Reward Learning Modulates the Attentional Processing of Faces in

region, relative to typically developing (TD) individuals [e.g., Dalton et al., 2005; Falck-Ytter & von Hofsten, 2011; Pelphrey et al., 2002; Spezio, Adolphs, Hurley, & Piven, 2006; Tanaka & Sung, 2013]. This eye-avoidance looking pattern in individuals with ASD prevents them from encoding and interpreting facial cues, and thus hinders effective social interaction with others [e.g., Behrmann, Thomas, & Humphreys, 2006; Tanaka & Sung, 2013; Tantam, Monaghan, Nicholson, & Stirling, 1989; Wallace, Coleman, & Bailey, 2008].

Social motivation theory has gained supporting evidence from research on reward learning in individuals with ASD. Such studies have demonstrated the difficulty among these individuals in forming reward representations of social stimuli [e.g., Delmonte et al., 2012; Lin, Rangel, & Adolphs, 2012]. Findings based on fMRI technique have provided direct support to this notion by showing significant activation reduction in brain areas associated with reward processing when children with ASD received social feedback as compared with monetary reward in a reward learning task [e.g., Delmonte et al., 2012; Scott-Van Zeeland, Dapretto, Ghahremani, Poldrack, & Bookheimer, 2010]. Such a dysfunction in processing social rewards in individuals with ASD hampers their development of joint attention, social communication skills, and face processing [e.g., Dawson et al., 2002; Geurts, Luman, & van Meel, 2008; Munson, Faja, Meltzoff, Abbott, & Dawson, 2008]. However, there is controversy concerning whether this abnormality of reward processing in ASD is a general dysfunction in reward learning or is instead specific to social stimuli. Some studies of ASD have reported impaired processing of non-social rewards (e.g., monetary rewards) similar to that of social rewards [e.g., Dichter et al., 2010; Dichter, Richey, Rittenberg, Sabatino, & Bodfish, 2011; Kohls et al., 2011], while others have suggested that the reward learning deficit in ASD is specific to the processing of social stimuli [e.g., Delmonte et al., 2012; Lin et al., 2012].

The learning of reward associations is considered by Pavlovian theories as a fundamental mechanism for survival and evolution [Pavlov, 1927; Rescorla & Wagner, 1972]. The predictive attribute of an object or a person for potential reward and punishment is established at a very early stage of development [Heerey, 2014; Stavropoulos & Carver, 2013]. Recent investigations have demonstrated that associating a visual stimulus (e.g., a visual feature or a face) with a reward can elevate the attentional deployment towards it, even when the visual stimulus is no longer predictive of the reward [Anderson, Laurent, & Yantis, 2011; Della Libera & Chelazzi, 2009; Hickey, Chelazzi, & Theeuwes, 2010; Raymond & O'Brien, 2009; Le Pelley, Pearson, Griffiths, & Beesley, 2015]. This effect can last for up to half a year [Anderson & Yantis, 2013; Della Libera & Chelazzi, 2009]. Moreover, the guidance of attention by reward associations is likely an automatic process instead of relying on motivational reinforcement [Sali, Anderson, & Yantis, 2014]. Due to the important role of attentional control in normal behavior, these findings provide direct evidence that the ability to associate rewards with both social and non-social stimuli is crucial to an individual's quality of life. Therefore, training children with ASD to establish associations between meaningful stimuli and rewards could be a critical step towards a successful behavioral intervention.

The importance of reward learning of faces in ASD rests on whether the learning results in a significant improvement on processing the faces in subsequent behavior. A straightforward measurement of such an improvement is to examine the efficacy of attentional processing of faces after reward learning (i.e., the time required to find a target in a face visual search task). However, this issue remains unclear in the current ASD literature. The present study aimed to investigate whether the children with ASD could effectively process faces after establishing the reward–face associations, even if they have shown difficulty in face processing [e.g., Dalton et al., 2005; Falck-Ytter & von Hofsten, 2011; Pelphrey et al., 2002] and in reward learning of social stimuli [e.g., Delmonte et al., 2012; Lin et al., 2012]. Specifically, we attributed different values to faces using the reward learning approach and examined how the associated values of faces modulate the recognition and attentional processing of faces in individuals with ASD. To maximize the associated value towards the children with ASD, we paired face identities with real non-social reward through simulated social interactions. After the reward learning process, faces were perceived as representation of persons with different characteristics (positive, negative, and neutral values). If lack of social motivation is attributed to impaired face processing in ASD, the manipulation of associating face identities to positive or negative values would modified their processing of and attention to these faces. We first asked children with and without ASD to participate in a reward learning task to establish face–reward associations. In this task, three female faces were associated with three types of rewards: gaining a reward (win-face), losing a reward (lose-face), and no change to the rewards (neutral-face). In a following face recognition task, we asked children to judge whether the face displayed was one of the three learned faces or a new face they had never seen before. To investigate the modulation of face–reward associations in attentional selection while controlling for motivation-related factors, we then presented the three reward–associated faces as distractors in a visual search task and compared the visual search performance between the trials with the reward–associated faces (win-face and lose-face) and the neutral face as distractors. With this design, we aimed to examine three important issues concerning reward learning in ASD children. First, we tested whether the children with ASD could learn face–reward associations; if so, we aimed to understand the extent to which they differed from the TD children in terms of learning efficacy (i.e., the number of trials needed to learn the associations). Based on the previous literature [e.g., Dichter et al., 2010; Dawson, Osterling, Rinaldi, Carver, & Mcpartland, 2001], we hypothesized that children with ASD would learn reward association less efficiently than TD children. Second, we tested children's memory of the three faces and how their face recognition would be affected by the face–reward associations. Third, we examined whether attentional processing of the win- and lose-faces could be enhanced to facilitate the visual search performance. Critically, we examined whether this modulatory effect, if any, differed between the ASD and TD groups.

Method

Participants

We recruited 20 high-functioning children with ASD and 20 age- and IQ-matched TD children from a special school and two normal preschools in China. The special school is a school specified for children with ASD, which provides intervention and education for children with ASD. One child with ASD was excluded from this experiment due to his loss of temper during the experiment. Three children with ASD were excluded from this experiment since they failed to pass the reward learning task. All 20 children in the TD group passed the reward learning task. Thus, the final sample consisted of 16 children with ASD (age range: 5.00–7.10 years, $M = 6.04$, $SD = 0.73$, 1 female), and 20 TD children (age range: 4.60–6.70 years, $M = 5.76$ years, $SD = 0.54$, 1 female). This age range was chosen according to our pilot results and previous literature [Faja, Murias, Beauchaine, & Dawson, 2013; Stavropoulos & Carver, 2014], to ensure that most children in our study could successfully learned the reward associations. Our tasks were also adapted for children at this age range.

All children with ASD had been previously diagnosed based on criteria included within the DSM-IV-TR [APA, 2000] by two professional pediatric clinicians with expertise in autism. Because the standard diagnostic scales [e.g., ADI-R, Lord, Rutter, & Le Couteur, 1994; and ADOS, Lord et al., 2000] have not been normalized and widely used in China, we used the Chinese version of the Autism Spectrum Quotient: Children's Version [AQ-Child; Auyeung, Baron-Cohen, Wheelwright, & Alison, 2008] and the Social Responsiveness Scale [SRS; Constantino & Gruber, 2002] to confirm the diagnosis for the children with ASD. The two groups were matched on their non-verbal IQ, measured by the Combined Raven Test (CRT-C2), and their verbal mental age, measured by the Chinese version of the Peabody Picture Vocabulary Test-Revised (PPVT-R) (see Table 1). All children were medication naïve.

Table 1. Characteristics of the Participants in Each Group

Variable	ASD	TD	Difference (*t* test) ASD vs. TD
N	16	20	NA
Male (female)	15 (1)	19 (1)	NA
Age range	5.00–7.10	4.40–6.70	NA
Mean age in years (*SD*)	6.04 (0.73)	5.76 (0.54)	1.27
NVIQ[a] Raw Score (*SD*)	31.25 (9.66)	29.55 (7.33)	0.60
Standardized NVIQ (*SD*)	106.75 (12.34)	107.68 (9.14)	−0.26
PPVT (*SD*)	97.63 (15.60)	107.45 (22.93)	−1.46
VMA[b] (*SD*)	7.13 (0.62)	7.75 (1.25)	−1.96
AQ (*SD*)	84.19 (11.79)	47.45 (13.18)	8.71***
SRS (*SD*)	82.13 (13.79)	36.00 (20.16)	7.80***

[a] NVIQ was measured by the Combined Raven Test (CRT-C2).

[b] VMA was measured by the Chinese version of the Peabody Picture Vocabulary Test-Revised (PPVT-R).

$^{***}P < 0.001$.

Material

We used a set of 75 frontal-view grey-scale images of Chinese female faces with neutral facial expressions in the experiment. We chose single-sex faces in order to eliminate the effect of the face gender on children's performance. Female faces were selected since children are known to be more familiar with female adult faces than male faces [Hu, Wang, Fu, Quinn, & Lee, 2014; Quinn, Yahr, Kuhn, Slater, & Pascalis, 2002]. The image set included 57 open-eye faces and 18 closed-eye faces.[1] All faces were normalized to a standard face template such that their core facial features (eyes, noses, and mouths) were located at approximately the same locations on the images. The faces were also overlaid with an ellipse-shaped window that masked the hair and ears (Fig. 1). Three open-eye faces were selected as the stimuli and randomly assigned to the three conditions (win, lose, and neutral) in the reward learning task. These three target faces were matched on attractiveness (3.53 in a 7-point rating scale) based on attractiveness ratings by 45 adults in a pilot study. A set of 21 open-eye faces were used as foil faces in the face recognition task. Besides the three faces to be learned, the remaining 54 open-eye faces were used in the visual search task, and each face appeared no more than twice. The

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[1] 10.22° × 14.27° in the reward learning task, 6.58° × 9.54° in the face selection task, 13.60° × 18.05° in the face recognition task, and 6.62° × 9.54° in the visual search task.

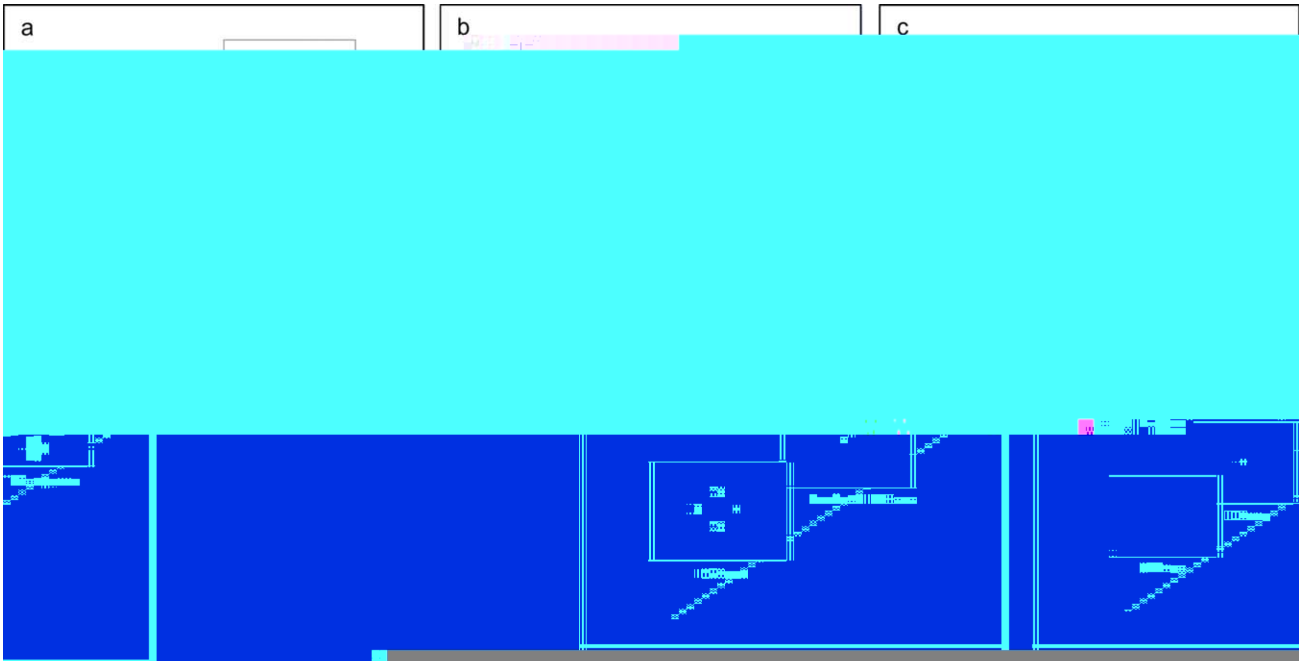

Figure 1. A schematic illustration of the stimuli and procedure in (**A**) the reward learning task, (**B**) the face selection task, (**C**) the face recognition task, (**D**) the practice visual search task, and (**E**) the visual search task.

18 closed-eye faces served as the targets in the visual search task.

Procedure

Children were tested in a quiet room where they were seated in front of a 15-inch touch-screen external monitor at a viewing distance of approximately 50 cm. All stimuli were presented with Psychotoolbox [Brainard, 1997; Pelli, 1997] in the Matlab programming environment (The MathWorks, Natick, MA). All children were required to complete the reward learning task, and the face recognition task and the visual search task if they had passed the face selection task that examined the outcome of the reward learning.

Reward learning. At the beginning of the reward learning task, children were asked to choose their favorite reward type out of five types of candies and stickers, and they were then initially assigned three pieces of the chosen rewards. We began each trial with a display of three turned-over cards on the screen and asked children to choose one card. After children made the choice, the card flipped over on the computer screen and one face (randomly chosen from the three target faces) appeared as the back of the card (Fig. 1A). When the win-face was presented, the children were told that the woman shown on the screen would give them a reward, and then a real reward was given to the children by the experimenter. When the lose-face was presented, the children were told that the woman on the computer screen would take a reward away from them, and a reward was then taken away from the children accordingly. When the neutral-face was presented, the children were told that the woman would do nothing to their rewards. There were 12 blocks, each of which consisted of three target pictures. The three target faces were randomly presented in each block. Thus, each face picture was presented for 12 times totally. The children received the reward for each positive trial and lost the prize for each negative one.

After the reward learning task, a face selection task was performed to determine whether the children had successfully learned the reward associations of the three faces. Children were randomly shown a pair of faces randomly selected from the three learned faces, and then they were asked to choose one face that would allow them to gain or avoid losing more rewards (Fig. 1B). After the children made their choice, the experimenter took an action according to their choices of the faces (i.e., giving a reward to the children, taking a reward away from the children, or doing nothing with the rewards). Children were considered as having learned the face-reward associations if they succeeded in choosing the face that would lead to a better outcome in at least 9 out of 12 trials in the face selection task. Children who failed to pass the face selection task were excluded from the study.

Face recognition. Children who passed the reward learning task proceeded with a face recognition task to test their memory of the three faces. In this task, children were shown faces one by one on the screen, and asked to identify whether the face was one of the three target faces they had seen in the reward learning task or a new face they had never seen before. A practice of face recognition was performed prior to the formal test. Each trial began with a 1,000 msec central fixation cross and then the recognition display presented until the children responded. Children received on-screen feedback (correct or incorrect) after each trial in the practice (as shown in Fig. 1C). The practice consisted of two blocks, each of which comprised 6 trials (1 win-face, 1 neutral-face, 1 lose-face, and 3 foil faces, in a random order). The formal test consisted of five blocks (each contained 6 trials as in the practice, 30 trials totally), and no feedback was provided after each trial.

Visual search. After the face recognition task and before the visual search task of faces, a 32-trial practice of visual search was performed to familiarize the children with the task and the touch-screen response (Fig. 1D). The practice was adopted and simplified from the paradigm used in Gliga, Bedford, Charman, Johnson, & The BASIS Team, 2015], in which children were instructed to search for a unique letter from a set of four letters. Children were asked to identify the target by touching its corresponding location on the monitor screen as fast as possible. Following the practice trials, children participated in the visual search task of faces (Fig. 1E). Each trial began with a 1,000 msec blank screen that was followed by a central fixation cross for 100 msec before the onset of the search display. The search display consisted of a closed-eye face (the target) and three open-eye faces (the distractors), which were presented until the children responded. The children were instructed to find a "sleeping person" (i.e., the closed-eye face) by touching the screen as fast as possible. Children were asked to put their hand back to the initial location after they made each response to prepare for the next trial. The first six trials served as warm up trials to get children familiar with the new visual search task (searching for a closed-eye faces among open-eye faces). In these warm-up trials, the experimenter taught and reminded children to look for the sleeping person, to respond as soon as possible, and to put the hand back to the initial location; in the remaining trials, experimenter did not remind them anymore. In each trial, one of the three open-eye faces was randomly selected from the three reward-associated faces (the win-face, the lose-face, and the neutral-face). The locations of the four faces were randomly assigned in each trial. The visual search task of faces comprised three blocks, each of which consisted of 18 trials (6 trials with the win-face distractor, 6 trials with the loss-face distractor, and 6 trials with the neutral-face distractor, in a random order). The first six warm-up trials were excluded from the final data analysis.

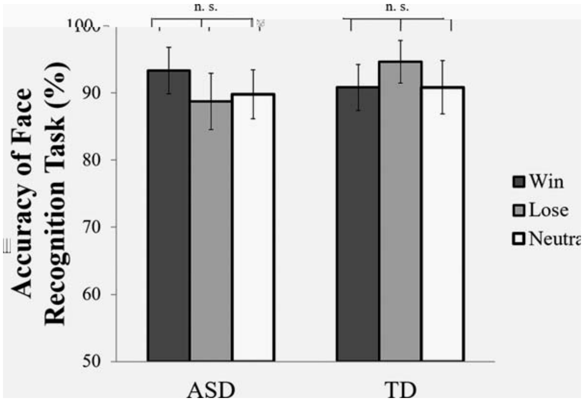

Figure 2. Mean accuracy of the win, lose, and neutral conditions in the face recognition task for each group. Error bars represent standard errors.

Results

Reward Learning

In the reward learning task, all TD children and 80% children with ASD passed and were considered successfully learned the face–reward associations. To further examine whether there was a group difference in reward learning, we computed two indices and compared them between groups: the *pass rate per trial*, defined as the percentage of children responding correctly in each trial, and the *accuracy*, defined as the percentage of correct trials per child. The results of the Mann–Whitney U tests indicated that TD group had a significantly higher pass rate compared to the ASD group (TD, $M = 0.96$, $SD = 0.05$; ASD, $M = 0.85$, $SD = 0.13$; $U = 19.50$, $W = 97.50$, $P = 0.001$). The accuracy of the TD group was also significantly higher than the ASD group (TD, $M = 0.96$, $SD = 0.05$; ASD, $M = 0.85$, $SD = 0.14$; $U = 106.00$, $W = 296.00$, $P = 0.02$). In summary, children with ASD learned the reward associations less efficiently than TD children.

Face Recognition

In the face recognition task, both groups of children reached high accuracies in recognizing the faces. A repeated measures Group (ASD and TD) × Reward (win-face, lose-face, and neutral-face) ANOVA on accuracy showed no significant effect of reward type ($F(2, 68) = 0.15$, $P = 0.86$, $\eta^2 = 0.00$, 95% CI [0.00, 0.05]), no significant effect of group ($F(1, 34) = 0.19$, $P = 0.67$, $\eta^2 = 0.01$, 95% CI [0.00, 0.13]), and no Group × Reward interaction ($F(2, 68) = 0.77$, $P = 0.47$, $\eta^2 = 0.02$, 95% CI [0.00, 0.11], see Fig. 2). Both groups of children distinguished learned faces and foil faces well after the learning phase, and there was no difference for recognition among the three learned faces.

Visual Search

For the visual search task, we excluded the first 6 warm-up trials from the data analysis for all children, as the responses were inconsistent due to their lack of familiarity with the face visual search task at the beginning. For the remaining trials, both groups of children reached high search accuracies in searching the target faces (ASD: 97.78%; TD: 98.96%). A repeated measures Group (ASD and TD) × Reward (win-face, lose-face, and neutral-face) ANOVA on accuracy showed no significant effect of reward type ($F(2, 68) = 0.20$, $P = 0.82$, $\eta^2 = 0.01$, 95% CI [0.00, 0.06]), no significant effect of group ($F(1, 34) = 3.16$, $P = 0.08$, $\eta^2 = 0.09$, 95% CI [0.00, 0.28]), and no Group × Reward interaction ($F(2, 68) = 0.32$, $P = 0.73$, $\eta^2 = 0.01$, 95% CI [0.00, 0.07]). For the analysis of visual search RT, the incorrect trials (1.39% of all trials) and the outliers beyond three *SD*s for each participant (0.93% of all trials) were excluded. A repeated measures Group (ASD and TD) × Reward (win-face, lose-face, and neutral-face) ANOVA revealed a significant main effect of reward type ($F(2, 68) = 4.94$, $P = 0.01$, $\eta^2 = 0.13$, 95% CI [0.01, 0.26]). Nonetheless, neither the main effect of group ($F(1, 34) = 1.79$, $P = 0.19$, $\eta^2 = 0.05$, 95% CI [0.00, 0.23]), nor the Group × Reward interaction was found ($F(2, 68) = 0.33$, $P = 0.72$, $\eta^2 = 0.01$, 95% CI [0.00, 0.07]). The planned contrasts between reward conditions showed that both groups of children responded significantly faster with the win-face or the lose-face as a distractor compared to the neutral-face as a distractor ($P = 0.02$, Cohen's $d = 0.59$, $P = 0.01$, Cohen's $d = 0.69$, respectively, Fig. 3). No significant difference was found between the win-face and lose-face conditions ($P = 0.63$, Cohen's $d = 0.10$).

To further evaluate the relative strength of the evidence for the null hypothesis (H0) and the alternative hypothesis (H1) of the RT analysis, we conducted additional analyses based on a Bayesian model selection approach, which calculated the Bayes Factor (BF) and the corresponding posterior probabilities for H0 and H1 [Masson, 2011; Raftery, 1995; Wagenmakers, 2007]. The results provided positive evidence in favor of H0 over H1 for the group effect ($BF = 2.38$, P

the ASD and TD groups. More specifically, both groups of children could distinguish learned faces and foil faces well and there was no difference among faces embedded with different associated values. However, children with and without ASD responded faster in the visual search task with a reward-associated face (win-face or lose-face) as a distractor than with a neutral face as a distractor.

In the visual search task, the children searched for a closed-eye face among three open-eye faces. Previous literature has suggested that visual search of faces is based on a serial feature-based search mode without a pop-out effect [Hershler & Hochstein, 2005; Nothdurft, 1993]. Under such a serial search mode, the attentional window is narrowed to focus on individual search items, making the attentional capture by salient items unlikely to happen [Theeuwes, 2004]. Furthermore, it has been shown that salient distractors can be effectively suppressed under the serial search mode, which leads to a more efficient visual search under conditions of physical salience or reward salience as distractors compared with conditions of neutral distractors [Gaspelin, Leonard, & Luck, 2015; Gong, Yang, & Li, 2016]. Our results were consistent with these previous findings and demonstrated similar effects in both the ASD and TD groups by showing faster RT in trials with a reward-associated face serving as the distractor. This facilitative effect on the visual search could be accounted for by two possible mechanistic interpretations. First, based on the signal-suppression hypothesis [Sawaki & Luck, 2010], the salient distractor first captures one's attention, but this salient signal can be subsequently suppressed, which leads to a faster disengagement to the next search item [Geng & DiQuattro, 2010]. This mechanism is generally indexed by a Pd component in recorded electroencephalogram (EEG) signals [Sawaki & Luck, 2010]. In our study, children's attention was captured by the salient face distractors that were associated with positive or negative values in the reward learning task, resulting in a faster disengagement and thus faster search time. Second, according to a previous finding [O'Brien & Raymond, 2012], the predictiveness of the winning or loss of a reward could accelerate the processing of the face, which could then also result in a faster response time. When the reward-associated faces served as the distractor face in our study, they may trigger children's learned predictiveness of the reward or punishment and accelerate the search time. The signal-suppression hypothesis and the acceleration from predictiveness hypothesis are not mutually exclusive: both hypotheses may account for the observed effects in the current study to certain degree. However, the exact contributions of each account are difficult to determine based on the current experimental design and beyond the scope of the present study. Future investigation with EEG recording is needed to address this issue. Nevertheless, in either case, our results suggested that when task-related factors (i.e., not being a search target) were controlled, reward associations enhanced the attentional processing of faces with positive and negative associated values and facilitated the behavioral performance of visual searches in both the ASD and TD groups.

Previous studies suggested impaired learning of social reward and its connection with the deficits in joint attention and social communication with ASD children [Dawson et al., 2002; Munson et al., 2008]. However, previous literature rarely discussed the impact of reward learning on the visual attention to social stimuli in ASD, particularly, whether their visual attention to faces, which are considered as important social stimuli due to their critical role in social interaction, would be modulated by enhanced social motivation. In the present study, we associated different social meanings to the faces with simulated social interaction in the reward learning task and therefore reinforced the social attributes of the faces in the subsequent visual search task. Orientating to social stimuli (e.g., faces) develops in early infancy and plays an important role in subsequent social development. According to the social motivation theory [Chevallier et al., 2012], the social motivation deficits (perceptual/attentional level) in ASD precede social cognition deficits (behavioral level). The early-onset of disrupted social attention in children with ASD deprives them of adequate social learning experience, and results in subsequent deficits in social interactions. Reward learning approaches have been used in the intervention for ASD to improve their behavioral performance (e.g., eye contact, social interaction). Our findings indicated that learning to associate faces with positive or negative values could modulate the visual attention towards faces in both ASD and TD groups. Furthermore, these findings serve as the first direct evidence for the perceptual-level modulatory effect of reward learning for faces embedded with social associated values in the ASD population. This perceptual-level modulatory effect is less susceptible to interference from higher-level factors such as the type of incentive feedback and the experimenter's instructions, and hence, points to the potential of reinforcement-based training of ASD children on their automatic social orientation to faces.

Superior visual search performance in individuals with ASD has been found in previous studies, which mainly used the search tasks based on simple features such as color and shape [e.g., Gliga et al., 2015; Kaldy, Kraper, Carter, & Blaser, 2011]. Few studies have directly compared children with ASD with typical children in the visual search performance based on face stimuli. Visual search of objects depends critically on the processing strategy of the searching items. It is well known that processing of faces is mostly holistic [e.g., Falkmer, Larsson, Bjällmark, & Falkmer, 2010; Jemel, Mottron, & Dawson, 2006; Maurer, Le Grand, & Mondloch, 2002], while local details are important for the recognition of simple visual features [e.g., Poiese, Spalek, & Di Lollo, 2008; Van Eylen, Boets, Steyaert, Wagemans, & Noens, 2015]. Therefore, the detailed-focused cognitive style in ASD [Dakin & Frith, 2005; Frith, 1989; Simmons et al., 2009] may facilitate their visual search for simple features, but less likely for the visual search for faces. The degree of allocated attention to the holistic configuration of faces is a key factor that determines the efficiency of the visual search performance of faces. In our study, we observed similar face searching efficiency in ASD relative to TD children, which is likely due to the enhanced attention towards the value-associated faces in ASD children.

One of the issues that emerged from these findings was that our face recognition task did not find any impact of the face–reward association on children's memory of the three faces—both groups have almost reached the ceiling for all three types of faces. This lack of effect of the face type is probably due to the low task demand of our face memory task: children needed to memorize only three faces and each of them had been learned for 12 times. With higher task demand, children may show enhanced memory of the faces with positive and negative associated values, which could be further examined in future investigations. It is also possible that our visual search task (i.e., to look for a closed-eye face among open-eye faces) could induce children to pay attention to the eyes and ignore other parts of faces. However, we assume that face processing is such a holistic process that even when you are looking for a closed-eye face, the other part of the faces could not be ignored. For instance, in the Face Composite Task, which presents two faces with the same top half face and different bottom half face, people found it difficult to selectively attend to only the cued top half of the face due to holistic interference caused by the to-be-ignored bottom half [Young, Hellawell, & Hay, 1987]. This assumption could be tested in future eye-tracking studies, which measures children's visual attention in our visual search tasks. Eye tracking could also be used in the future investigations to examine how the learning of the face–reward associations could modulate children's face processing patterns. Future studies could also use different visual search tasks (looking for the faces based on other characteristics) and examine the generalizability of our conclusions. Moreover, the absence of a strong and reliable confirmation of the ASD diagnosis, such as the ADOS or ADI-R, was another limitation of the current study. Due to limited access to these two diagnostic scales in China, we used the Chinese version of the AQ and SRS scales to compensate. Future studies should use more reliable measurJ0-1. wast86.6(a)0(n)19.53.52.4(s)0(u)18.4(r)13.3(CLS)15.9(Dc)18.97.4(gn)

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Supporting Information

Additional Supporting Information may be found in the online version of this article at the publisher's website.

Figure A. Mean response time of the win, lose, and neutral conditions in the visual search task for each group in our unpublished dataset. Error bars represent standard errors. Asterisks indicate the significant differences in response times between conditions (**$p < 0.01$, *$p < 0.05$).

Figure B. Samples of stimuli used in the Face Composite task. A composite face is created by the joining the top half of one face with the bottom half or another face. In the example, participants would be asked to judge whether the top halves of the faces are the same or different when the composite faces are either a aligned or b misaligned (from Tanaka & Sung, 2013).

Figure C. Samples of stimuli used in the "looking for a male face among female faces" visual search task. (both the left and the right faces have been identified as male faces on the left picture, and both the top and the bottom faces have been identified as male faces on the right picture)

Figure D. The heterogeneity of visual search RT in the first 2 trials and the remaining trials.

Table A. Comparisons of the means when the first 6 trials excluded vs. all trials included vs. the first 2 trials excluded in the current study.

Table B. Comparisons of the means when the first 6 trials excluded vs. all trials included vs. the first 2 trials excluded in our unpublished dataset.