk music for only approximately 2 weeks, North American 12-month-old infants, but not adults, learned to detect violations in the metrical structure of Balkan folk tunes containing complex meters, which are uncommon in North American music (Hannon & Trehub, 2005b). Another possibility is that there is a more gradual decline in the flexibility of the face processing system across development, but that our training paradigm was not sensitive enough to bring out these age-at-training effects. It is possible that using a shorter training procedure, or using one with fewer exemplars might reveal differences in the flexibility of the face processing system at these different ages. In their study, Macchi Cassia et al. (2009) tested participants who had had much longer exposure to the novel face category (i.e., on average 12 months) than participants in the current study (i.e. 3 days), but only to one exemplar. Future training studies could address this contrast in findings by comparing several ages, spanning from early childhood to adulthood. In addition, the length of the training procedure and the number of exemplars included could be varied.

Other Findings

The results also revealed several main effects of age, which, although not pertinent to our main research question, are nonetheless interesting from a developmental perspective. We found that for the matching-to-sample task with chimpanzee faces, accuracy improved with age. Adults performed significantly

better than both 8- and 10-year-olds. These results are consistent with a previous study, which found that adults were more sensitive than 8-year-olds to the spacing between the features of monkey faces (Mondloch et al., 2006). The present study extends previous findings by demonstrating that even by age 10, children are not adult-like in their accuracy at discriminating chimpanzee faces. Since children do not gain experience individuating chimpanzee faces between age 8 and adulthood, the improvement may result from the known improvements in more general cognitive and perceptual abilities such as improvements in memory, attention or vernier acuity (i.e., the ability to perceive fine misalignments between two lines) (as reviewed in Crookes & McKone, 2009).

Accuracy in the human condition also improved with age. Adults were significantly better than both 8- and 10-year-olds. This finding replicates several previous studies that demonstrated that the recognition of identity in upright human faces improves with age and into adolescence, especially if faces differ in point of view (e.g., Carey & Diamond, 1977; de Heering et al., 2012; Mondloch, Geldart, Maurer, & Le Grand, 2003; Mondloch et al., 2002; Mondloch, Le Grand, & Maurer, 2003).

As expected, participants at all ages were better at discriminating human faces than chimpanzee faces. This finding is consistent with previous reports of an own-species bias in 8-year-olds and adults (Dufour et al., 2004; Pascalis, & Bachevalier, 1998; Pascalis et al., 2002; Mondloch et al., 2006). This own-species bias also increased with age: adults displayed a significantly larger bias than both

8- and 10-year-olds. This finding reflects greater improvement for human faces, which children have experience differentiating, than chimpanzee faces during this period of development. Contrary to our finding, Mondloch and collaborators (2006) found that both 8-year-olds and adults were 9% more accurate at making same/different judgments about human faces than monkey faces, all of which differed only in the spacing of their features (i.e., second-order relations). This inconsistency in results can likely be attributed to methodological differences. Mondloch and collaborators (2006) used a task that tapped children's and adult's sensitivity to second-order relations in faces: a sensitivity that develops into adolescence for upright human faces (Mondloch et al., 2002; Mondloch, et al., 2003). However, individuals also use information about facial features and contour to differentiate between individual faces (Mondloch et al., 2002; Want, Pascalis, Coleman, & Blades, 2003). In the present study, participants completed a matching-to-sample task with chimpanzee faces that provided participants with several diagnostic cues that are likely processed in combination in everyday life to differentiate faces. Therefore, these findings suggest that children show an adult-like pattern in their sensitivity to second-order relations, but not in their ability to process information about facial features, contour, and second-order relations in combination, or perhaps not in their ability to pick up on these cues despite variation in other cues.

Overall, we found that discrimination of both human and chimpanzee faces improves with age. In addition, the own-species bias is already present at 8

years and becomes stronger with age. This increase in bias for human faces may be driven by the wealth of experience that individuals gain differentiating upright human faces during development.

Limitations

Our conclusions regarding the plasticity of the face processing system throughout development depend strongly on the assumption that participants at all ages gained comparable experience individuating 10 chimpanzee faces. To make it easier for children and adults to participate in this study, we had participants complete the training at home. Although participants and parents of the child participants were provided with detailed instructions both verbally and in writing, we cannot be certain that every participant completed the training paradigm properly. In an effort to monitor their completion of the training day-by-day, we did ask participants to log their time and record their responses for the training test on answer sheets that they returned to the experimenter at their follow-up session. We excluded the three participants (out of 59) who, based on their answer sheets and feedback, did not complete the training properly. Nevertheless, it is possible that there was some variation in how participants completed the training paradigm that was correlated with age.

Another limitation of the study is that it is difficult to compare exposure to an unfamiliar category of stimuli for 60 minutes in an experimental video to more extensive exposure in a natural setting. It did, however, allow us to control the

quantity and quality of exposure that participants received, and therefore to test hypotheses about the mechanisms involved in the acquisition of face expertise, and possible age-at-training effects.

To summarize, our findings suggest that 8-year-olds, 10-year-olds and adults are all receptive to the effects of perceptual training, and that only 3 days of exposure to 10 individual chimpanzee faces is sufficient to improve their accuracy at discriminating these faces. As a result of this improvement, participant's own-species bias was reduced after training. However, this effect of training was exemplar-specific and did not generalize to novel exemplars. Lastly, we found that this adaptability appears to be stable between 8 years of age and adulthood.

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APPENDIX

Training Video Script: “The Quest for the Golden Banana”

Slides 1 and 2

This is the tale of the quest for the Golden Banana. On an island far, far away, deep in the jungle, a group of 10 monkeys were gathering. All of the most important monkeys in the jungle were there!

Slide 3

Koko the chatterbox arrived first. Koko was famous for his ability to communicate with all of the animals in the jungle, even the tiniest critters!

Slide 4

Walter was the second to arrive. Walter was the best swimmer in the jungle. He had won 5 gold medals in swimming.

Slide 5

Fred turned up next! Fred loved climbing. He could always pick the bananas that were all the way at the top of the tallest trees.

Slide 6

Edwin was the next one to show up. Edwin was the smallest monkey in the jungle, but he was not afraid of anyone or anything; he loved adventure!

Slide 7

Max came too. Max was really, really strong and could do over 1,000 push-ups in a row!

Slide 8

Brian swung in next. Brian was a professional gymnast; he loved doing routines on the balance beam for everyone to see!

Slide 9

Albert came in just after. Albert was the smartest of all the monkeys and loved solving riddles!

Slide 10

Then came Stan! Stan loved puzzles; he had solved 1352 puzzles to date!

Slide 11

Lucky shuffled in, worried he was late. Lucky was named after his good fortune. He was always lucky in life!

Slide 12

And of course, last but not least, Dario came in, late as usual! Dario was the most musical monkey in the jungle and could play over 10 instruments!

Slide 13 - 21

The monkeys were gathering because they had heard that Koko had found the ancient map that lead to the *Golden Banana*. According to an ancient legend, that had been passed down from generation to generation, whoever possessed the *Golden Banana* would have an endless supply of bananas, and never run out of food.

Slides 22 and 23

Once all the monkeys had calmed down and were listening, Koko announced, “Attention everyone! The rumours are true. I’ve found the ancient map that leads to the *Golden Banana*!” Look closely; it appears that there are 5 obstacles that we need to overcome in order to reach the *Golden Banana*. We’ll need to work together to pass these obstacles! The other monkeys cheered and followed Koko.

Slides 24 - 29

All of the monkeys followed the trail indicated on the map, swinging through the trees and singing along the way; Edwin, Stan, Walter, Fred, Max, Albert, Lucky, Koko, Dario and Brian, until they reached the end of a cliff. They arrived at their first obstacle.

Slide 31

“How are we all going to get across?” Max yelled to everyone.

Slide 32

“Well look,” responded Fred, “there’s a thin tree that has been pushed on its side and is stretching across to the other side. It’s awfully thin though; I don’t think we can get across it without falling.”

Slide 33

“Look over there,” replied Stan, “there’s a long tree branch on the other side, if we can swing it over here somehow, we can all swing across to the other side. I know! Brian is a gymnast and has great balance; he can walk across the tree!”

Slide 34

Can you find Brian? Point to Brian.

Slide 35

1 distractor - Walter (Alpha)

Slide 36

There’s Brian!

“And Edwin isn’t afraid of anything”, added Stan, “he can go across on Brian’s back and grab the branch and swing it over here”.

Slide 37

Can you find Edwin? Point to Edwin.

Slide 38

1 distractor - Max (Kehg)

Slide 39

There’s Edwin!

Slides 40 and 41

So Brian balanced his way across the tree with Edwin on his back, and when they reached the other side, Edwin grabbed the branch and swung it back to the other monkeys. One at a time, the monkeys swung over the cliff to join Brian. All of the monkeys cheered when they made it to the other side! They passed their first obstacle!

Slides 42 - 47

When they were ready to go, Koko pulled out the map and lead the way. Four obstacles left to overcome! They continued on the trail to the *Golden Banana*, swinging through the trees and singing along the way; Edwin, Stan, Walter, Fred, Max, Albert, Lucky, Koko, Dario and Brian. They continued until their path was blocked once again.

Slide 48

A lion was blocking their path, and would not let them pass unless they correctly answered his riddle!

Slide 49

Walter exclaimed, “Koko you’ll need to talk to the lion! No one else speaks to the lion. You can translate for Albert who is the smartest monkey here and loves solving riddles! Together you two can get us past the lion!”

Slide 50

Can you find Koko? Point to Koko.

Slide 51

1 distractor – Lucky (Mahsho)

Slide 52

There’s Koko!

Slide 53

Now can you find Albert? Point to Albert.

Slide 54

1 distractor – Fred (Doyle)

Slide 55

There’s Albert!

Slide 56

Koko talked to the lion and translated the riddle to Albert, “Albert, what is black and white and red all over?”

Slide 57

“That’s easy! A sunburned penguin, of course!” replied Albert.

Slide 58

“That’s right! The lion will let us pass! Good job Albert!” said Koko.

All of the monkeys cheered!

Slides 59 - 65

The 10 monkeys could now continue on their quest to find the *Golden Banana*. They followed the trail, swinging through the trees and singing along the way; Edwin, Stan, Walter, Fred, Max, Albert, Lucky, Koko, Dario and Brian. They continued until they reached their third obstacle, a river.

Slide 66

“How are we going to get across the river?” Edwin asked.

Slide 67

“Well,” answered Dario, “ look there’s a boat on the other side of the river. Walter, who’s won 5 gold medals in swimming, should swim over to it and row it back to this side. Then Max, who is the strongest, can row us all across the river.”

Slide 68

Can you find Walter? Point to Walter.

Slide 69

1 distractor – Albert (Magic)

Slide 70

There’s Walter!

Slide 71

Can you find Max? Point to Max.

Slide 72

1 distractor – Koko (Lyle)

Slide 73

There's Max!

Slides 74 and 75

So Walter swam across the river, got into the boat and rowed it back to where the other monkeys are waiting. All of the monkeys got into the boat and Max rowed them to the other side of the river so that they could continue on their quest for the *Golden Banana*.

Slide 76

“Hooray!” they all yelled together when they got out of the boat.

Slides 77 - 82

The 10 monkeys had successfully passed 3 obstacles! They continued along the path, swinging through the trees and singing along the way; Edwin, Stan, Walter, Fred, Max, Albert, Lucky, Koko, Dario and Brian.

Slide 83

They continued until their path was blocked by a gate that was guarded by a wizard. The wizard was holding four instruments; a guitar, a flute, a trumpet and a set of drums. He told the group of monkeys that in order to open the gate they would need to play the Jungle song perfectly on the correct instrument. However, he would give them only one chance to pick an instrument and play the tune.

Slide 84

“Lucky should be the one to pick the instrument,” announced Brian, “he's always lucky in everything he does! He'll be able to pick the instrument that'll open the gate!”

Slide 85

Can you find Lucky? Point to Lucky.

Slide 86

1 distractor – Brian (April)

Slide 87

There's Lucky!

Slide 87a

“After Lucky chooses the instrument, Dario should be the one to play the Jungle song,” added Brian.

Slide 88

Can you find Dario? Point to Dario.

Slide 89

1 distractor – Stan (Lulu)

Slide 90

There's Dario!

Slide 91

So Lucky went up to the wizard to pick an instrument. He got a strong feeling that the trumpet was the right choice, so he reached out, grabbed it and handed it to Dario to play.

Slide 92

Dario took the trumpet and played the Jungle song.

Slide 93

The gate started to open! They did it! Lucky picked the right instrument and Dario played the song perfectly.

Slide 94

They had passed their fourth obstacle and had just one left to go before they reached the *Golden Banana!*

Slide 95 - 100

The monkeys continued along the path, swinging through the trees and singing along the way; Edwin, Stan, Walter, Fred, Max, Albert, Lucky, Koko, Dario and Brian. They continued until they finally reached the *Golden Banana Tree.*

Slide 101

“We’ve finally made it!” exclaimed Lucky, “But look, there’s one more obstacle; a puzzle. Maybe solving the puzzle will give us a clue about where the *Golden Banana* is...Stan should solve the puzzle, he’s solved over 1352 of them!”

Slide 102

Can you find Stan? Point to Stan.

Slide 103

1 distractor – Edwin (Angie)

Slide 104

There’s Stan!

Slides 105 and 106

So Stan quickly solved the puzzle, which revealed an upward pointing arrow.

Slide 107a

“Look, it’s the *Golden Banana*! It’s all the way at the very top of the tree!” Koko remarked.

Slide 107b

“Fred should climb up and get it!” he added. “He’s the best climber in the jungle!”

Slide 108

Can you find Fred? Point to Fred.

Slide 109

1 distractor – Dario (Muffin)

Slide 110

There’s Fred!

Slide 111

So all of the monkeys watched in silence as Fred climbed up higher, and higher, and higher, until he reached the very top and reached up and grabbed the *Golden Banana*! “I’ve got it”, Fred exclaimed with excitement.

Slide 112

All of the monkeys cheered! Fred climbed down and the monkeys celebrated all together!

Slide 113

They had passed all 5 obstacles, found the *Golden Banana* and reached the end of their quest! Now they could have all the bananas they could ever dream of!

Slide 114

The End!