Can the reward associated with gaze leading train faster gaze shifts to a jointly attended target?

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Running head: Can the reward associated with

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Can the reward associated with

Abstract

We investigated whether the reward that has previously been associated with initiated joint attention (the experience of having one's gaze followed by someone else; Pfeiffer et al., 2014, Schilbach et al., 2010) can influence gaze behaviour and, similarly to monetary rewards (Blaukopf & DiGirolamo, 2005; Manohar et al., 2017; Milstein & Dorris, 2007), elicit learning effects. To this end we adapted Milstein and Dorris (2007) gaze contingent paradigm, so it required participants to look at an anthropomorphic avatar and then conduct a saccade towards the left or right peripheral target. If participants were fast enough, they could experience social reward in terms of the avatar looking at the same target as they did and thus engaging with them in joint attention. One side had higher reward probability than the other (80 % vs 20 %; on the other fast trials the avatar would simply keep staring ahead). We expected that if participants learned about the reward contingency and if they found the experience of having their gaze followed rewarding, their latency and success rate would improve for saccades to the high rewarded targets. Although our current study did not demonstrate that such social reward has a long lasting effect on gaze behaviour, we found that latencies became shorter over time and that latencies were longer on congruent trials (target location was identical to previous trial) than on noncongruent trials (target location different than on previous trial), which could reflect inhibition of return.

In everyday life, human behaviour is to a large extent driven by the pursuit of pleasurable rather than unpleasurable experiences, which has been extensively studied through reinforcement learning paradigms (e.g., De Houwer & Beckers, 2002; Sescousse et al., 2013). Such reward-based learning has been evidenced using various rewards (e.g. food, money, smiley faces) and shown to activate similar interconnected brain areas, known as the brain reward system (for review see Sescousse et al., 2013). The brain reward system stores representations of the reward and predicts future rewards, which in turn informs action selection (for reviews see Daniel & Pollmann, 2014; O'Doherty et al., 2017). Importantly, this brain reward system is also activated in a social situation where at least two people look at the same entity in the environment, known as joint attention, indicating a hedonistic value of this form of social interaction which also implies its role as a social reward (Gordon et al., 2013; Pfeiffer et al., 2014; Schilbach et al., 2010). Crucially for the current study, the activation in the brain reward system is usually greater when one looks to the object first (initiated joint attention) rather than when one follows the other's gaze (responding joint attention; Gordon et al., 2013; Oberwelland et al., 2016; Schilbach et al., 2010). Whereas it has been demonstrated that monetary rewards can influence oculomotor behaviour such as saccade latency and velocity, (Chen et al., 2014; Clark & Gilchrist, 2018; Manohar et al., 2017; Milstein & Dorris, 2007), it is not known whether the reward associated with initiated joint attention can produce similar behavioural effects. If so, this might point towards how social interaction provides its own proximal reward in reactions of others, which in turn modifies our own behaviour. The current study adapted Milstein and Dorris' (2007) saccade reward paradigm to investigate whether initiated joint attention can have a long-lasting effect on gaze behaviour (Schilbach et al., 2013).

Can the reward associated with

The brain's reward system in a social context

It has been demonstrated that various social (e.g. smiley faces) and non-social rewards (e.g. money) activate similar interconnected brain areas (i.e. the brain reward system) including the amygdala, ventral striatum, medial prefrontal cortex, which are responsible for processes such as reward processing, attention and memory (Garrison et al., 2013; Izuma et al., 2008; Lin et al., 2012; Schultz, 2006). In particular, reward processing involves storing representations of the reward and predicting future rewards that allows choosing action that yields most desired reward (Daniel & Pollmann, 2014; O'Doherty et al., 2017). For example, the ventral striatum is responsible for the reward prediction error that allows to compare the expected reward and the received reward (Berridge & Robinson, 2003; Berridge et al., 2009) while the amygdala allows predicting negative outcomes of actions (Ernst et al., 2005). Similarities in brain activation during processing of various rewards indicate an existence of "common reward currency" that allows comparing different rewards (Izuma et al., 2008; for review see O'Doherty et al., 2017).

Recruitment of similar brain areas for different reward types does not mean these rewards elicit the same degree of activation. A meta-analysis by Sescousse et al. (2013), which compared reward paradigms that used monetary rewards, erotic stimuli or food, indicated that the striatum activation was highest during processing of monetary rewards. They argued that these discrepancies in reward processing could be explained by methodological differences between paradigms. Monetary rewards are often used in probabilistic tasks with reward being contingent on behaviour while experiments using food or erotic rewards often employ passive paradigms with entirely predictable rewards. An alternative explanation for the discrepancy in reward processing was offered by Daniel and Pollman (2014) who argued that food and

Can the reward associated with

erotic stimuli could have been associated with less striatal activation because human beings, contrary to animals, are not usually deprived of food or sex before the experiment, and even if they were they would probably be able to meet their needs after the study. Nevertheless, using similar paradigms for different rewards might at least to some extent allow for a better understanding of their neural processing and impact on behaviour (Schilbach et al., 2013).

Spreckelmeyer et al., (2009) demonstrated that it is possible to adapt monetary reward paradigms to study social rewards, and that social rewards can influence behaviour and neural processing. To this end, they adapted the monetary incentive delay (MID) task that has been extensively studied over the last 20 years to investigate the impact of monetary rewards and punishments (for a review see Lutz & Widmer, 2014; Oldham et al., 2018). The MID task is an adapted version of classical conditioning tasks, whereby participants learn to associate the reward cue with the reward that they could receive, provided that they are quick enough (Lutz & Widmer, 2014). In a basic version of this paradigm, participants are presented with a reward cue (low, medium, high, no reward) that indicates the magnitude of reward which they could receive on each trial providing that they are fast enough. Next, participants see a target and their task is to press a single key as fast as possible. If they are quicker than the threshold, they get the monetary reward predicted by the cue, otherwise they get nothing. In these studies, it is usually found that reaction times are quickest, and the activation of the brain reward is highest after seeing high reward cue.

Spreckelmeyer et al., (2009) adapted the MID task to study the effects of social approval (i.e. social reward). In their experiment, participants completed a standard MID task in which the monetary reward was operationalised by showing a

Can the reward associated with

picture with a wallet with one, two, three or no coins representing respectively low, medium, high and no reward. In addition, participants completed the social incentive delay task (SID) which was similar to the MID task but could yield social reward in the form of a picture with a happy expression that was smiling with closed mouth, smiling with open mouth or smiling with very wide mouth, or a blurred face, which respectively represented low, medium, high or no reward. They found that both monetary and social reward activated the brain reward system and that this activation increased with the increase in the reward level. In addition, they observed that overall reaction times were faster in the MID than in the SID and that reaction times were faster towards high than no reward in both types of tasks. Such a “common neural currency” for social and monetary rewards has repeatedly been established (Gu et al., 2019; Izuma et al., 2008; Rademacher et al., 2010; see Matyjek et al., 2020, for a general comparison).

Joint attention as social reward

Most, if not all, of the social rewards used in the aforementioned studies (see Matyjek et al., 2020) typically use social reward that has a previously established intrinsic positive social value, such as a smile, a Facebook “like”, a good reputation, etc. However, few studies have looked at whether the mere experience of seeing someone react to your own behaviour, carries such a social reward. One of the most fundamental building blocks of social interaction is the ability to coordinate attention to the same entity in the environment by using gaze, pointing, head movements and other actions, which is called joint attention or triadic social interaction (for review see Mundy, 2018), something we can do irrespective of the intrinsic value of the other or the entity looked at. In that respect, joint attention allows two or more agents to establish “perceptual common ground” that might enable them to understand the

Can the reward associated with

other's intentions and thoughts about the object of attention and predict the other's behaviour (Edwards et al., 2015). For example, imagine that you are visiting a friend who gave you a piece of cake which you have already eaten. There is an empty plate in front of you and you would like to somehow signal to your friend that you would like another piece of cake without interrupting the conversation. You could achieve this by looking at your friend until they look at you and then by looking at the empty plate and then again at your friend. In particular, using gaze to establish joint attention has been suggested to play a crucial role in development of socio-cognitive skills such as language and theory of mind (Baron-Cohen, 1991; Brooks & Melzoff, 2005; Dawson et al., 1998; Emery, 2000; Nelson et al., 2007; Tomasello et al., 2005).

In experimental settings, joint attention is often operationalised by looking at the other's eyes to establish mutual gaze, then one person looks towards an object of interest (known as gaze leading or initiating joint attention, i.e. IJA); after which the other looks towards the same entity (known as gaze following or responding joint attention i.e. RJA) (Mundy & Newell, 2007). Responding joint attention has been extensively studied using in gaze following paradigms that adapt the Posner's (1980) gaze cuing task in which reaction times are faster towards the target that was earlier looked at by a face than in the opposite direction (Lachat et al., 2012; for review see Frischen et al., 2007). By contrast, initiated joint attention, which is the focus of the our study, has started being investigated in experimental settings only relatively recently through gaze-leading paradigms in which participants interact with a photograph, a video recording or a virtual avatar that is responsive to their gaze and whose eyes movements might reflect a real person's behaviour (Bayliss et al., 2013; Gordon et al., 2013; Schilbach et al., 2010; for review see Caruana et al. 2017).

Can the reward associated with

Neuroimaging studies of joint attention that investigated similarities and differences underlying processing of initiated and responding joint attention demonstrated that broadly speaking joint attention activates various brain networks: social-cognitive (including mentalising), attentional and reward processing (for review see Redcay & Schilbach, 2019). In relation to the current experiment, the fundamental finding of those studies is that activation in the brain reward system, in particular the striatum, is usually associated with initiated rather than responding joint attention (Gordon et al., 2013; Oberwelland et al., 2016; Schilbach et al., 2010). The striatum is linked with hedonistic and motivational experience of rewards (Liu et al., 2007, Rolls et al., 2008), and the striatal activation during initiated joint attention suggests that having one's gaze followed and thus directing other's attention to the same object constitutes a form of a social reward (Bayliss et al., 2013; Edwards et al., 2015; Schilbach et al., 2013).

For example, Schilbach et al. (2010), using a gaze-contingent paradigm, found that initiated joint attention was more strongly associated with activation in the ventral striatum than responding joint attention. Their participants interacted with an avatar, which they believed was controlled by another person. During gaze leading trials, participants' task was to direct the other's attention to one of three objects by looking at it. Subsequently, the avatar would follow the participant's gaze (initiated joint attention) or would look at a different object (non-joint attention). During gaze following trials, participants were instructed to respond to the other by either following their gaze to the object (responding joint attention) or by looking at a different object (non joint attention). The authors suggested that activation in the striatum during initiated joint attention might be due to participants succeeding in directing the attention of the autonomous other to an object. Schilbach et al. also

Can the reward associated with

stated that the striatal activation could indicate that human beings like to exert control over others.

Using a similar paradigm, Pfeiffer et al. (2014) found that initiated joint attention with a virtual avatar recruited the ventral striatum provided that participants believed that they interacted with another human but not when they thought that they interacted with a computer. These findings indicate that activation in the striatum might be linked to interactions with humans only. However, Gordon et al. (2013) found the striatal activation during initiated joint attention even if participants knew that they did not interact with another human being. In their study, participants completed a gaze leading task during which they were required to direct Sally's gaze to one of two peripheral avatars. Sally was a pre-recorded video of a person that would either follow participant's gaze to the avatar they looked at (initiated joint attention, congruent trials) or would look in the opposite direction (non joint attention, incongruent trials). The results demonstrated higher activation during initiated joint attention trials in social, reward and attention networks compared to non joint attention trials. To sum up, initiated joint attention is linked with the activation in the brain reward system, in particular striatum, suggesting the rewarding nature of initiated joint attention and its role as a social reinforcer (Gordon et al., 2013; Pfeiffer et al., 2014; Schilbach et al., 2010). However, to our knowledge, the influence of gaze as a social reinforcer on behaviour has not been investigated experimentally yet. Since there is a reward associated with it, it must logically follow that there is a behaviour that is modified by this reward.

Impact of reward on eye movements

The most proximal candidate for sensitivity to reward associated with gaze behaviour, is gaze behaviour itself: if my looking somewhere is rewarded, I could

Can the reward associated with

reasonably be expected to look there more often, faster, more accurately, which in turn may have evolutionary benefit in the sense that I will be becoming better at communicating attention to an object, intentions, etc, to a conspecific who reacts to my gaze. Indeed, oculomotor behaviour is known to be influenced by rewards (for review see Wolf & Lappe, 2021), and hence seems to be the obvious candidate for exploring the potential impact of initiated joint attention on behaviour. In particular, a lot of interest has been diverted towards studying saccades which are fast eye movements that allow reorientation of the fovea, a very small part of the visual system that facilitates accurate vision (Stewart et al., 2020). Investigations into the saccade system, a “microcosm of the brain” (Carpenter, 1981) allowed to advance knowledge about various cognitive processes such as learning and reward processing (Wolf and Lappe, 2021). Saccadic responses (rapid gaze shifts, either reflexive in response to a change in the environment or more intentional) are known to be influenced by bottom-up processes such as stimuli luminance but also by top-down processes such as monetary rewards (Blaukopf & DiGirolamo, 2005; Blaukopf & DiGirolamo, 2006; Chen et al., 2014; Clark & Gilchrist, 2018; Manohar et al., 2017; Milstein & Dorris, 2007).

Wolf and Lappe (2020), in an overview of how reward influences saccadic eye movements, distinguish between three ways in which a saccade can be rewarded: first, the stimulus towards which the saccade is executed can be intrinsically rewarding (pleasant; Collins, 2012; Sedaghat-Nejad et al., 2019; cf Wolf & Lappe, 2020); second, the target can be perceptually relevant (reducing visual uncertainty; Bray & Carpenter, 2015; Wolf & Schütz, 2017; cf Wolf & Lappe, 2020); and finally, there can be a prospect of reward following the saccade (Chen et al., 2014; Clark & Gilchrist, 2018; Milstein & Dorris, 2007; cf Wolf & Lappe, 2020). Collins (2012)

Can the reward associated with

argues that for sensory-motor systems the intrinsic reward that lies in perceptual relevance is probably more important. Furthermore, Collins points out that reward as outcome can both be explicit (such as money), or more implicit (such as the target remaining visible for longer, or any other action consequence that is not immediately apparent), and in fact such implicit reward can have more extreme effects than explicit reward (Clark & Gilchrist, 2018). The way in which these rewards influence saccades can be diverse. Wolf and Lappe (2020) list a number of aspects of oculomotor behaviour that can be influenced by reward, notably saccade latency (the time it takes to initiate the saccade after the target onset), saccade kinematics such saccade amplitude (saccade distance in terms of visual angles), which in turn determines factors such as peak velocity and saccade duration, and finally saccade accuracy.

The current study focuses on reward as a consequence of an oculomotor response, as the goal is to investigate how a conspecific's (gaze) reaction to my own (gaze) behaviour, influences the latter, independent of the intrinsic value of the stimulus or the informational gain associated with a gaze shift. In this context, crucial to the current study, is a study by Milstein and Dorris (2007). They demonstrated that gaze behaviour is influenced by experience of different reward contingencies. In their lengthy study that took at least 5 days to complete, participants were required on the majority of trials to conduct quick saccades towards a single left or right peripheral target that would result in a monetary reward providing those saccades were faster than a threshold. Importantly, reward magnitude, target probability and expected value were manipulated across 15 blocks. They found that saccadic latency was negatively correlated with reward magnitude, target probability, and reward expected

Can the reward associated with

value. In other words, saccades were initiated quicker towards targets associated with higher reward magnitude, target probability, and expected value.

The current study

Considering that studying initiated joint attention is a relatively new area of research, it seems that more research needs to be done to better understand the conditions under which initiated joint attention recruits the brain reward system and behaviour (Caruana et al., 2017, Schilbach et al., 2010). The current study aims to address this gap by investigating if the supposedly rewarding nature of initiated joint attention has, besides neurobiological correlates (Caurana et al., 2017; Gordon et al. 2013; Schilbach et al., 2010), a long-term behavioural modification usually associated with such reward (reward-based learning). Specifically, we ask whether such reward can influence faster gaze orientation towards the target to which participants gaze is followed more often by an anthropomorphic avatar. To this end, we adapted Milstein and Dorris' (2007) eye tracking study which investigated if human saccades could be influenced by monetary rewards. They found that high value peripheral targets resulted in shorter latencies than low value targets, which indicates that human eye movements can be influenced by rewards. In the current study, after looking at the centrally located anthropomorphic avatar, participants were asked to look as quickly as possible to a peripheral right or left target. During the training blocks, if on a given trial a participant's saccade towards the target were fast enough, they could receive social reward in terms of the avatar following their gaze towards the target, which resulted in the initiated joint attention. Importantly, the probability of this reward was different for each side (the value of the reward on one trial cannot be modified, as gaze following is binary). On one side the reward probability was 80% (high) whilst on the other it was 20% (low). The avatar was used

Can the reward associated with

because virtual avatars have good ecological validity but also allow for experimental control over characteristics such as gender or attractiveness that might influence the neural activation and behaviour (Wilms et al., 2010; Pfeiffer et al., 2012; Pfeiffer, Vogeley & Schilbach, 2013). We expected that if participants learned about the reward contingency and if they found the experience of having their gaze followed as rewarding, their latency and success rate would improve over time for saccades to the high reward side, to a larger degree than towards the low reward targets.

Method

Participants and Apparatus

Sixty participants who had normal or corrected to normal vision took part in the experiment. However, the data of fifteen participants were excluded from the analysis due to withdraw ($n = 2$), technical issues ($n = 10$) or a mistake ($n = 3$). The remaining forty five participants (11 males) were aged 17 to 29 ($M = 20.44$, $SD = 2.23$). Participants were selected through opportunity sampling mostly from the students community using the SONA Systems Research Management System and word of mouth. Participants recruited through SONA received three course credits for participation in the study. All participants provided signed written informed consent before conducting experimental tasks. The study was approved by the Psychology Ethics Committee of the University of Aberdeen and the researchers adhered to British Psychology Society guidelines.

The experiment was built in Vizard 4.1 Development Edition (WorldViz, Santa Barbara, California, USA), a Python-based virtual environment program, run in Windows 7 on a personal computer. The stimuli were displayed on 23.6-inch Asus HDMI monitor with a screen resolution 1920 x 1080 pixels (41.3 x 23.9 visual angles)

Can the reward associated with

and refresh rate of 144 Hz situated approximately 71 cm in front of participants whose heads were stabilised by a headrest. Participants' eye movements were recorded monocularly (left eye) using an Eyelink 1000 Desktop Mount eye tracker (SR Research Ltd., Ottawa, Ontario, Canada; sampling rate: 1000 Hz monocular accuracy: 0.25°–0.5°; resolution: 0.01°RMS (root mean square)). Thirteen point calibration and validation were used at the start of each block to ensure that the eye tracker recorded the correct gaze position in relation to the stimuli displayed on the screen. Drift correction between trials was not incorporated in this experiment due to technical issues.

Stimuli.

The central stimulus was a female anthropomorphic avatar (width = 360 pixels » 8.1 visual angles, height = 590 pixels » 12.2 visual angles) developed in FaceGen (Singular Inversions, Toronto, Ontario, Canada) displayed on the black background. The target was a small yellow ball (17 pixels diameter yielding 0.4 visual angles), which was randomly displayed on the right or the left side of the avatar (see Figure 1).

Figure 1 Experimental stimuli. Panel A shows the experimental stimuli as were displayed on the screen. Panel B shows the zoomed experimental stimuli.

Questionnaires. After finishing the experimental tasks, participants were asked to complete three computer questionnaires built in PsychoPy (v1.85.3; Pierce

Can the reward associated with

et al., 2019) in the following order: the Autism Quotient (Baron-Cohen et al., 2001), the High Sensitive Person Scale (HSPS; Aron & Aron, 1997), and the Empathy Quotient (Baron-Cohen & Wheelwright, 2004). The scores from those questionnaires were not included in the current analysis.

Design & Procedure

The experiment employed a 2 x 8 design with two within-subject factors being reward probability (high or low) and block (0 to 7). The dependent variables were success rate and latency. Success rate refers to the proportion of trials during which saccades to the target were conducted within 400 ms of target onset but were not initiated earlier than 70 ms after the target onset. Latency refers to the time required for initiation of the saccade after the target onset.

Participants were provided with verbal and written instructions before starting the experiment. They were asked to complete eight experimental blocks that consisted of 80 trials each, which required them to fixate on the avatar and then to look as fast as possible towards a peripheral (right/left) target. After each block, participants had an opportunity to take a break, and they started the next block when they were ready. The duration of each block varied slightly depending on how long it took participants to fixate on the avatar, conduct the saccade towards the target and the type of feedback they received. After completing all experimental blocks, participants were asked to fill in computer questionnaires; they could skip any question or opt out from answering any of the questionnaires. At the end of the experiment, which lasted approximately 1.5 hours, participants were provided with verbal and written debrief. An example trial is depicted in Figure 2.

Can the reward associated with

Figure 2 Example of a successful trial (with zoomed stimuli)

Participants were required to fixate on the avatar for at least 600 ms within 5000 ms of the face appearing.

Successful fixations were followed by the avatar blinking for 400 ms, which constituted a warning period, after which, a peripheral (right/left) target appeared, and participants were required to look as fast as possible towards it. Only if an accurate (on-target) saccade was conducted (i.e. landed on target) faster than 400 ms after the target onset, would the avatar follow the participant's gaze (reward) with a given probability. During training blocks (1 to 6) reward payoff was fixed for each side, and the probabilities of the avatar following the participant's gaze to the target on fast enough trials were 80% on the "high reward" side and 20% on the "low reward" side, with the remainder of the fast enough trials receiving no reward – the avatar kept looking straight ahead in 20% ("high reward" side), respectively 80% ("low reward" side) of the fast enough trials. During baseline blocks (0 and 7) no trials were rewarded which means that the avatar looked straight ahead and did not move their eyes. Irrespective of the side, trials during which participants did not fixate long enough at the avatar and trials with saccades conducted 400 ms or later after target onset always resulted in a red X being displayed (punishment) in the centre of the avatar.

Task. In each trial, participants had 5000 ms to fixate for at least 600 ms on the avatar's eyes (the fixation area included the eyes and nose: width = 320 pixels i.e. 7.2 visual angles, height = 300 pixels i.e. 6.7 visual angles). Successful fixation was followed, similarly to Milstein and Dorris' (2007), by a 400 ms warning period to allow for the preparation of saccadic response, during which the avatar blinked for

Can the reward associated with

400 ms signalling that the target would shortly appear. Immediately after the warning period, the target was randomly displayed to the left or the right side of the avatar (50% right, 50% left in each block) and participants were required to look as fast as possible to the target (the fixation area was larger than the ball: width = 130 pixels i.e. 2.9 visual angles, height = 300 pixels i.e. 6.7 visual angles). The height of the fixation area for the face and the ball were similar in order to avoid penalising those participants who would fixate on the face below eyes and to prevent issues that might arise from the lack of the drift correction in the experiment. Participants had to conduct saccades within 3000 ms from the target onset. Saccades conducted within 400 ms of the target onset were classified as successful and could yield reward (the avatar followed participant's gaze to the target) or nonreward (the avatar did not follow participants gaze and remained with direct gaze) during training blocks, whereas slower saccades were classified as unsuccessful and always resulted in a punishment (a red X being displayed in the centre of the avatar). The threshold of 400 ms was selected as a result of a pilot, which indicated that with 300 ms cut off participants were not able to do the task while with 500 ms cut off the task was too easy for them. To avoid ceiling and floor effects, the threshold was set at 400 ms.

Successful trials. Saccades completed within 400 ms of the target onset were classified as successful. During baseline blocks (0 and 7), all successful saccades were nonrewarded meaning that the avatar looked straight ahead and did not follow participant's gaze. Importantly, during the training blocks (1 to 6), depending on reward probability successful saccades could result in either social reward (the avatar followed participant's gaze to the target) or nonreward (the avatar did not follow participants gaze and remained with direct gaze). On the high reward probability there was 80% probability of reward and 20% probability of nonreward.

Can the reward associated with

On the low rewarded probability there was 20% probability of reward and 80% probability of nonreward. Reward probability was kept constant across blocks and was counterbalanced across participants.

Unsuccessful saccades. Saccades conducted later than 400 ms from the target onset were classified as unsuccessful. The outcome of unsuccessful saccades, regardless of block type and reward probability, was punishment in terms of a red X being displayed in the centre of the avatar. Contrary to Milstein and Dorris (2007), the current study did not penalise participants for conducting anticipatory saccades towards the target (up to 70 ms after the target onset), however similarly to their paper, these saccades were excluded from the analysis.

Baseline blocks (0 vs 7). In the first and the last block (*baseline blocks*), after successful saccades (completed within 400 ms of the target onset) the stimuli (the avatar and the ball) were displayed on the screen for 2100 ms but the avatar did not follow participants' gaze (nonreward). If participants did not manage to conduct saccade within 3000 ms from the target onset or it took them 400 ms or longer to conduct saccade, the trial was unsuccessful. During unsuccessful trials, 1000 ms after conducting the saccade, a red "X" (width = 120 i.e. 2.7 visual angles, height = 90 pixels i.e. 2.0 visual angles) was displayed in the centre of the avatar for 500 ms after which the trial ended.

Training blocks (1 to 6). Depending on reward probability after successful saccades (conducted within 400 ms of the target onset) during training blocks (1 to 6), participants might have received social reward (i.e. the avatar followed their gaze to the target) or nonreward (i.e. the avatar did not follow their gaze but continued to look straight ahead). During social reward, 600 ms after participant completed fast enough saccade (within 400 ms of the target onset), the avatar shifted their gaze

Can the reward associated with

towards the target and looked at it for 1500 ms; next, the avatar would look straight ahead for 1000 ms to allow participants to notice the avatar's gaze shift. The 600 ms avatar's gaze response was chosen based on Pfeiffer et al. (2012) who found that participants perceived gaze latencies between 400 and 800 ms as most reactive to their own gaze shifts. After successful saccades that were not rewarded, the avatar did not follow participants gaze but kept looking straight ahead. Similarly to the baseline blocks, the outcome of the unsuccessful saccades was always punishment (i.e. a red X displayed in the centre of the avatar). Participants were not informed that if they look towards the ball quickly, the avatar might follow their gaze. This was done in order to avoid the situation that participants try harder on the low rewarded side because they might interpret the avatar not following their gaze as an indication that their saccades were too slow on that side.

Inter trial interval. Similarly, to Milstein and Dorris (2007), the inter trial interval in baseline and training blocks lasted 1000 ms during which only the black background was displayed.

Data analysis

Successful trials. Selection criteria were similar to those used by Milstein and Dorris (2007). Successful trials that entered analysis were those during which participants fixated on the face (28726 of 28800 trials, 99.74 % of all trials) and then completed a successful saccade (i.e. within 400 ms from target onset; 20893 of 28800 trials, 72.55%). Additionally, trials with anticipatory saccades (initiated up to 70 ms after targets onset) were coded at the analysis stage as unsuccessful (128 of 28800 trials, 0.44 % of all trials) and were excluded from the analysis. This resulted in 20765 of 28800 trials (72.10 %) were considered as successful in the analysis.

Can the reward associated with

The eye tracker files were converted to asci files and a Python script was used to extract from those files experimental data in Vizard 4.1 Development Edition (WorldViz, Santa Barbara, California, USA); next, the data was analysed in R Studio (1.0.153; R language version 3.4.1). For multilevel modelling of latencies and success rate, “lmer” and “glmer” functions from “lme4” package (Bates et al., 2015) were used respectively; “lmerTest” package (Kuznetsova et al., 2017) was used to obtain p values for multilevel linear models via Satterthwaite approximations to degrees of freedom. The analysis of contingencies using ANOVA and pairwise comparison were performed using “compute.es” (Re ACD, 2013), “multcomp” (Hothorn et al., 2008) and “nlme” (Pinheiro et al., 2020) packages. Cluster analysis was performed using “factoextra” (Kassambara & Mundt, 2020), “clValid” (Brock et al., 2008), and “cluster” (Maechler et al., 2019) packages. T-tests were performed using “car” package (Fox & Weisberg, 2019).

Transparency and openness

We do not report how we determined our sample size. We report all data exclusions (if any), all manipulations, and all measures in the study, and we follow APA Style Journal Article Reporting Standards (JARS; Kazak, 2018). All data, analysis code, and research materials are not available. However, data will be made available upon the publication. This study’s design and its analysis were not pre-registered.

Statistical Analysis

Main analysis. The main analysis, which explored the impact of reward probability (high vs low) and block on success rate and latency, was conducted separately for training blocks (1 to 6) and for baseline blocks (0 vs 7). The analysis of baseline blocks was conducted to explore any possible carry over effects from the

Can the reward associated with

training. These analyses were performed using multilevel models with the most complex random effect structure that converged, allowed a non singular fit, and made sense. It has been argued that models with maximum random structure allow better generalisation of the results than models with intercepts only (Barr, 2013; Barr et al., 2013). In case the maximum random effect structure did not converge we explored the random effect structure of partially converged models and excluded later the slopes that contributed least to it (Barr et al., 2013). In order to make coefficient interpretation more meaningful, the following predictors were treated as categorical with Helmert weighted contrast: reward probability (high vs low), block in baseline analysis (0 vs 7). Block (1 to 6) in training analysis was treated as a continuous variable that was centred at block 1.

Manipulation check. In the current experiment, the reward probability was set so that on the side with high reward probability 80% of successful saccades (i.e. completed within 400 ms of the target onset) were rewarded and 20% of successful saccades were not rewarded, while the opposite was the case on low reward probability. Additionally, unsuccessful saccades (that took more than 400 ms to complete) were always punished (i.e. red X was displayed in the centre of the screen). Those reward probabilities were set during the initiation of each block and were not reassessed on a trial-by-trial basis, which taken together with the lack of a staircase procedure for the reward threshold meant that the number of rewarded, nonrewarded and punished trials varied across participants. The proportion of successful saccades which were rewarded or nonrewarded for each reward probability across blocks ranged from 5 % to 100 % ($M = 72.66 \%$, $SD = 20.1 \%$). On the high reward probability, the proportion of successful saccades that were rewarded ranged from 66.67 % to 100 % of ($M = 80.26 \%$, $SD = 4.18 \%$). On the low

Can the reward associated with

reward probability, the proportion of successful saccades that were rewarded ranged from 0 % to 35.29 % ($M = 20.08$ %, $SD = 4.41$ %). The difference between the proportion of successful saccades that were rewarded on high and low reward probability (aimed to be 60%) ranged from 36.65 % to 91.67 % ($M = 60.18$ %, $SD = 6.25$ %). Furthermore, in absolute trial numbers, only if all of the 80 trials were fast enough (100% success rate), would a 60% difference result in a 24-trial difference in reward. Certainly, at the outset of the experiment, success rates were lower, and for instance a 70% success rate could result in an absolute difference of only 17 rewarded trials between high- and low-rewarded side. The better participants were, or became, the larger this difference. These statistics illustrate that the variability in participants latency resulted in differences in terms of feedback (reward or nonreward for successful trials, and punishment for unsuccessful trials) they received during the experiment. To explore this variability further, we conducted trial by trial contingency and cluster analysis that are described below.

Trial by trial contingencies analysis. We explored the impact of trial by trial changes on success rate and latency by accounting for a change in the target side compared to the previous trial (congruent vs incongruent) and the type of feedback that participants received on previous trial (reward, nonreward, punishment) during learning blocks (1 to 6). This analysis was conducted using ANOVA on by block aggregated scores (except the first trial).

Cluster analysis. Due to the individual variability in performance, in particular latency, participants created their own experience of how much reward and punishment they received during the experiment on high and low reward probability. If someone was able to conduct mainly saccades faster than 400 ms of the target onset they would receive a lot of reward and little punishment. Conversely, if

Can the reward associated with

someone was hardly ever able to conduct such fast saccades, they would receive little reward and a lot of punishment. We conducted hierarchical cluster analysis to explore whether participants could be grouped in meaningful clusters based on their latency as well as their experience of reward and punishment during training blocks (1 to 6). To this end, for each participant we calculated the difference in reward and punishment between high and low reward probability as well as difference in latency on successful trials between high and low reward probability. The suitability of using these three computed variables for cluster analysis was assessed by comparing Hopkins statistics for the data set to a random data (Lawson & Jurs, 1990); this comparison indicated that there might be meaningful clusters in the data set. Next, the `clValid` function was used to assess the optimal number of clusters and the best clustering method which indicated that hierarchical clustering with 2 or 3 clusters would be the best clustering method. The hierarchical cluster analysis was conducted using the Ward.D method with the square Euclidean distance technique. A two cluster solution was selected after inspecting dendrogram, and visualisation of the total within sum of squares for each cluster. The validity of the grouping was assessed using independent sample t-tests for each variable (Yamamori et al. 2003). Due to the unequal number of participants in each cluster, we performed additionally one sample t-test against 0 on all variables for each cluster.

Results

Main analysis of success rate

Training blocks (1-6). The analysis of the impact of reward training on success rate during training blocks as a function of block (1 to 6) and reward probability (high and low) with by subject interactive slopes for block and reward probability did not

Can the reward associated with

show any main effects or interaction (see Table 1 and see Figure 3). This suggests that seeing the avatar following participant's gaze more often on high than low reward probability did not influence success rate.

Baseline blocks (0 vs 7). Even though reward was not present during baseline blocks (0 and 7), we compared success rate before and after training at each reward probability to see whether the training had any carry over effects. If there were carry over effects from the training, we would observe Block x Reward Probability interaction that would be driven by a difference in success rate between high and low probability in block 7 but not in block 0. The model with baseline Blocks (0 vs 7) and Reward Probability (high vs low) with by subject interactive slopes for both variables showed a main effect of Block [$b = 0.496$, $SE = 0.110$, $z = 4.514$, $p < 0.001$] with participants success rate improving by 7.61 % from block 0 ($M = 66.89$ %, $SD = 19.66$ %) to block 7 ($M = 74.5$ %, $SD = 19.46$ %) (see Figure 3). However, there was no effect of Reward Probability or interaction (see Table 1), which suggests that the training (blocks 1 to 6) did not differentially improve success rate on the high reward probability compared to the low reward probability.

Can the reward associated with

Figure 3 The mean Success rate during blocks 0 to 7. Baseline blocks are blocks 0 and 7. Training blocks are blocks 1 to 6. The error bars represent 95% CI

Table 1 The analysis of the impact of block and reward probability on success rate during training blocks (1-6) and baseline blocks (0 vs 7).

SUCCESS RATE									
Predictor	Training Blocks (1 to 6)				Baseline Blocks (0 vs 7)				
	Estimate	SE	z value	p	Estimate	SE	z value	p	
(Intercept)	1.099	0.135	8.128	<0.001	1.082	0.135	8.014	<0.001	***
Block	0.034	0.026	1.307	0.191	0.496	0.110	4.514	<0.001	***
Reward Probability	0.026	0.122	0.211	0.833	-0.003	0.110	-0.029	0.977	
Block x Reward Probability	0.040	0.037	1.089	0.276	0.031	0.194	0.161	0.872	

Sign. Codes: *** 0.001, **0.01, * 0.05, . 0.1

Main analysis of latencies

Training blocks (1-6). The analysis of the impact of reward training on latencies during training blocks as a function of Block (1 to 6) and Reward Probability (high vs low) with by subject interactive slopes for both variables showed a main effect of Block [$b = -2.578$, $SE = 0.330$, $t = -7.84$, $p < 0.001$]; the remaining effect

Can the reward associated with

and the interaction were not significant (see Table 2). Further analysis, replacing the fixed effect of Block with polynomial orthogonal contrast, revealed the following trends for block: linear [$b = -550.696$, $SE = 71.017$, $t = -7.754$, $p < 0.001$], quadratic [$b = 110.453$, $SE = 32.313$, $t = 3.418$, $p < 0.001$], and cubic [$b = -65.485$, $SE = 32.267$, $t = -2.029$, $p < 0.05$]. This reflects two larger drops in latencies after the first training block, and then again to a lesser degree in the final training blocks (see Figure 4).

Baseline blocks (0 vs 7). The model with baseline Blocks (0 vs 7) and Reward Probability (high vs low) with by subject interactive slopes for both variables likewise showed only a main effect of Block [$b = -21.481$, $SE = 2.285$, $t = -9.402$, $p < 0.001$] with latencies being 20.95 ms shorter in block 7 ($M = 204.75$ ms, $SD = 33.99$ ms) than in block 0 ($M = 225.70$ ms, $SD = 37.69$ ms) (see Figure 4). Again, there was no effect of Reward Probability or interaction (see Table 2), which suggests that the training did not improve latencies on high reward probability more as compared to low reward probability.

Can the reward associated with

Figure 4 Mean latencies during training blocks 0 to 7. Baseline blocks are blocks 0 and 7. Training blocks are blocks 1 to 6. The error bars represent $\pm$ 95% CI.

Table 2 The analysis of the impact block and reward probability on latencies during training blocks (1-6) and baseline blocks (0 vs 7).

LATENCIES									
Predictor	Training Blocks (1 to 6)					Baseline Blocks (0 vs 7)			
	Estimate	SE	t value	p		Estimate	SE	t value	p
(Intercept)	220.343	2.619	84.130	<0.001	***	217.209	2.334	93.071	<0.001
Block	-2.578	0.330	-7.804	<0.001	***	-21.481	2.285	-9.402	<0.001
Reward Probability	-1.297	2.180	-0.595	0.555		-1.129	2.069	-0.546	0.588
Block x Reward Probability	0.187	0.413	0.452	0.653		1.862	2.496	0.746	0.460

Sign. Codes: *** 0.001, **0.01, * 0.05, . 0.1

Analysis of trial by trial contingencies during training blocks (1 to 6)

In order to find out whether feedback received on the previous trial (previous feedback: reward, nonreward, punishment) and change in target side compared to the previous trial (congruent vs incongruent) influenced participants' performance during training blocks (1 to 6), we performed separate ANOVAs on aggregated means (with the exception of the first trial) for success rate and latencies.

Can the reward associated with

Success rate. Firstly, we performed ANOVA on success rate as a function of Block (1 to 6), Change in Target Side (congruent vs incongruent) and Previous Feedback (reward, nonreward, punishment). Due to violated assumption of sphericity using Greenhouse-Geisser correction was used in analysis. The ANOVA demonstrated the interaction between Change in Target Side and Previous Feedback [$F(1.6, 65.68) = 10.344, p < 0.001$]. ANOVAs conducted separately for each side indicated that this interaction was due to the effect of Previous Feedback on the congruent side [$F(2,80) = 8.803, p < 0.05$] but not on the incongruent side [$F(2,80) = 2.410, p = 0.096$]. The follow-up pairwise comparison with Bonferroni correction showed that the effect of Previous Feedback on the congruent side was due to a lower success rate following a punished ("X") trial ($M = 65.15\%$, $SD = 25.85\%$) than either following a rewarded trial ($M = 71.64\%$, $SD = 20.1\%$; $p < 0.01$) or nonrewarded trial ($M = 72.81\%$, $SD = 22.93\%$; $p < 0.01$), but there was no difference between reward and nonreward ($p > 0.999$; see Figure 5). These findings suggest that when the target appeared at the same side as in the previous trial, seeing a red X on a previous trial made it more difficult for participants to complete the saccades within 400 ms of the target onset compared to seeing the avatar following participant's gaze (reward) or looking straight ahead (nonreward). However, when the target switched sides, there was no influence of the previous trial.

Can the reward associated with

Figure 5 Mean success rate by change in the target side (congruent vs incongruent) and previous feedback (reward, nonreward, punishment). The error bars represent $\pm 95\%$ CI.

Latencies. The ANOVA on mean latencies as a function of Block (1 to 6), Change in Target Side (congruent vs incongruent) and Previous Feedback (reward, nonreward, punishment) again demonstrated the effect of Block [$F(5,160) = 13.050$, $p < 0.001$]. Further analysis with polynomial contrast for block revealed linear trend [$t = -7.331$, $p < 0.001$] indicating a linear decrease in latencies over time (see Figure 6). Additionally the analysis demonstrated the effect of Change in Target Side [$F(1,32) = 11.517$, $p < 0.05$] with latencies being 3.96 ms slower for a target presented on the congruent ($M = 214.35$ ms, $SD = 21.00$ ms) than incongruent side ($M = 210.39$ ms, $SD = 20.57$ ms) compared to the previous trial (see Figure 6). This finding could reflect some form of inhibition of attention to previously attended location which is known as inhibition of return (IOR, Wang et al., 2018). The remaining effects and interactions were not significant.

Can the reward associated with

Figure 6 Mean latencies by block (panel A) and change in the target side (panel B). The error bars represent $\pm$ 95% CI.

Cluster analysis

Due to the individual variability in performance, in particular latency, participants created their own experience of how much reward and punishment they received during training blocks on high and low reward probability. If someone was able to mainly conduct saccades faster than 400 ms of target onset they would receive a lot of reward and little punishment. Conversely, if someone was hardly ever able to conduct such fast saccades, they would receive little reward and a lot of punishment. We conducted hierarchical cluster analysis to explore whether participants could be grouped in meaningful clusters based on their latency as well as their experience of reward and punishment during training blocks (1 to 6).

To this end, we performed a hierarchical cluster analysis using 3 sets of data points: (A) block differences between high and low reward sides in the absolute number of trials that were rewarded and (B) that were punished as well as (C) block differences in latency on successful trials between high and low reward sides. The two cluster solution was selected based on the elbow and silhouette method, with each of the clusters being bigger than 10% of the sample (Rochat et al., 2019).

Can the reward associated with

Cluster 1 consisted of 39 participants (86.67 % of the sample) whilst cluster 2 consisted of 6 participants (13.33 % of the sample). Independent sample two tailed t-tests indicated that the two clusters differed significantly in by-block and average reward and punishment differences, and also across three blocks and average latency differences (see Table 3 and Figure 7). However, to different size of clusters, we also performed one sample two tailed t-tests against 0 for all variables separately for each cluster, which indicated that in cluster 1 only reward differences varied significantly from 0, whereas in cluster 2 both reward and punishment differences as well as latency differences in block 5 varied significantly from 0. Given big discrepancy in cluster sizes, there were only six people in cluster 2 and 39 in cluster 1, the differences between clusters are likely not to be very robust.

Can the reward associated with

Figure 7 By-cluster means for A) reward difference B) punishment difference C) latency difference

Panel A) shows reward difference which is the difference in the number of rewarded trials between high and low reward probability. Panel B) shows punishment difference which is the difference in the number of punished trials between high and low reward probability. Panel C) shows latency difference which is the difference in latency between high and low reward probability. In this figure, 0 means an equal number of rewarded (A) or punished (B) trials on each reward probability or equal latencies (C) on high and low reward probability. Positive differences indicate higher number or rewarded (A) or punished (B) trials and slower latencies (C) on high than low reward probability. Negative differences indicate lower number of rewarded (A) or punished (B) and faster latencies (C) on high than low reward probability.

Absolute Reward Difference. This difference was included in the analysis as we wanted to see whether some participants might have experienced little actual difference in reward between high- and low-reward sides. Positive reward difference would indicate that participants had more rewarded trials on high than on low reward probability, whereas negative reward difference would indicate that participants had

Can the reward associated with

more rewarded trials on low than on high reward probability. Indeed, the degree to which participants experienced a larger or smaller difference in absolute number of rewarded trials on high- and low-reward sides depended on their success rate. If the success rate on both sides was 100% participants would have 32 rewarded trials on the high rewarded side and 8 rewarded trials on low rewarded side. In such scenario the reward difference would be 24. However, with a decreasing overall success rate, the absolute difference in experienced reward between high- and low-reward sides would be progressively smaller. In the current experiment, the average absolute reward difference was 18.35 trials (SD = 3.62) for cluster 1 (reflecting an overall success rate of just over 75%: $.75 \cdot 40 \cdot .8 = 24$, and $.75 \cdot 40 \cdot .2 = 6$, difference = 18 trials) which was significantly higher than 10.14 trials (SD = 1.85) for cluster 2 (reflecting an overall success rate of less than 45%; $.45 \cdot 40 \cdot .8 = 14.4$, and $.45 \cdot 40 \cdot .2 = 3.6$, difference = 10.8 trials). One-sample two tailed t-tests against 0 demonstrated that in both clusters participants' reward difference was significantly higher than 0 in each block and on average. This finding suggests that participants had more rewarded trials on high than low reward probability. Independent sample two tailed t-tests comparing the reward difference indicated that those in cluster 1 had significantly higher reward difference than those in cluster 2 on average and across all blocks (see Table 3). As such, in principle cluster 1 participants experienced a more marked difference between high- and low-reward sides than cluster 2, but on the other hand cluster 1 were, already from block 1, better than cluster 2, who grew somewhat worse over blocks (lower absolute difference reflecting lower overall success rate).

Punishment Difference. Besides the absolute difference in number of rewarded trials on both sides, we should also look at how much punishment ("X")

Can the reward associated with

participants received on each side. This is not simply a function of the previous measure, but rather orthogonal to it. Indeed, the previously explained simple relationship between success rate and absolute difference in number of rewarded trials *only* holds if one assumes equal success rates on both sides (something which Figure 3 overall seems to suggest). For example, if a participant has a 50% success rate on both sides, their absolute difference in experienced reward will be 12, half of what it would be if they were 100% successful on both sides. However, if that participant's 50% success rate is instead the result of 90% success on the high reward side and 10% on the low reward side, their absolute difference in experienced reward will be $28.8 - 0.8 = 28$, which is 4 *more* than for the participant with 100% success rate on both sides. More problematic, if a participant's 50% success rate is the result of, contrary to expectations, a 10% success rate on the high reward side and a 90% success rate on the low reward side, their absolute difference in experienced reward will be $3.2 - 7.3 = -4$, meaning that they would actually experience **more** reward on the low reward side!

One sample two tailed t-tests against 0 demonstrated that in cluster 1 participants punishment difference was not different than 0 on average and across blocks, which suggests that in cluster 1 participants had a similar number of punished trials at each reward probability. However, in cluster 2 punishment difference on average and across blocks was significantly higher than 0 indicating that participants in that cluster received more punishment on high than on low reward probability. Independent sample two tailed t-tests comparing the punishment difference conducted separately for each block and for blocks average indicated that participants in cluster 2 had significantly higher punishment difference than those in cluster 1 in all but first block, which indicates that participants in cluster 2 received

Can the reward associated with

almost always more punishment on high than on low reward side compared with participants in cluster 1 (see Table 3). As such, whereas cluster 1 participants were equally good on both sides and remained that way (which however does not mean that overall their accuracy remained equal, just that it remained equal between both sides), cluster 2 participants saw a progressive divergence depending on reward, getting comparatively worse on the high rewarded side (or better on the low rewarded side). Crucially though, this latter group, in line with the findings from Absolute Reward Difference, did not experience our manipulation very strongly, and progressively less so over the course of the experiment.

Latency Difference. Finally, we can explore the data depicted in Figure 4 more in depth by looking at whether, like in the Reward and Punishment Differences, there is a subsection of participants who do show latency differences between high- and low-reward sides. Positive latency difference would indicate that participants were slower on high than low reward probability, whereas negative latency difference would indicate the opposite, that participants were slower on low than on high reward probability. One sample two tailed t-tests against 0 demonstrated that in only in cluster 2 latency difference was not different than 0 only in block 5 suggesting that in this block participants were slower on high than on low reward probability. All remaining one sample tests were nonsignificant suggesting that in cluster 1 and in cluster 2 latencies were equal across blocks and on average on both reward probability with the exception of latency difference in block 5 in cluster 2. Additionally, independent sample two tailed t-tests comparing the latency difference conducted separately for each block and average scores indicated that participants in cluster 2 had significantly higher latency difference than those in cluster 1 in blocks 2, 5, 6 and on average (see Table 3).

Can the reward associated with

In summary, cluster 1 characterises participants who were relatively good at the task from the outset, which was reflected in the larger absolute difference in experienced reward on high/low reward probability with respect to the other cluster, but they were good on both sides throughout (zero punishment difference), which precludes a very large difference in experienced reward. Indeed, they were equally fast on both sides. In contrast, cluster 2 participants start out rather poorly, with progressively more punishment on the high than on the low reward probability, which means the difference in reward between those sides is not only low, but also gradually diminishes. However, these findings might not be robust due to a big difference in size between clusters.

If our manipulation had worked, we would have expected a progressively decreasing high-low latency difference, possibly accompanied by progressively decreasing high-low punishment difference, both of which resulting in an increasing high-low reward difference. In contrast, apart from the 6 participants who did not experience the experimental manipulation as designed, the cluster analysis shows that the 39 cluster 1 participants showed, from the outset and across all blocks, no side difference with respect to latency and punishment, and experienced from the outset a relatively marked absolute difference in reward, which however failed to elicit, over time, differential saccadic behaviour to the differently rewarded sides.

Can the reward associated with

Table 3 By-cluster means and standard deviations for A) reward differences, B) punishment differences, C) latency differences.

Variable	Cluster 1				Cluster 2				Cluster 1 vs Cluster 2		
	(n = 39, 86.67%)				(n = 6, 13.33%)						
	M (SD)	t	p		M (SD)	t	p		t	p	
A) Reward differences											
Block 1	18.00 (5.32)	21.144	<0.001	***	12.33 (3.08)	9.819	<0.001	***	2.530	0.015	*
Block 2	18.21 (5.27)	21.563	<0.001	***	13.33 (3.33)	9.818	<0.001	***	2.185	0.034	*
Block 3	18.26 (5.46)	20.876	<0.001	***	9.50 (5.43)	4.284	0.008	**	3.659	< 0.001	***
Block 4	18.56 (6.04)	19.199	<0.001	***	8.00 (7.40)	2.647	0.046	*	3.878	< 0.001	***
Block 5	18.38 (4.96)	23.168	<0.001	***	10.00 (5.22)	4.697	0.005	**	3.834	< 0.001	***
Block 6	18.67 (4.87)	23.918	<0.001	***	7.67 (5.24)	3.583	0.016	*	5.101	< 0.001	***
Average	18.35 (3.62)	31.634	<0.001	***	10.14 (1.85)	13.394	<0.001	***	8.607^a	< 0.001	***
B) Punishment differences											
Block 1	-0.51 (6.77)	0.473	0.639		4.67 (4.08)	2.800	0.038	*	1.813	0.077	
Block 2	-1.26 (5.51)	1.424	0.163		8.50 (3.99)	5.222	0.003	**	4.155	< 0.001	***
Block 3	-0.67 (6.96)	0.599	0.553		14.50 (6.06)	5.863	0.002	**	5.043	< 0.001	***
Block 4	-1.54 (6.71)	1.432	0.161		13.67 (12.21)	2.742	0.041	*	2.982 ^a	0.027	*
Block 5	-1.10 (7.30)	0.944	0.351		9.83 (4.62)	5.211	0.003	**	3.543	< 0.001	***
Block 6	-0.56 (6.36)	0.554	0.583		14.17 (3.76)	9.220	<0.001	***	5.492	< 0.001	***
Average	-0.94 (3.70)	1.587	0.121		10.89 (1.85)	14.449	<0.001	***	7.631	< 0.001	***
C) Latency differences											
Block 1	-0.59 (15.89)	0.234	0.816		4.81 (27.43)	0.429	0.686		0.470 ^a	0.656	
Block 2	-0.44 (16.33)	0.166	0.869		17.04 (16.65)	2.507	0.054		2.435	0.019	*
Block 3	-1.46 (11.92)	0.767	0.448		17.59 24.77	1.739	0.143		1.851	0.119	
Block 4	-1.65 (15.53)	0.661	0.512		5.84 (14.77)	0.968	0.378		1.105	0.275	
Block 5	-1.32 (12.62)	0.652	0.518		14.67 (10.01)	3.590	0.016	*	2.954	0.005	**
Block 6	-1.41 (13.90)	0.634	0.530		11.84 (19.26)	1.506	0.193		2.066	0.045	*
Average	-1.14 (10.96)	0.652	0.518		11.96 (13.03)	2.249	0.074		2.664	0.011	*

Sign. Codes: *** 0.001, **0.01, * 0.05, . 0.1

^a corrected due to unequal variances by use of Welch two sample t-test

Descriptive statistics 0 means an equal number of rewarded (A) or punished (B) trials and equal latencies (C) on high and low reward probability. Positive differences indicate higher number or rewarded (A) or punished (B) trials and slower latencies (C) on high than low reward probability. Negative differences indicate lower number of rewarded (A) or punished (B) trials and faster latencies (C) on high than on low reward probability

Discussion

The current study aimed to investigate whether the supposedly rewarding nature of initiated joint attention has, besides neurobiological correlates (Caurana et al., 2017; Gordon et al. 2013; Schilbach et al., 2010), a long-term behavioural modification usually associated with such reward (reward-based learning).

Specifically, we asked whether such reward can influence faster gaze orientation towards the target to which participants gaze is followed more often by an anthropomorphic avatar. During the training blocks (1 to 6), if participants conducted saccades faster than 400 ms within the target onset, they could receive social reward in terms of the avatar following their gaze to the target, which resulted in the imitated joint attention. Importantly, the probability of this reward was different for each side (the value of the reward on one trial cannot be modified, as gaze following is binary). On one side the reward probability was 80% (high) whilst on the other it was 20% (low). The remainder of the fast enough trials received no reward – the avatar kept looking straight ahead. During baseline blocks (0 and 7) all fast enough trials were nonrewarded. Saccades conducted later than 400 ms from the target onset were classified as unsuccessful. The outcome of unsuccessful saccades, regardless of block type and reward probability, was punishment in terms of a red X being displayed in the centre of the avatar.

The main analysis investigated whether seeing the avatar following participant's gaze (self-initiated joint attention) more often to one than to the other side (high vs low reward probability) would influence latency and success rate of saccades to a target over time during training blocks (1 to 6). There were no effect in success rate analysis during training blocks. The analysis of latency showed only the effect of block during training blocks indicating that latencies became shorter during

Can the reward associated with

training (blocks 1 to 6). Additionally, we investigated whether there were any carry over effects of this training evident when comparing baseline blocks (0 and 7). The analysis of the success rate demonstrated only higher success rate in block 7 than block 0 which might simply reflect the effect of practice. Additionally, the latencies were shorter at block 7 than at block 0. Neither of those analyses demonstrated the effect of reward probability or interaction between block and reward probability, which suggests that latency and success rate were not influenced by social reward in the current experiment.

In the current study, participants had to conduct saccades within 400 ms of the target onset for these saccades to be classified as successful and to be considered to be subject to any reward contingencies. The variability in participants latency resulted in differences in number of rewarded, nonrewarded and punished trials during the experiment, which contributed to unique experiential experience. To explore the impact of this variability, we conducted trial by trial contingency and cluster analysis. Changes on success rate and latency by accounting for a change in the target side compared to previous trial (congruent vs incongruent) and the type of feedback that participants received on previous trial (reward, nonreward, punishment) during learning blocks (1 to 6). The analysis demonstrated that success rate was lower after punishment than reward or nonreward received on previous trial providing that the target appeared on the same side as in previous trial (congruent). Taking into account that success rate reflected mainly the proportion of trials on which participants conducted saccades faster than 400 ms of the target onset, these findings seem to indicate that seeing a red X (punishment) on a previous trial slowed participants towards congruent targets. Additionally, it was found that latencies became shorter over time and that latencies were longer on congruent trials (target

Can the reward associated with

location was identical to previous trial) than on noncongruent trials (target location different than on previous trial) which could reflect inhibition of attention to previously attended location, which is known as inhibition of return (IOR, Wang et al., 2018).

Hierarchical cluster analysis was conducted to explore whether participants could be meaningfully grouped into clusters depending on the difference in the number of rewarded and punished trials as well as in latency between high and low reward probability. This analysis allowed to identify two distinctive and vastly different in size clusters. Cluster 1, which consisted of the majority of participants, was characterised by a higher number of rewarded trials on high than on low reward probability and lack of difference in number of punished trials and latency between high and low reward probability. In contrast, cluster 2, which consisted of only 6 participants, was characterised by a higher number of punished trials on high than on low reward probability resulting in low and gradually diminishing difference in reward between high and low reward probability. However, these findings might not be robust due to a big difference in size between clusters.

Previous studies demonstrated that reward paradigms can be adapted to train ocular or simple motor responses with a different form of reward (Milstein and Dorris, 2007; Milstein and Dorris, 2011; Sesscousse et al., 2013; Spreckelmeyer et al., 2009). The lack of reward probability effect in the current study might be due to participants being not very good conducting saccades faster than the threshold of 400 ms, which prevented them from receiving 80% of reward on high reward probability and 20% of reward on low probability. Consequently, it might have been more difficult for participants to associate one side with higher reward probability than the other side. Nevertheless, the experiment took a lot of time and most of participants were in high rewarded cluster whereby they received more reward on

Can the reward associated with

high than on low reward probability cluster, so they did have a reasonable opportunity to learn about the reward contingency. Having said that, future studies could employ a staircase procedure, so that all participants have a similar experience in terms of the number of rewarded, nonrewarded and punished trials during the experiment (Bucker & Theeuwes, 2014; Spreckelmeyer et al., 2009).

Conversely, it might be argued that the lack of reward effect during the experiment does not necessarily mean that social reward is not effective. It might be that it is not effective in the short term but is unknown if it could have a long lasting effect and that it requires sleep for consolidation (Fischer & Born, 2009; Tamaki et al., 2020). In some experimental studies, such as Abe et al. (2011), the effect of rewards on sequential motor training was not present during or immediately after the training. However, the benefit of reward on motor learning has been demonstrated during recall tests that occurred 6 hours, 24 hours and 30 days after training. They argued that reward based motor learning, which is an association with dopaminergic regions such as striatum and midbrain, might require time for the development of long term motor memories. Future research could assess whether the effects of motor training using contingencies in joint attention would be pronounced during similar delayed recall.

The lack of the effect of social reward raises a question whether the effect would be present if participants interacted with a real individual or at least were led to believe that they did so (Schilbach et al., 2010). Previous studies indicated the ventral striatum is active during joint attention only when participants interact with another human being but not when they interact with a computer (e.g. Rilling et al., 2002) which was the case in the current study. Using avatars in experimental studies have been demonstrated to provide good ecological validity and enable good

Can the reward associated with

level of experimental control over characteristics such as attractiveness that otherwise could confound the results of the experiment (Pfeiffer et al., 2012; Pfeiffer, Vogeley & Schilbach, 2013). In the future, ensuring that participants believe that they interact with another human being might be sufficient to ensure that the effects of reward probability are present also during baseline blocks when the reward is removed (Pfeiffer et al., 2014).

Despite the current study showing no clear evidence that having one's gaze followed is rewarding in terms of improving saccade latency over time, it is possible that perhaps participants do find this rewarding but in the experimental paradigm used they could not accurately infer or learn the reward contingencies. It is plausible that it would be easier for participants to learn about reward contingencies if reward was provided on each trial (Berridge & Robinson, 2003; Rademacher et al., 2010; Spaniol et al., 2015). However, Dayan et al. (2014) demonstrated that reward motor training is most effective when rewards occur on 50% of the trials and the least effective when rewards are administered in every trial. Future research could explore how manipulating reward probability as a between-subject factor (e.g., 100%, 50%, 75% probability) would affect motor training in the current paradigm similarly to Dayan et al. An alternative explanation of the lack of the reward probability effect might be that participants did not find .

Moreover, the analysis of contingencies in terms of change of target location and previous feedback did not demonstrate reward advantage on latency. However, the analysis demonstrated that participants were on congruent trials (target location was identical to previous trial) than on noncongruent trials (target location different than on previous trial), which could reflect inhibition of return. Inhibition of return refers to slower responses to targets at cued than uncued locations which last up to

Can the reward associated with

3000 ms after the cue (Bennet & Pratt, 2001; Bucker & Theeuwes, 2014; Dodd & Pratt, 2007). It was also demonstrated that success rate was lower to the congruent side after trials that were punished rather than those that were rewarded or nonrewarded which indicates that it was more difficult for participants to be faster than the threshold after having been punished. In the current study, the interval between seeing a target on previous and current target could in some trials be less than 3000, in particular after trials that resulted in punishment due to punishment period being shorter than reward or nonreward. Further analysis of the data would be required to state whether this indeed was the case.

In conclusion, the current study aimed to find out whether gaze following can facilitate changes in saccadic latency over time. To this end, we adopted Milstein and Dorris (2007) saccadic training paradigm by replacing monetary rewards with social reward in terms of the avatar following participant's gaze (self-initiated joint attention) more often to one side than to the other side. Although our current study did not demonstrate that such social reward has a long lasting effect on gaze behaviour, we found that latencies became shorter over time and that latencies were longer on congruent trials (target location was identical to previous trial) than on noncongruent trials (target location different than on previous trial), which could reflect inhibition of return.

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