Current Psychiatry Reports (2021) 23: 32
https://doi.org/10.1007/s11920-021-01247-7

AUTISM SPECTRUM DISORDERS (ES BRODKIN, SECTION EDITOR)

Social and Nonsocial Reward Anticipation in Typical Development and Autism Spectrum Disorders: Current Status and Future Directions

Cara M. Keifer[1,2] · Talena C. Day[1] · Kathryn M. Hauschild[1] · Matthew D. Lerner[1]

Accepted: 24 March 2021 / Published online: 13 April 2021

Abstract

Purpose of Review While there has been sustained interest in understanding the role of reward processing in autism spectrum disorder (ASD), researchers are just beginning to focus on the anticipation phase of reward processing in this population. This review aimed to briefly summarize recent advancements in functional imaging studies of anticipatory social and nonsocial reward processing in individuals with and without ASD and provide suggestions for avenues of future research.

Recent Findings Reward salience and activation of the complex network of brain regions supporting reward anticipation vary across development and by important demographic characteristics, such as sex assigned at birth. Current research comparing social and nonsocial reward anticipation may possess confounds related to the mismatch in tangibility and salience of social and nonsocial experimental stimuli. Growing evidence suggests individuals with ASD demonstrate aberrant generalized reward anticipation that is not specific to *social* reward.

Summary Future research should carefully match social and nonsocial reward stimuli and consider employing a longitudinal design to disentangle the complex processes contributing to the development of reward anticipation. It may be useful to conceptualize differences in reward anticipation as a transdiagnostic factor, rather than an ASD-specific deficit.

Keywords Autism spectrum disorder · Reward · Anticipation · Social motivation · EEG · Neuroimaging

Introduction

Reward processing shapes goal-directed behavior whether that be in the pursuit of basic needs like food or more complex needs such as developing and maintaining meaningful relationships with others [1]. In the last decade, particular attention has been paid to the role of reward processing in the etiology of autism spectrum disorder (ASD; e.g., [2, 3]). For instance, the social motivation theory of ASD claims that individuals with ASD[1] demonstrate deficits in *social* reward processing which contribute to a developmental cascade of social difficulties [4]. However, a recent meta-analysis [5] indicated that autistic individuals demonstrate a broad reward processing deficit (not limited to social context), which likely impacts social development. Developing a better understanding of these processes in ASD is especially important given that virtually all of the evidence-based interventions for ASD capitalize on rewards to motivate change (e.g., ABA [6], PRT [7], SDARI [8]).

The psychological components of reward can be broken up into distinct components including "wanting" or anticipation of a reward (i.e., the motivated approach towards a reward), "liking" or consumption of a reward (i.e., the hedonic experience), and learning [9, 10]. These three components are

This article is part of the Topical Collection on *Autism Spectrum Disorders*

✉ Cara M. Keifer
Cara.keifer@stonybrook.edu

✉ Matthew D. Lerner
Matthew.lerner@stonybrook.edu

1 Stony Brook University, Stony Brook, NY, USA

2 Yale Child Study Center, New Haven, CT 06511, USA

[1] Individuals with autism spectrum disorder use a range of terms to self-identify. Therefore, we use both person-first and identity-first language in this review.

associated with discrete brain regions and neurotransmitter systems and are all needed for effective reward processing [9, 10]. Therefore, anticipatory, consummatory, and reward learning processing may be differentially impacted in individuals with ASD and uniquely contribute to the difficulties associated with ASD. However, studies in this area have largely focused on the "liking" aspect of reward processing and there is a limited understanding of the ways in which anticipatory and learning processes function in autistic individuals [5, 11]. It is important to deepen our understanding of reward anticipation in youth with ASD because, transdiagnostically, attenuated anticipation of rewards is associated with higher subsequent stress reactivity, higher affective instability, cognitive difficulties (e.g., working memory, cognitive flexibility), and poorer social functioning in youth [12, 13]. Therefore, reward system dysfunction at the anticipation stage may serve as an indicator of increased risk for broader social and psychological challenges.

The aim of the present review is to offer a brief summary of recent advancements in functional imaging studies of anticipatory reward processing research in typical development (TD), review the more limited research in this area in individuals with ASD, and leverage what has been learned in the TD population to guide future research in ASD.

Advancements in Reward Anticipation Research: Typical Development

Functional Magnetic Resonance Imaging Recent works examining reward anticipation in typically developing (TD) populations have aimed to better delineate developmental trajectories of neural responses underlying reward anticipation as well as examine whether the processing of social and nonsocial rewards recruit overlapping or distinct neural networks. Adolescence represents a sensitive period of development during which the neural networks supporting reward anticipation undergo normative reorganization [14, 15], and the saliency of social and nonsocial rewards is heightened [16–18]. Indeed, engagement of reward-related brain regions is amplified during adolescence relative to other age groups [19], supporting the notion that adolescence is a time of increased reward valuation.

Studies utilizing functional magnetic resonance imaging (fMRI), a methodology that measures brain activity via changes in blood oxygen levels and offers high spatial resolution, have revealed that changes in neural organization related to reward anticipation across development are reflected in enhanced activation of mesolimbic brain regions (Table 1; [19]). Beyond activation, a recent work has examined age-related reward processing changes in functional coupling, that is, the connectivity of brain regions [23]. Coupling of the ventral tegmental area (VTA) and the nucleus accumbens (NAc) decreases [23] from preadolescence to adulthood (e.g., 10- to 25-year-olds) while preparing to engage in motivated behavior. This suggests that adolescence is marked by heightened engagement of, and communication between, reward regions during the anticipation of motivationally salient tasks. Another study demonstrated age-related behavioral improvements on the antisaccade reward task, which involve older participants exhibiting greater inhibitory control to receive rewards relative to younger participants. Task improvements were mediated by the salience and motor networks. These findings support the dissociable components of "wanting" and "liking," and that neural "wanting" of rewards increases from adolescence to adulthood which facilitates better inhibitory control in pursuit of rewards [24]. One interpretation of these findings is that age-related changes may be due in part to hormonal changes (e.g., the onset of puberty) which impact neural development. For example, higher estradiol levels were found to be related to decreased bilateral caudate activation in girls but, interestingly, not boys [25]. The authors postulate that estradiol modulates reward sensitivity highlighting the need to characterize not only age-related changes but also puberty-related changes in reward anticipation processing. This finding is limited to girls; however, their sample consisted of pre- and early adolescents (10- to 13-year-olds) and thus warrants further study in later adolescence and adulthood.

In recent years, considerably fewer studies have attempted to disentangle potential differences in the processing of social and nonsocial rewards, with equivocal findings [26]. While a review by Gu and colleagues (2019) suggests that the brain regions implicated in anticipating social and nonsocial rewards are similar [27], other works indicate that neural networks responsible for the anticipation of social and nonsocial rewards are distinct. Specifically, a Humorous Incentive Delay (HID) analog to the classic Monetary Incentive Delay (MID) task showed monetary rewards elicited greater activation in the NAc, anterior cingulate cortex (ACC), and midbrain than humorous rewards [28]. Notably, participants reported more motivation during the MID than the HID tasks [28]. This may be due, in part, to a failure of these tasks to adequately match reward valence and magnitude. For example, many paradigms investigating social reward processing utilize smiling faces or other indices of social approval as rewards. However, tasks examining nonsocial reward processing often provide an opportunity for participants to gain additional monetary compensation. In an experimental setting, more tangible monetary rewards likely confer higher value, leading to greater motivation and task engagement overall. Thus, it is unclear if differences in the recruitment of these neural regions are due to differences in social versus nonsocial reward anticipation or confounds related to stimulus selection [29].

Table 1 Brain regions [20, 21] and ERP components [22] involved in the anticipation of rewards

fMRI	Region	Description
	Ventral tegmental area (VTA)	A midbrain structure comprising dopamine neurons that project to mesolimbic areas.
	Nucleus accumbens (NAc)	Apart of the mesolimbic pathway; specifically, the ventral striatum. Plays an important role in processing aversion and motivation.
	Caudate	Implicated in multiple processes including relaying information to mesocorticolimbic structures.
	Anterior cingulate cortex (ACC)	A structure in the frontal cortex that is involved in motivation.
ERP	**Component**	**Description**
	Cue-P3	Cue evaluation stage. Decide if an action will lead to a reward.
	Contingent-negative variation (CNV)	Motor preparation. Motor response to pursue a reward (e.g., push button).
	Stimulus-preceding negative (SPN)	Feedback anticipation. Elicited while waiting for feedback about a reward.

Electroencephalogram/Event-Related Potentials In addition to understanding changes in neural organization and network recruitment, it is also critical to understand changes in the efficiency of neural processing related to reward anticipation. Event-related potentials (ERPs) measured via electroencephalogram (EEG) index the electrophysiological response to distinct sensory or cognitive stimuli or events. ERP methodology offers high temporal resolution and thus can be a useful tool for isolating the rapidly unfolding stages of reward processing. Consequently, recent works have begun examining age-related changes in ERP components implicated in reward anticipation (i.e., cue-P3, contingent-negative variation [CNV], stimulus-preceding negativity [SPN]; Table 1). Findings from these studies indicate that increasing age is related to attenuated cue-P3 and CNV, but not SPN, amplitudes in a large sample of adults [30]. However, no work to date has examined potential age-related changes in anticipatory ERP components during adolescence despite the notable changes in neural network structure reported in the neuroimaging literature.

Similar to the fMRI literature, ERP responses to social and nonsocial reward anticipation have been studied utilizing an adapted MID task, known as the Social Incentive Delay (SID) task. Akin to many paradigms designed to measure social reward processing, these SID paradigms frequently use the presentation of emotion-laden faces as a social reward. In a study using this paradigm, adolescent girls demonstrated an enhanced SPN in anticipation of social punishment (angry faces), but not nonsocial punishment (monetary loss), social reward (smiling face), or nonsocial reward (monetary gain) when compared to boys [31]. These results suggest that adolescent girls may be particularly sensitive to the prospect of social rejection. This again raises the questions of whether social and nonsocial reward anticipation differs by sex assigned at birth and what role hormonal changes related to puberty may play in these processes. However, the use of emotional facial expression stimuli as an indicator of social approval or acceptance (i.e., social reward) may in and of itself introduce a confound as differences in face perception ability and processing are frequently observed by sex assigned at birth [32]. In order to circumvent this concern, other works have utilized thumbs up/down (i.e., Facebook) stimuli as a means of delivering social reward. In one such study, the cue-P3 and SPN were found to be similar across social and nonsocial tasks while the CNV was only modulated during the nonsocial (MID) task [33]. Given that ERPs did not differ significantly by task, Oumeziane and colleagues (2017) suggest that neural responses are indicative of general reward anticipation processing and do not differ by social or nonsocial reward type [33].

Taken together, the findings summarized above highlight the importance of considering the salience of social stimuli as well as the age and sex of participants to disentangle whether social and nonsocial reward anticipation is processed distinctly in youth, particularly during adolescence.

Advancements in Reward Anticipation Research: Autism Spectrum Disorder

Functional Magnetic Resonance Imaging The nature of reward anticipation deficits in ASD remains ambiguous. While some studies indicate aberrant reward anticipation specific to *social* rewards (e.g., [34]), others demonstrate atypical reward anticipation to both social and nonsocial rewards (e.g., [35–37]), and still others found no significant differences between individuals with ASD and TD individuals (e.g., [38]). In an attempt to clarify this mixed literature, a meta-analysis by Clements et al. (2018) on a small number of functional magnetic resonance imaging (fMRI) studies demonstrated that autistic individuals show hypoactivation in reward regions while anticipating social rewards but hyperactivation while anticipating nonsocial rewards [5]. These results add to the growing evidence that individuals with ASD possess generalized reward processing differences that are not specific to the social domain. A recent fMRI study [39] utilizing the Monetary Incentive Delay (MID) and Social Incentive Delay (SID) tasks also indicated that individuals with ASD demonstrated generalized reward processing differences when anticipating both social and nonsocial rewards. However, while Clements et al. (2018) found hypoactivation of reward regions while anticipating social rewards and hyperactivation while anticipating nonsocial rewards, Baumeister et al. (2020) found striatal hypoactivation in both domains [5, 39]. Thus, while autistic individuals seem to demonstrate reward anticipation differences across reward types, it is still not clear if these differences are characterized by hypo- or hyper-engagement of reward regions and whether this differs across stimuli. Evidence of generalized decreased sensitivity to rewards in ASD is consistent with recent work that has identified decreased reward sensitivity as a transdiagnostic factor present in other conditions including schizophrenia, bipolar disorder, and symptoms related to depression [13, 40]. A key limitation of the SID and MID tasks broadly, as noted above, is that the typical social (smiling face) and monetary rewards (image of 2-euro coin) included may not be comparable in terms of reward magnitude.

Another recent fMRI study utilizing the MID framework attempted to address this methodological confound by including both the standard version of the MID task and a version in which participants earned monetary rewards for another participant in the study [41]. Unlike the results of the study by Baumeister et al. (2020), no group differences were found during the reward anticipation phase for either the vicarious reward condition or the standard reward condition. Thus, it may be that differences in reward anticipation disappear when using a task where the social and nonsocial reward conditions are well-matched. However, this study included only 16 adults with ASD and 15 TD adults and differences in reward processing may be too nuanced to detect without a larger sample size.

Electroencephalogram/Event-Related Potentials In a recent cued incentive delay task with concurrent EEG, Matyjek et al. (2020) examined anticipatory processing across monetary, social, and combined monetary and social reward conditions [42]. Researchers examined the relationship between the contingent-negative variation (CNV) and ASD traits in 55 neurotypical adults. Results of this study indicated that participants with more symptoms of ASD demonstrated larger CNV amplitudes across all conditions in the early anticipation phase but not the late anticipation phase (directly before reward reception). This study was the first to examine differences in reward anticipation across early and late temporal stages. Importantly, these findings suggest that, by collapsing over temporal stages of anticipation, researchers may be missing modulation in the relationship between ASD symptoms and reward-related processes. This highlights an important area for future research, particularly in electroencephalogram/event-related potential (EEG/ERP) studies, which provide more temporal precision than fMRI studies. However, it is important to note that this study was conducted with TD adults. It is not clear whether the same pattern of results would extend to individuals with more severe symptoms of ASD and future studies should replicate these methods in individuals with a broader range of symptoms. Additionally, given the evidence that reward salience and engagement of reward-related brain regions change across development, findings in adult samples may not generalize to children and adolescents. Therefore, longitudinal studies are needed to better understand when differences in reward anticipation emerge in individuals with ASD and how they may evolve across the lifespan.

Summary and Future Directions

Reward anticipation is composed of complex and multifaceted neural functions, and the equivocal nature of research findings in TD and ASD populations reflects this complexity. As researchers continue to disentangle this complexity, important areas for future investigation have emerged. Namely, researchers should carefully consider demographic characteristics such as age and sex assigned at birth when identifying a target sample for reward anticipation studies. Reward sensitivity and processing changes across typical development, particularly during the onset of puberty and the accompanying hormonal changes [23, 24]. Additionally, recent works examining reward "liking" have revealed sex assigned at birth as a moderator that bears investigation in reference to reward anticipation. Results of a neuroimaging study revealed sex assigned at birth differences in reward processing between girls and boys with ASD [43]. Results indicated that girls with ASD demonstrated increased neural responsivity to social rewards as compared with boys with ASD and TD girls. However, while sex assigned at birth differences in reward "liking" have been observed in autistic individuals, associations between reward anticipation and gender have yet to be examined and bear future investigation [43]. Special attention should therefore be paid to the interaction of age and sex assigned at birth in characterizing reward anticipation. This is particularly the case when studying individuals with ASD given the neurodevelopmental nature of and sex assigned at birth differences observed in ASD.

We have also identified important methodological considerations for future studies. While the MID and SID tasks are widely used and are beneficial in terms of replicability and clear delineations between reward anticipation and receipt stages, a potential confound is that the social and nonsocial rewards typically used in these tasks may not be comparable in terms of reward tangibility and magnitude [29]. Researchers should continue to investigate potential alternative stimuli that may serve as social and nonsocial rewards. Additionally, it may be useful to examine multiple stages of reward processing within a given task to examine temporal differences in reward processing engagement [42].

Conclusions

Reward anticipation is a complex process that varies by important demographic characteristics such as age and sex assigned at birth. In the future, researchers should employ longitudinal study designs to better understand the way reward anticipation evolves across development. Growing evidence suggests that individuals with ASD demonstrate aberrant generalized reward processing not specific to social reward. Therefore, it may be useful to conceptualize differences in reward anticipation as a transdiagnostic factor, rather than an ASD-specific deficit [13].

Compliance with Ethical Standards

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

References

1. Baumeister RF, Leary MR. The Need to Belong: Desire for Interpersonal Attachments as a Fundamental Human Emotion. Psychol Bull. 1995;117:497–529.
2. Dichter GS, Felder JN, Green SR, Rittenberg AM, Sasson NJ, Bodfish JW. Reward circuitry function in autism spectrum disorders. Soc Cogn Affect Neurosci. 2012;7:160–72.
3. Kohls G, Schulte-Rüther M, Nehrkorn B, Müller K, Fink GR, Kamp-Becker I, et al. Reward system dysfunction in autism spectrum disorders. Soc Cogn Affect Neurosci. 2013;8:565–72.
4. Chevallier C, Kohls G, Troiani V, Brodkin ES, Schultz RT. The social motivation theory of autism. Trends Cogn Sci. 2012;16:231–9.
5. Clements CC, Zoltowski AR, Yankowitz LD, Yerys BE, Schultz RT, Herrington JD. Evaluation of the social motivation hypothesis of autism: a systematic review and meta-analysis. JAMA Psychiatry. 2018;75:797–808.
6. Foxx RM. Applied behavior analysis treatment of autism: the state of the art. Child Adolesc Psychiatr Clin N Am. 2008;17:821–34.
7. Verschuur R, Didden R, Lang R, Sigafoos J, Huskens B. Pivotal response treatment for children with autism spectrum disorders: a systematic review. Rev J Autism Dev Disord. 2014;1:34–61.
8. Lerner MD, Mikami AY. A preliminary Randomized Controlled Trial of Two Social Skills Interventions for Youth With High-Functioning Autism Spectrum Disorders. Focus Autism Other Dev Disabl. 2012;27:147–157.
9. Berridge KC, Robinson TE. Parsing reward. Trends Neurosci. 2003;26:507–13.
10. Berridge KC, Robinson TE, Aldridge JW. Dissecting components of reward:'liking','wanting', and learning. Curr Opin Pharmacol. 2009;9:65–73.
11. Keifer CM, Dichter GS, McPartland JC, Lerner MD. Social Motivation in Autism: Gaps and Directions for Measurement of a Putative Core Construct. [Commentary on Jaswal & Akhtar]. Behav Brain Sci. 2019;42:27–29.
12. Vidal-Ribas P, Benson B, Vitale AD, Keren H, Harrewijn A, Fox NA, et al. Bidirectional associations between stress and reward processing in children and adolescents: a longitudinal neuroimaging study. Biol Psychiatry Cogn Neurosci Neuroimaging. 2019;4:893–901.
13. Schwarz K, Moessnang C, Schweiger JI, Baumeister S, Plichta MM, Brandeis D, et al. Transdiagnostic prediction of affective, cognitive, and social function through brain reward anticipation in schizophrenia, bipolar disorder, major depression, and autism spectrum diagnoses. Schizophr Bull. 2020;46:592–602.
14. Nelson EE, Jarcho JM, Guyer AE. Social re-orientation and brain development: an expanded and updated view. Dev Cogn Neurosci. 2016;17:118–27.
15. Nelson EE, Leibenluft E, McClure EB, Pine DS. The social re-orientation of adolescence: a neuroscience perspective on the process and its relation to psychopathology. Psychol Med. 2005;35:163–74.
16. Burnett S, Sebastian C, Cohen Kadosh K, Blakemore S-J. The social brain in adolescence: evidence from functional magnetic resonance imaging and behavioural studies. Neurosci Biobehav Rev. 2011;35:1654–64.
17. Jones RM, Somerville LH, Li J, Ruberry EJ, Powers A, Mehta N, et al. Adolescent-specific patterns of behavior and neural activity during social reinforcement learning. Cogn Affect Behav Neurosci. 2014;14:683–97.
18. Urosevic S, Collins P, Muetzel R, Lim K, Luciana M. Longitudinal changes in behavioral approach system sensitivity and brain structures involved in reward processing during adolescence. Dev Psychol. 2012;48:1488–500.
19. Shulman EP, Smith AR, Silva K, Icenogle G, Duell N, Chein J, et al. The dual systems model: review, reappraisal, and reaffirmation. Dev Cogn Neurosci. 2016;17:103–17.
20. Dafny N, Rosenfeld GC. Neurobiology of drugs of abuse. In: Conn's Transl. Neurosci: Academic Press; 2017. p. 715–22.
21. Bush G, Vogt BA, Holmes J, Dale AM, Greve D, Jenike MA, et al. Dorsal anterior cingulate cortex: a role in reward-based decision making. Proc Natl Acad Sci. 2002;99:523–8.
22. Glazer JE, Kelley NJ, Pornpattananangkul N, Mittal VA, Nusslock R. Beyond the FRN: broadening the time-course of EEG and ERP components implicated in reward processing. Int J Psychophysiol. 2018;132:184–202.
23. Murty VP, Shah H, Montez D, Foran W, Calabro F, Luna B. Age-related trajectories of functional coupling between the VTA and nucleus accumbens depend on motivational state. J Neurosci. 2018;38:7420–7.
24. Hallquist MN, Geier CF, Luna B. Incentives facilitate developmental improvement in inhibitory control by modulating control-related networks. Neuroimage. 2018;172:369–80.
25. Ladouceur CD, Kerestes R, Schlund MW, Shirtcliff EA, Lee Y, Dahl RE. Neural systems underlying reward cue processing in early adolescence: the role of puberty and pubertal hormones. Psychoneuroendocrinology. 2019;102:281–91.
26. Richards JM, Plate RC, Ernst M. A systematic review of fMRI reward paradigms used in studies of adolescents vs. adults: the impact of task design and implications for understanding neurodevelopment. Neurosci Biobehav Rev. 2013;37:976–91.
27. Gu R, Huang W, Camilleri J, Xu P, Wei P, Eickhoff SB, et al. Love is analogous to money in human brain: coordinate-based and functional connectivity meta-analyses of social and monetary reward anticipation. Neurosci Biobehav Rev. 2019;100:108–28.

28. Chan Y-C, Hsu W-C, Chou T-L. Dissociation between the processing of humorous and monetary rewards in the ‘motivation’and ‘hedonic’brains. Sci Rep. 2018;8:1–11.
29. Matyjek M, Meliss S, Dziobek I, Murayama K. A Multidimensional View on Social and Non-social Rewards. Front. Psychiatry. 2020;11.
30. Hill KE, Oumeziane BA, Novak KD, Rollock D, Foti D. Variation in reward-and error-related neural measures attributable to age, gender, race, and ethnicity. Int J Psychophysiol. 2018;132:353–64.
31. Greimel E, Bakos S, Landes I, Töllner T, Bartling J, Kohls G, et al. Sex differences in the neural underpinnings of social and monetary incentive processing during adolescence. Cogn Affect Behav Neurosci. 2018;18:296–312.
32. Lawrence K, Campbell R, Skuse D. Age, gender, and puberty influence the development of facial emotion recognition. Front Psychol. 2015;6:1–14.
33. Oumeziane BA, Schryer-Praga J, Foti D. “Why don’t they ‘like’me more?”: comparing the time courses of social and monetary reward processing. Neuropsychologia. 2017;107:48–59.
34. Stavropoulos KKM, Carver LJ. Reward anticipation and processing of social versus nonsocial stimuli in children with and without autism spectrum disorders. J Child Psychol Psychiatry Allied Discip. 2014;55:1398–408.
35. Damiano CR, Cockrell DC, Dunlap K, et al. Neural mechanisms of negative reinforcement in children and adolescents with autism spectrum disorders. J Neurodev Disord. 2015;7:1–11.
36. Richey JA, Rittenberg A, Hughes L, Damiano CR, Sabatino A, Miller S, et al. Common and distinct neural features of social and non-social reward processing in autism and social anxiety disorder. Soc Cogn Affect Neurosci. 2014;9:367–77.
37. Stavropoulos KKM, Carver LJ. Oscillatory rhythm of reward: anticipation and processing of rewards in children with and without autism. Mol Autism. 2018;9:1–15.
38. Delmonte S, Balsters JH, McGrath J, Fitzgerald J, Brennan S, Fagan AJ, et al. Social and monetary reward processing in autism spectrum disorders. Mol Autism. 2012;3:1–13.
39. Baumeister S, Moessnang C, Bast N, et al. Attenuated anticipation of social and monetary rewards in autism spectrum disorders. bioRxiv. 2020. https://doi.org/10.1101/2020.07.06.186650.
40. Han GT, Tomarken AJ, Gotham KO. Social and nonsocial reward moderate the relation between autism symptoms and loneliness in adults with ASD, depression, and controls. Autism Res. 2019;12: 884–96.
41. Greene RK, Damiano-Goodwin CR, Walsh E, Bizzell J, Dichter GS. Neural Mechanisms of Vicarious Reward Processing in Adults with Autism Spectrum Disorder. Autism Res Treat. 2020 https://doi.org/10.1155/2020/8014248
42. Matyjek M, Bayer M, Dziobek I. Autistic traits affect reward anticipation but not reception. Sci Rep. 2020;10:1–12.
43. Lawrence KE, Hernandez LM, Eilbott J, et al. Neural responsivity to social rewards in autistic female youth. Transl Psychiatry. 2020;10:1–12.