Non-Social Reward Processing in Autism Spectrum Disorder: a Systematic Review

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Abstract

One of the key characteristics of autism spectrum disorder (ASD) is impaired social functioning. It has been hypothesized that people with autism lack motivation for social stimuli due to social reward hyposensitivity. Recent research suggests hyposensitivity during reward processing in ASD is not restricted to social rewards. The main objective of the current study was to investigate if ASD-individuals are hyposensitive towards non-social stimuli as well. A systematic review is performed where 23 studies were included for qualitative analysis. The findings are inconclusive. Less than half of the included studies showed aberrant results that would indicate under responsiveness (physiological and behavioural responses) during non-social reward processing in ASD-individuals compared to typically developing individuals. There was no clear evidence that differences between studies in methodological approaches could explain these inconsistent findings regarding non-social reward processing in ASD. Nevertheless, taking the current findings and findings of social reward processing into account there seems to be at least some evidence for altered (non-)social reward processing in ASD-individuals. Furthermore, some studies indicate possible altered reward sensitivity towards specific or domain related stimuli. So the term 'non-social' might be too broad. Future research might focus on sensitivity towards specific types of reward in ASD-individuals.

Keywords: ASD, autis*, reward processing, non-social

Introduction

Autism spectrum disorder (ASD) is a neurodevelopmental disorder that develops at an early (preschool) age. The estimated prevalence of ASD is 1 or 2 percent of the population around the globe (Wiśniowiecka-Kowalnik & Nowakowska, 2019). ASD is characterized by main features including restricted repetitive behaviours and patterns, restricted interests, and pervasive deficits in social functioning. The deficits in social functioning are expressed in impairments in social communication, social interaction and social cognition (American Psychiatric Association, 2013). These features of ASD can result in deficits in several domains throughout the lifespan such as in social, academic, professional and personal domains and are thereby affecting daily-life functioning (Pierce & Courchesne, 2001; Rosello et al., 2020; Hancock et al., 2017).

Much research is conducted on the impairments in the social domain in individuals diagnosed with ASD. Several theories try to explain these impairments in social functioning. One of these theories is the Theory of Mind (ToM) (Premack & Woodruff, 1978). The ToM can be described as the understanding of one's own mind and the realisation and understanding of the existence of the other's mind, mental states and perspectives. As well as the realisation that the mind of others is independent of their own mind. There has been hypothesized that the ToM is impaired in individuals that are diagnosed with ASD. Deficits in ToM is also referred to as mind blindness and expresses in, among other things, a lack of empathy (Baron-Cohen, Leslie, & Frith, 1985). Baron-Cohen et al. (1985) proposed that specific cognitive deficits, instead of general retardation, are at the basis of an impaired ToM, possibly resulting in deficits in social functioning. Since then, ToM and social cognition in ASD is widely studied. Other than the traditional view described by the ToM, where cognitive dysfunctions and the lack of empathy are central components in social dysfunctions, a new perspective emerged where not cognitive

dysfunctions but rather motivation is a key factor in the impaired social functioning. Chevallier et al. (2012) introduced the Social Motivation Theory of Autism (SMT). In this framework, the impaired social cognition and lack of interest in social stimuli (e.g. social interaction or seeking social contact) might be due to a diminished motivation towards these social stimuli. Here, reduced social motivation is described as a cause for these impairments rather than a consequence. Social motivation can be divided into three subcategories, respectively 'social orienting', that is a preference to focus attention towards social stimuli, 'social reward', that is taking pleasure in and seeking social interaction and 'social maintenance', that is investing in social relationships and maintaining them (Chevallier et al., 2012).

The current study focuses on the rewarding aspect of the SMT. Reward consists of three components, including 'wanting', 'learning' and 'liking'. The 'wanting' component represents the incentive value and is related with reward seeking, the 'learning' component refers to the classic and instrumental associations and cognitive representations of reward and the 'liking' component represents the hedonic value, the pleasurableness of reward (Berridge & Robinson, 1995; Berridge, 2009). To experience a stimulus as rewarding, the reward system, or the mesocorticolimbic pathway is of great importance (Fibiger & Phillips, 1988). This system consists of multiple brain areas and neural tracts (Olds & Milner, 1954) and several neurotransmitters are involved in this pathway. A simplified representation of the reward system is the following, starting in the mesencephalon, where the ventral tegmental area (VTA) is located. The VTA contains mostly dopamine and gamma-aminobutyric acid (GABA) producing neurons (Merrill et al., 2015). Dopamine is a neurotransmitter that is important in (among other things) reward/motivation directed behaviour (Schultz, 2007). The VTA projects dopamine signals to the Nucleus Accumbens (NAcc) and other parts of the striatum in the mesolimbic

pathway and projects dopamine signals to cortical/(pre)frontal brain areas in the mesocortical pathway (Tu, Bi, Zhang, Wei, & Hu, 2020). Alterations in these pathways (e.g. aberrant activation of relevant brain regions, altered chemical balance) could possibly affect reward related behaviour.

Multiple studies have been performed to test the SMT of autism and several studies found results indicating a hyposensitivity towards social stimuli (Choi et al., 2015; Demurie et al., 2011; Dubey et al., 2017; Shafritz et al., 2015). However, statistical examination and systematic investigation of the results of various studies showed atypical responses not only during social reward processing, but also during non-social reward processing in ASD-participants when compared to typically developing (TD) individuals (Clements et al., 2018; Bottini, 2018). Thus, there is growing evidence that reward processing deficits in ASD are possibly not limited to social stimuli. Furthermore, the SMT of autism is not fully satisfying, it leaves questions about key characteristics such as restricted interests and repetitive behaviour unanswered. Hyposensitivity for reward in general, not limited to social reward, caused by altered or atypical reward mechanisms, may provide an insight into underlying causes of these other features of ASD. Although Bottini (2018) found some evidence for aberrant non-social reward processing in ASD, the main aim of that specific systematic review was to examine evidence for the SMT. To shift the perspective, in the current study, solely non-social reward processing in individuals with a diagnosis of ASD will be systematically reviewed. Hopefully contributing to an understanding of reward processing in ASD. The main objective is to investigate whether published studies found evidence for a hyposensitivity for non-social reward in ASD diagnosed individuals. Furthermore, possible contributors to non-social reward processing in participants with ASD will be investigated.

Methods

Search Strategy

In the current systematic review the checklist from 'Preferred Reporting Items for Systematic Reviews and Meta-Analyses' (PRISMA) (Moher, Liberati, Tetzlaff, & Altman, 2009) was used to systematically screen and review the studies. The inclusion criteria were formulated in advance. The inclusion criteria contain the following requirements for inclusion; (1) a group of participants in the study is diagnosed with ASD (or autism); (2) the study must describe a quasi-experimental design, where an experimental group consisting of individuals that are diagnosed with ASD is compared with a control group; (3) non-social reward processing is incorporated as a measurable variable and included as outcome measure; (4) Finally, the studies are published in an international scientific journal between the first of January 2000 and the first of January 2020 and the studies are written in English. One exclusion criteria was determined, specifically, studies using incentives as an intervention for enhancing particular behaviour in ASD individuals were excluded because suchlike studies focus somewhat on another aspect of reward related behaviour and are thereby not suitable for inclusion in the current study.

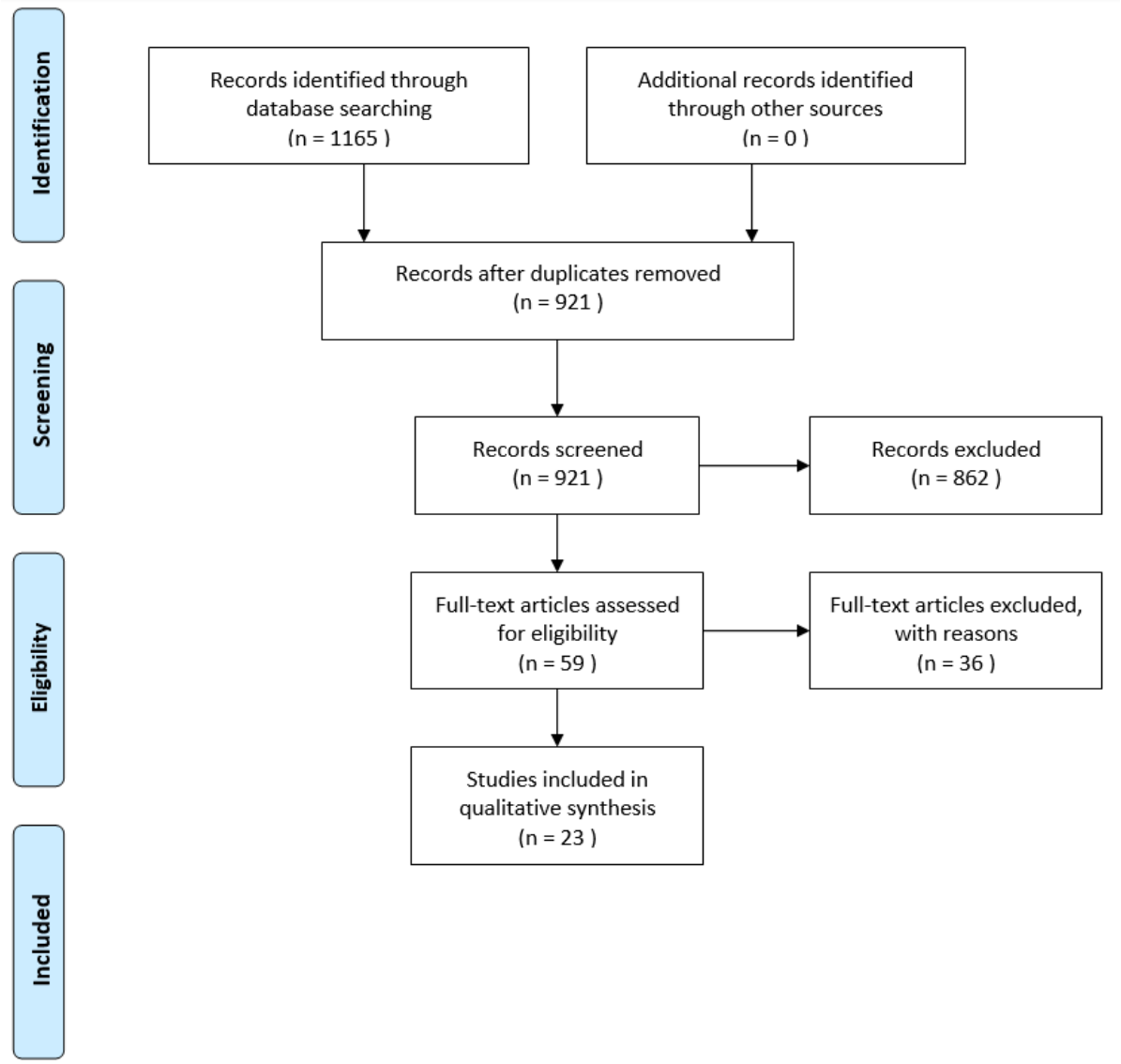
The electronic databases PsycInfo and PubMed were searched for studies published in academic journals. The key search terms were terms related to the diagnosis of autism spectrum disorder, including *autis** or *ASD*. These terms were paired with search terms related to (non-social) reward processing, *reward* and/or *delay discounting.* The search results of both PubMed and PsycInfo were then exported to RefWorks (Legacy version), whereafter duplicate references were searched and removed. After removing the duplicates, the studies were screened in two rounds. During the first round, the studies were selected through title and abstract analysis. Thereafter, full-texts were further screened. The studies that did not meet the inclusion criteria were excluded, even as studies that were not suitable for reasons (e.g. case studies).

Results

The database search delivered 432 hits in PubMed and 733 hits in PsycInfo, with a total of 1165 hits. After deleting duplicates, abstract screening and full-text analysis, 23 articles were included for qualitative synthesis. For a description of the separate steps see the PRISMA flow diagram (Moher et al., 2009) in Figure 1.

Figure 1

Flow-Diagram, overview of article selection per step for qualitative analyses.



The studies included for analysis were published between 2008 and 2020. Most studies that were included were published in 2012. The 23 studies were conducted by 19 different research groups. For an overview of the characteristics of the studies see Table 2.

Participants Characteristics

The total number of participants examined in the included studies was 1058. Of these participants, 458 participants were diagnosed with ASD, 495 participants were labelled as typically developing (TD) participants, and 105 participants were diagnosed with another disorder (obsessive compulsive disorder (OCD), attention deficit hyperactivity disorder (ADHD) and/or comorbid ASD/ADHD). The participants that were diagnosed with OCD, ADHD or comorbid ASD/ADHD were included as a distinct experimental group separate from the ASD group. In all studies the diagnosis was based on the expertise of a psychologist and was according the guidelines of the International Statistical Classification of Diseases and Related Health Problems (ICD-10), the Diagnostic and Statistical Manual of Mental Disorders (IV/IV-TR/V) and/or the Autism Diagnostic Interview-Revised (ADI-R). In some studies an Autism Diagnostic Observation Schedule (ADOS) was administered by a trained examiner to verify and confirm the earlier diagnosis. In 17 studies the samples consisted of children and/or adolescents, in six studies the participants were adults. Of the ASD-participants 90% was male and 10% was female (two studies were excluded from this calculation because of an unknown male/female ratio in the samples). In all studies, the experimental (ASD) group was matched on age and IQ with the TD control group.

Experimental Paradigms and Type of Reward

The three most used experimental paradigms are (modified) incentive delay task (k = 5), temporal discounting (or delay discounting, or delay of gratification) (k = 4) and guessing task (k = 4). Two studies used an incentive go/no go paradigm and two studies used a(n)

(implicit) learning task paradigm. The remaining six studies used other paradigms such as (k = 1 per study): Effort-expenditure for rewards task, Iowa Gambling Task for Children, Simple computer game, Continuous performance test, Monetary / econometric choice task and a block design were images of food were shown to children that had fasted for at least four hours. For an overview of the experimental paradigms that were used in the included studies, see Table 1.

In 18 of the 23 studies, a monetary reward was included as a non-social stimulus. Mostly in a gain or neutral/loss condition where a certain magnitude of a monetary reward was provided, often through visual presentation of the reward during the task (e.g. image of coins, overview of earned money), but also through auditory presentation (e.g. sound of falling coins). The other non-social stimuli included are images of food, objects (e.g. high/low autism interest), distorted faces and arrows composed of scrambled face elements and goldfish, a video clip of a person's favourite interest and a cookie.

Type of Measurement

In total 17 studies included physiological responses (EEG (k = 6); fMRI (k = 10); electrodermal response (k = 1)) as an outcome measure. Four studies used temporal discounting variables such as '*k'* and the Area Under the Curve (AUC). Both '*k'* and AUC are rates/measures of how the experienced value of reward declines over a certain period in time. The remaining studies used performance score/accuracy, reaction time and/or choice as a measurement type. Most studies used more than one measurement type. Reaction time and accuracy was most used, mostly in combination with other measurement types (e.g. fMRI, EEG) (see Appendix for a description of the measurement types used in the included studies).

Table 1

Experimental paradigms used in the included studies with description, in alphabetic order

Experimental Paradigm	Description
Block-Design	Passively viewing images of food (reward) after fasting for 4 hours (fMRI), afterwards making a (performance) memory task.
Continuous Performance Test	Computerized performance test with monetary incentive. Letter stream of stimuli with target stimuli 'X' and 'O' 24 times included, one of the two is linked to reward, pressing a button during the right target stimuli provides a reward.
Econometric Choice Task	Choosing between a scrambled image of a face paired with a constant reward (sound of coins) and an image (social, HAI, LAI) paired with reward (sound of coins) for the duration of less or more seconds.
Effort-Expenditure Task	Choosing between an 'easy task' (less motoric effort) paired with a stable, small monetary reward, or a 'hard task' (more motoric effort) paired with a variable but larger monetary reward.
Go/No-Go Task	Performance task where an action is required in the 'go' trial (e.g. pressing a button) and where an action must be suppressed in the 'no go' trial (e.g. not pressing a button). Accurate responses were paired with a monetary reward.
Guessing Game/Task	Guessing between presented stimuli (images), where after feedback is provided (positive/negative/neutral reward).
Learning Task	A learning task with positive or negative outcomes (e.g. in a monetary reward condition: to win money or lose money) when choosing an option (picture). Learning through the positive or negative feedback paired with the chosen stimulus.
Iowa Gambling Task	Decision making, with feedback (reward, e.g. a gain or a loss of money) provided after a decision that is made.
(Modified) Monetary Incentive Delay Task	Responding to the target stimulus as quickly as can to earn reward after the presentation of a cue stimulus and a blank screen. After the response a feedback screen is presented.
Simple Computer Game	Pressing a button that corresponds with the digit presented on a screen. Adequate responses provide a reward (e.g. monetary).
Temporal/Delay Discounting	Choosing between a smaller immediate reward or a larger reward over a longer time period.

Note: fMRI=functional Magnetic Resonance Imaging, HAI=High Autism Interest, LAI=Low Autism Interest.

Non-Social Reward Sensitivity per Experimental Paradigm

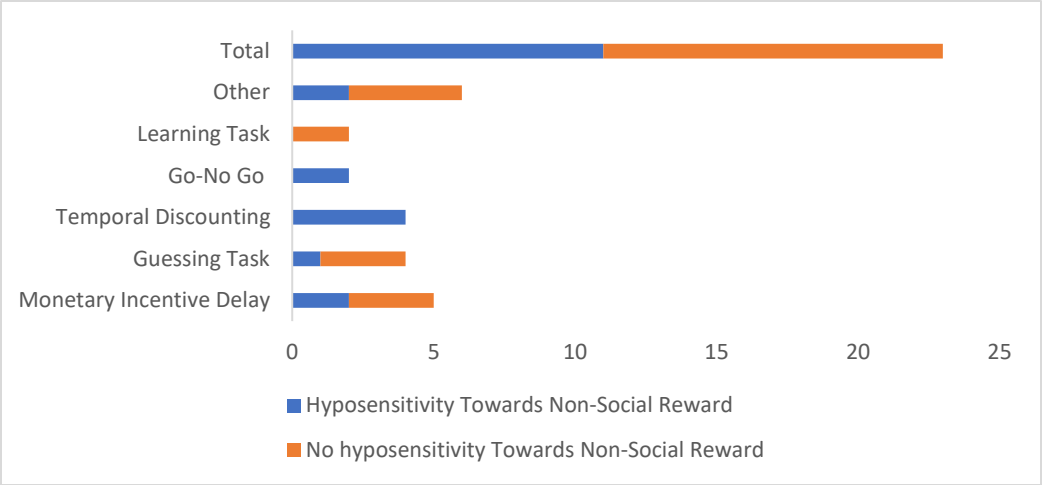
The results of the studies are first described per type of experimental paradigm. The order in which the results are described is from most studies per paradigm to fewest studies per paradigm, thus as following, Monetary Incentive Delay task, Temporal Discounting, Guessing Game, Incentive Go/No Go, Implicit Learning task, and the group of studies with all different paradigms. For an overview of the findings per experimental paradigm see Figure 2.

Starting with the (modified) monetary incentive delay paradigm. Of the five studies that used this paradigm, two studies found responses indicating aberrant reward processing in ASD (Dichter et al., 2012a; Dichter et al., 2012b). These studies found evidence for a diminished sensitivity towards a non-social, monetary, reward in ASD-individuals when compared to TD-individuals. Interestingly, Dichter et al. (2012a) found this effect only during the monetary condition and not during the other non-social condition 'images of objects'. Two studies did not find significant differences between the ASD- and TD-groups (Delmonte et al., 2012; Demurie et al., 2011). One study (Kohls et al., 2018) found opposite results where ASD-participants perceived specific personal interests as more rewarding than TD-participants did, suggesting a hypersensitivity towards this type of non-social reward.

All studies (k = 4) using a temporal discounting/delay of gratification paradigm found results indicating a hyposensitivity towards non-social rewards in ASD-participants in comparison with TD-participants (Carlisi et al., 2018; Chantiluke et al., 2014; Faja & Dawson, 2015; Warnell et al., 2019). In these studies the ASD-participants discounted the non-social (monetary) reward more steeply than TD-participants did and would/could not wait as long as TD-participants for a reward. These findings represent a preference for an immediate smaller reward instead of a larger delayed reward in individuals diagnosed with ASD.

Figure 2

Overview of the results per experimental paradigm



Note: Results concerning non-social reward processing in individuals diagnosed with ASD compared to TD-individuals, indicating hyposensitivity in blue and indicating no hyposensitivity in red.

Of the studies using a guessing game paradigm (k = 4), one study found significant aberrant results in the ASD-group when compared to the TD-group (Stavropoulos & Carver, 2018). Stavropoulos and Carver (2018) showed ASD-participants were less sensitive than TD-participants to the non-social reward that was presented during the feedback, reward, processing phase. The diminished sensitivity in ASD-participants was not found during the anticipation of the non-social reward. The other three studies did not find any group differences (ASD versus TD) (Stavropoulos and Carver, 2014; Larson et al., 2011; McPartland et al., 2012).

Both (k = 2) studies using the incentive go/no go paradigm found significant aberrant results in ASD-participants during the non-social condition (Kohls et al., 2011; Kohls et al., 2013). Both studies found ASD-participants were less responsive during the ‘go’ trial than TD-

participants, indicating hyposensitivity. The under responsiveness was not found during the 'no go' trial. One study (Kohls et al., 2011) found ASD-participants made more mistakes than TD-participants during all conditions.

Of the studies (k = 2) that used a(n) (implicit) learning task, no study found evidence for a hyposensitivity towards non-social reward in ASD (Lin et al., 2012; Scott-Van Zeeland et al., 2010). Moreover, Lin et al. (2012) found that ASD-participants learnt faster than the TD-group during the monetary condition. Suggesting that the ASD-group experienced the non-social stimulus as rewarding. Scott-Van Zeeland et al. (2010) did not find significant differences between the ASD-participants and TD-participants.

Of the studies that all used a different experimental paradigm per study (group of studies combined (k = 6)) two studies found some evidence for a hyposensitivity in ASD towards non-social stimuli (Damiano et al., 2012; Watson et al., 2015). Damiano et al. (2012) and Watson et al. (2015) showed ASD-participants preferred hard tasks over easy tasks more often than TD-participants, also when the monetary reward would be lost or when the reward probability would be reduced. Indicating no particular sensitivity for the monetary reward that was paired with the tasks. Two studies found opposite results. Cascio et al. (2012) found ASD-individuals were more sensitivity to a primary non-social (food) reward than TD-individuals and Schmitz et al. (2008) found ASD-participants were more sensitive toward the monetary reward than TD-participants during a continuous performance test. The other two studies did not find any differences between the ASD-group and the TD-group (Neuhaus et al., 2015; Gonzalez-Gadea et al., 2016).

Table 2

An overview of characteristics and results of the included studies

Authors	N	Sex (m/f)	Age (M ± SD in years)	Diagnosis	Experimental paradigm	Non-social stimulus	Control stimulus	Measurement type	Results (non-social condition - ASD versus TD)	Hypo-sensitivity non-social stimuli
Carlisi et al. (2017)	20 ASD 20 OCD 20 TD	20/0 20/0 20/0	14,7 ± 1,8 15,7 ± 1,4 15,3 ± 1,8	ICD-10, ADI-R, ADOS	Temporal discounting	Monetary	n/a	fMRI, temporal discounting variable (k)	Smaller AUC. Reduced activity in OFC, precuneus, cerebellum, posterior cingulate, ACC, vmPC	Yes
Cascio et al. (2012)	17 ASD 18 TD	17/0 17/1	12,8 ± 2,5 13,2 ± 3,4	ADOS, ADI-R, DSM-IV	Block design, where children viewed pictures after at least 4 hours without food	Food images	n/a	fMRI Memory-task-scores	Increased activity in bilateral insula and anterior cingulate. No differences in activation of NAcc, amygdala and OFC. Score on memory-task: non-significant	No
Chantiluke et al. (2014)	15 ASD 18 ADHD 13 both 18 TD	15/0 18/0 13/0 18/0	14,8 ± 1,9 14,4 ± 2,1 14,1 ± 1,4 15,3 ± 1,8	ICD-10, ADI-R, ADOS.	Temporal discounting	Monetary	n/a	fMRI, temporal discounting variable (k)	Greater k-value, smaller AUC, relatively little disorder specific brain abnormalities	Yes
Damiano et al. (2012)	20 ASD 38 TD	17/3 34/4	25,95 ± 8 20,42 ± 5,6	Clinical judgement of licenced psychologists, ADOS	Effort-expenditure for rewards task	Monetary	n/a	Choice for task (hard vs. easy) Reaction Time	ASD choose more often the hard task, but decreased sensitivity towards reward probability. RT or performance: non-significant	Choice task – No Monetary - Yes
Delmonte et al. (2012)	21 ASD 21 TD	un-known	17,6 ± 3,5 17,0 ± 3,4	DSM-IV-TR ADI-R, ADOS.	Monetary incentive delay	Monetary, Distorted face picture	Image of face	fMRI, Reaction Time, Accuracy	Reduced dorsal striatum activity for SID, not for MID. RT and Accuracy: non-significant	No

Demurie et al. (2011)	31 ASD 35 ADHD 40 TD	27/4 25/10 28/12	11,4 ± 1,8 12,5 ± 2,1 12,4 ± 2,36	DSM-IV-TR ADI-R, ADOS	Monetary incentive delay	Monetary	n/a	Reaction Time	Faster RT in monetary condition	No
Dichter et al. (2012a)	15 ASD 16 TD	15/0 16/0	30,1 ± 11,6 27,5 ± 7,5	Clinical judgement of licenced psychologists, ADOS	(Modified) Incentive delay	Monetary, Object images (e.g. train)	n/a	fMRI, Reaction Time	Decreased NAcc activation during monetary and not object (anticipation & outcome). RT: Slower than NT in all conditions.	Yes
Dichter et al. (2012b)	16 ASD 20 TD	14/2 14/6	26,0 ± 9,1 25,4 ± 7,0	Clinical judgement of licenced psychologists, ADOS	(Modified) Incentive delay	Monetary	Image of face	fMRI, Reaction Time	Hypoactivation (anticipation phase) in right NAcc, hippocampus, OFC, ACC. RT: non-significant	Yes
Faja and Dawson (2015)	21 ASD 21 TD	un-known	6,8 ± 0,6 6,7 ± 0,6	ADI-R, ADOS, DSM-IV-TR	Delay of gratification	Treat (e.g. cookie)	n/a	Behavioural performance (Time waited, Pass/Fail)	Less time waited by ASD individuals. More fails than TD.	Yes
Gonzalez-Gadea et al. (2016)	28 ASD 19 ADHD 22 TD	27/1 13/6 14/8	10,4 ± 2,1 11,7 ± 2,5 11,4 ± 2,4	DSM-V	Iowa Gambling Task for Children (Monetary decision making)	Monetary gain/loss	n/a	ERP – feedback error-related negativity and ACC activation	No significant group differences in ACC activation and fERN responses	No
Kohls et al. (2011)	16 ASD 20 TD	16/0 20/0	14,5 ± 2,8 14,5 ± 2,8	ICD-10, DSM-IV, ADI-R.	(Modified) Incentive go/no-go	Monetary	Mosaic Pictures (neutral), faces (social)	EEG – ERP - P3-response, Reaction Time, accuracy	RT: non-significant Accuracy: ASD less accurate (all trials). Go-cue P3-response lower in all conditions. Within-subjects ASD: NR = MR > SR	Yes

Kohls et al. (2013)	15 ASD 17 TD	15/0 17/0	14,6 ± 3,3 13,9 ± 3,0	ICD-10, DSM-IV ADOS, ADI-R	Incentive go/no-go, blocked design.	Monetary	Mosaic pictures (non-reward)	fMRI, Reaction Time, accuracy	No-go: non-significant. Go: decreased activation (MR) in midbrain, thalamus, amygdala, dorsal & ventral striatum/NAcc. Ventral-, anterior dorsal-, posterior dorsal-, pregenual ACC. RT and accuracy: non-significant (group effect).	Yes
Kohls et al. (2018)	39 ASD 22 TD	29/10 17/5	12,6 ± 2,4 12,9 ± 2,1		(Modified) Incentive delay	Video clip of persons favourite interest	Videoclip of a person and 'TV static'	fMRI, Reaction Time, Accuracy	Greater activity of caudate during CI RT and accuracy: non-significant	No
Larson et al. (2011)	25 ASD 25 TD	23/2 24/1	13,9 ± 2,5 14,1 ± 2,7	Clinical judgement of licenced psychologists, ADOS	Guessing task	Monetary loss/gain	n/a	EEG – ERP – FRN amplitude, P300, N1. Reaction Time	RT: non- significant. FRN amplitude: No significant group differences	No
Lin et al. (2012)	10 ASD 10 TD	7/3 7/3	28 ± 3,1 27 ± 3,1	DSM-IV, ADOS, ADI-R.	Instrumental learning task	Monetary	Image of face plus matching sound effects	Choice performance, Learning curve Reaction Time	More choices for monetary than social stimuli (opposite pattern of NT). Faster learning curve in monetary condition. Reaction Time: non-significant	No
McPartland et al. (2012)	26 ASD 28 TD	22/4 17/1	11,2 ± 2,5 12,1 ± 0,95	DSM-IV, ADOS, ADI-R	Guessing game	Monetary gain	Neutral draw	EEG - Early visual processing associated ERP's (N1,	No significant differences between groups for N1, P2 and FRN scores.	No

								P2), FRN amplitude		
Neuhaus et al. (2015)	18 ASD 18 TD	18/0 18/0	10 ± 1,1 10 ± 0,9	DSM-IV-R ADI-R ADOS	Simple computer game	Monetary	(un)familiar social, non-reward	Electrodermal responses, reaction time, accuracy	Non-significant (all measurement types)	No
Schmitz et al. (2008)	10 ASD 10 TD	10/0 10/0	20 – 50 y/o	ICD-10, ADI	Continuous performance test with monetary incentive	Monetary		Event-Related fMRI, accuracy, Reaction Time (RT= within group, reward vs. non-reward)	Increased anterior cingulate gyrus activation. RT and accuracy: non-significant	No
Scott-Van Zeeland et al. (2010)	16 ASD 16 TD	16/0 16/0	12,4 ± 2,14 12,3 ± 1,76	ADI-R, ADOS.	Learning task - Two event-related mixed-trial rewarded learning tasks	Monetary (picture 3 gold coins vs picture 3 gold coins with 3 crosses through the coins)	Face of a woman (smiling or frowning).	fMRI, Learning curve	No significant group differences in neural responses and in reward related learning.	No
Stavropoulos and Carver (2014)	20 ASD 23 TD	19/1 22/1	6 – 8 y/o	Formal evaluations autism centre or school. ADOS	Guessing game	Arrow composed of scrambled face elements and goldfish	Images of faces (social)	EEG (ERP-SPN and FRN amplitude)	SPN: non-significant FRN: non-significant (for arrow conditions)	No
Stavropoulos and Carver (2018)	20 ASD 23 TD	19/1 22/1	6 – 8 y/o	Formal evaluations autism centre or school. ADOS	Guessing game	Arrow composed of scrambled face elements and goldfish	Images of faces (social)	EEG – alpha band activity (8-12 Hz) and theta band activity (4-6 Hz)	Reward anticipation: alpha band – more left hemisphere suppression during arrow and less during face condition. Reward processing: more alpha suppression and less theta activity	Reward anticipation: No Reward Processing: Yes

									regardless of condition (arrow/face).	
Warnell et al. (2019)	27 ASD 27 TD	21/6 21/6	20,98 19,81	Clinical judgement of licenced psychologists, ADOS	Delay discounting	Monetary	Social	Degree of discounting (via AUC)	Smaller AUC in both monetary and social discounting	Yes
Watson et al. (2015)	12 ASD 22 TD	9/3 20/2	15,3 ± 2,9 13,4 ± 2,5	ADOS-G	Monetary / econometric choice task	HAI (images of trains, electronics), LAI (images of clothes, nature). Sound of coins.	Images of faces	Choice (for money and image category)	HAI, more choices and even willing to forgo money. LAI, no group-differences Social: no group-differences	HAI – No Monetary - Yes

*Note***:** ASD=Autism Spectrum Disorder, OCD=Obsessive Compulsive Disorder, ADHD=Attention Deficit Hyperactivity Disorder, TD=Typically Developing, RT= Reaction Time, fMRI= functional Magnetic Resonance Imaging, CI= Circumscribed Interests, AUC=Area Under the Curve, HAI=High Autism Interests, LAI=Low Autism Interest, EEG=Electroencephalography, ERP=Event-Related Potential, SPN=Stimulus-Preceding Negativity, FRN=Feedback-Related Negativity , ICD-10=International Statistical Classification of Diseases and Related Health Problems, DSM-IV/V=Diagnostic and Statistical Manual of Mental Disorders (IV/V), ADOS=Autism Diagnostic Observation Schedule, ADI-R=Autism Diagnostic Interview-Revised, NR= Neutral Reward, SR= Social Reward, MR= Monetary Reward, ACC=Anterior Cingulate Cortex, vmPC, ventromedial Prefrontal Cortex, OFC=Orbito-Frontal Cortex, NAcc=Nucleus Accumbens, SID=Social Incentive Delay, MID=Monetary Incentive Delay.

Non-Social Reward Sensitivity per Type of Measurement

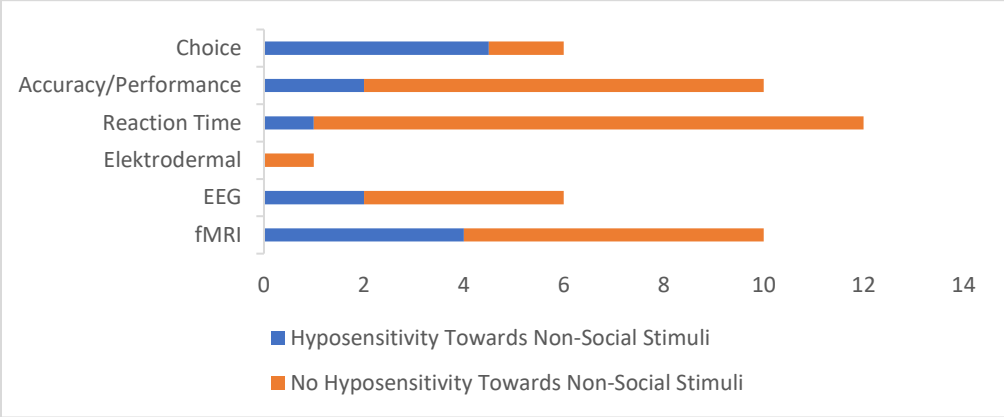
The results per type of measurement were also investigated in the current systematic review. Here the results will be described in the following order; first physiological results (fMRI, EEG, and electrodermal responses), then behavioural results (reaction time, performance score/accuracy, choice (including AUC and 'k'). For an overview of the results per measurement type, see Figure 3.

Starting with fMRI-data. Of all studies (k = 10) examining neural activation using fMRI measurements, four studies found significant aberrant activation in brain regions associated with the reward circuitry in the ASD-group compared to the TD-group that would indicate a hyposensitivity during the non-social condition (Carlisi et al., 2017; Dichter et al., 2012a; Dichter et al., 2012b; Kohls et al., 2013). These brain regions include parts of the striatum (e.g. Nucleus Accumbens, left caudate nucleus) and (pre-/orbito-)frontal regions of the cortex. See Table 3 for an overview of the specific analysed brain regions per study. Some interesting results were found by Dichter et al. (2012a) where less reward-circuitry related brain activity was found in the ASD-group than in de TD-group during the anticipation phase, that is the anticipation for the reward, in the monetary condition but no significant group effect was found in the object (also non-social) condition. In the outcome phase, significantly less activation was found in the monetary condition, and significantly more activation was found in the object condition. Dichter et al. (2012b) found similar results in the non-social reward condition, with hypo-activity during the anticipation phase and hyperactivity during the outcome phase in the ASD-group compared with the TD-group. In contrast of the findings described above, some studies (k = 3) found increased activation in reward related brain regions during the non-social condition in ASD-participants compared to TD-participants (Cascio et al., 2012; Kohls et al., 2018; Schmitz et al.,

2008), indicating a sensitivity towards the presented non-social stimuli. The other studies (k = 3) did not find significant differences in brain activity between ASD- and TD-participants during non-social reward processing (Chantiluke et al., 2014; Scott-Van Zeeland et al., 2010; Delmonte et al., 2012).

Figure 3

Presentation of results per measurement type.



Note: Results concerning non-social reward processing in individuals diagnosed with ASD compared to TD-individuals, indicating hyposensitivity in blue and indicating no hyposensitivity in red.

Of the studies that used EEG data (k = 6) two studies found results where ASD-individuals had significantly altered EEG measurements in comparison with TD-individuals during a non-social condition what would indicate a hyposensitivity towards the presented non-social reward cue (Kohls et al., 2011; Stavropoulos & Carver, 2018). Kohls et al. (2011) found significantly lower p300 (p3) responses in the ASD-group than in the TD-group. A lower p3 response (amplitude) represents diminished responsiveness and thereby a possible

hyposensitivity towards the non-social reward. Within-subject analysis (ASD-group) showed the lowest p3 response (amplitude) during the 'go cue' in the social reward trial and non-significant different p3 responses during the monetary reward and non-reward trials (Thus, p3 responses: NR = MR > SR). Suggesting the least sensitivity towards social stimuli and no different sensitivity towards non reward and monetary reward. Stavropoulos and Carver (2018) found participants with ASD showed less theta activity than TD-participants during non-social reward processing. Indicating less oscillatory brain activity during non-social reward processing in ASD than in TD-children and thus a probable hyposensitivity towards the stimulus in the processing phase. However, in the anticipation phase increased left hemisphere alpha suppression was found in the non-social condition, suggesting more sensitivity in the anticipation phase for the presented non-social cue. The other EEG-studies (k = 4) did not find significant differences in the EEG measurements (e.g. FRN-, N1-, P300-, P2-, fERN-amplitudes) between the ASD- and TD-group (Stavropoulos & Carver, 2014; Larsen et al., 2011; McPartland et al., 2012; Gonzalez-Gadea et al., 2016).

One study included electrodermal responses as outcome measure, no significant group differences were found in electrodermal responses during non-social reward processing in the ASD-group compared to the TD-group (Neuhaus et al., 2015).

Next, the behavioural responses will be described, starting with 'reaction time' and followed by 'accuracy/performance score' and 'choice'. Of the studies (k = 12) that used reaction time as measurement type, one study found significant slower reaction times in the ASD-group in comparison with the TD-group during the presentation of a non-social stimulus, indicating hyposensitivity (Dichter et al., 2012a). In contrast, Demurie et al. (2011) found faster reaction times in the ASD-group than in the TD-group, what would indicate a sensitivity towards the

presented non-social stimuli. The other (k = 10) studies did not find significant group differences (ASD versus TD) in reaction times (Damiano et al., 2012; Delmonte et al., 2012; Dichter et al., 2012b; Kohls et al., 2011; Kohls et al., 2013; Kohls et al., 2018; Larson et al., 2011; Lin et al., 2012; Neuhaus et al., 2015; Schmitz et al., 2008).

Next to reaction time, accuracy/performance score was investigated. Of the studies (k = 10) that included accuracy or performance score in their studies, two studies found ASD-participants performed significantly less accurate or worse during a non-social condition than TD-participants (Kohls et al., 2011; Faja & Dawson, 2015). However, Kohls et al. (2011) found less accurate responses in the ASD-group in all conditions (also in social and neutral conditions) than in the TD-group. One study found opposite results (Lin et al., 2012) where the ASD-group scored significantly higher learning rates during the monetary condition than the TD-group. Most studies (k = 7) found no significant differences in accuracy/performance scores between ASD-participants and TD-participants during non-social reward trials (Cascio et al., 2012; Delmonte et al., 2012; Kohls et al., 2013; Kohls et al., 2018; Neuhaus et al., 2015; Schmitz et al., 2008; Scott-Van Zeeland et al., 2010).

Lastly, the choices that were made by the participants during the non-social conditions will be described. Of the studies (k = 6) studies where participants made choices, three studies found quite clear results that would suggest hyposensitivity towards non-social stimuli in ASD (Warnell et al., 2019; Carlisi et al., 2017; Chantiluke et al., 2014). These three studies mentioned above, all found smaller AUC's in individuals diagnosed with ASD than in TD-individuals. Representing more choices for a smaller but immediate reward instead of a greater reward later in time. The other three studies showed less clear results. Damiano et al. (2012) found ASD-participants choose the hard tasks (paired with a variable amount of monetary reward) more

often than the easy tasks (paired with a stable low amount of monetary reward) than TD-participants did. In addition, Watson et al. (2015) found ASD-participants choose 'high autism interest' (HAI) images (non-social) significantly more often than TD-participants and were willing to receive less monetary reward when choosing the HAI-images. There were no group-differences found in the 'low autism interest' (LAI) and in the 'social' condition. Lin et al. (2012) found ASD-participants choose the monetary reward more often than the social reward in comparison with TD-participants, no neutral reward was included.

Table 3

Summary of analysed brain regions per study

Study	Experimental Paradigm	Brain regions	Non-social Hyposensitivity
Carlisi et al. (2017)	Temporal Discounting	Right ventro medial and lateral orbito frontal cortex, medial inferior prefrontal cortex, cerebellum, posterior cingulate, precuneus, left caudate	Yes
Cascio et al. (2012)	Block design showing images of food	Clusters in bilateral insula and anterior cingulate cortex	No
Chantiluke et al. (2014)	Temporal Discounting	Inferior parietal lobe, superior temporal lobe	Yes
Delmonte et al. (2012)	Incentive Delay Task	dorsal striatum, left caudate	No
Dichter et al. (2012a)	Incentive Delay Task	Nucleus Accumbens	Yes
Dichter et al. (2012b)	Incentive Delay Task	Nucleus Accumenbens, orbito frontal cortex, anterior cingulate cortex	Yes
Kohls et al. (2013)	Incentive go/no-go	Ventral striatum, dorsal striatum, thalamus, dorsal cingulate, posterior cingulate, precuneous	Yes
Kohls et al. (2018)	Incentive Delay task	Left caudate	No
Schmitz et al. (2008)	Continuous Performance Test	Insula, anterior cingulate cortex, middle frontal gyrus, superior frontal gyrus, middle frontal gyrus, superior parietal lobe	No
Scott-Van Zeeland et al. (2010)	Two event-related mixed-trial rewarded learning tasks	Ventral striatum, anterior cingulate gyrus	No

Discussion

In the current study, a systematic review was conducted to evaluate studies on reward sensitivity towards non-social stimuli in participants diagnosed with ASD. The hypothesis was that individuals with ASD are less sensitive towards non-social stimuli than TD-individuals are. The results are inconsistent. After analysing the included studies, no clear evidence and consistent patterns were found. Somewhat less than half of the studies show aberrant neural activation or altered behavioural responses in the presence of a non-social reward stimulus in ASD-individuals compared to TD-individuals that would suggest a hyposensitivity to this stimulus. However, within certain 'groups' of the included studies (e.g. group of studies with the same experimental paradigm or with the same measurement type) some small patterns were found. The most consistent evidence was found in the four studies using a temporal discounting/delay of gratification paradigm and to a lesser extent in the two studies using a go/no go paradigm. These six studies showed significantly altered responses in the non-social reward condition that support the current hypothesis.

Concerning the temporal discounting paradigm, findings suggest participants with ASD prefer an immediate but smaller (non-social) reward over a larger reward later in time more often than TD-individuals (Chantiluke et al., 2014; Faja & Dawson, 2015; Warnell et al., 2019; Carlisi et al., 2017). In temporal discounting the time period is a critical factor. Apart from reward sensitivity, fore-sight and executive functions, such as planning and inhibition, also play a great role in decision making behaviour during such tasks. Temporal/Delay discounting and executive functioning play an important role in self-regulatory behaviour (Hofmann, 2012). It has been hypothesised that executive functioning is impaired in individuals with neurodevelopmental disorders such as ASD (Johnston et al., 2019; Hill & Bird, 2006). According to Mobini et al.

(2007) discounting values can be related to (cognitive) impulsiveness and non-planning. Therefore, deficits in executive functions, such as inhibition control and planning, could possibly be confounding variables, affecting decision making and thereby the outcomes of the task. Suggesting not the lack of motivation or a hyposensitivity towards non-social reward, but rather executive dysfunctions (in ASD) could affect the choice for the immediate smaller reward over the larger but later reward. Not much research is conducted on social discounting in individuals with ASD. One study (Warnell et al., 2019) focussed on a social aspect during a discounting task, namely, the choice for a monetary reward for the participant self or for a monetary reward for a friend or family member. Though not significant, Warnell et al. (2019) found a trend where individuals with ASD prefer a smaller monetary reward for themselves over a greater reward for a person close to them more often than TD-participants. Perhaps this could be due to deficits in social functioning in ASD, but it could also represent the same pattern of other types of behaviour more related to executive functions as described above.

Next to the temporal discounting tasks, the two studies that used an incentive 'go/no-go' paradigm showed evidence for non-social reward hyposensitivity in individuals diagnosed with ASD, particularly in the neurophysiological responses. Namely, ASD-participants showed less neuronal activation (brain activity (fMRI) and p3-responses (EEG)) compared to TD-participants during the 'go' trial, when an action had to be performed in the non-social condition (Kohls et al., 2011; Kohls et al., 2013). During the 'no-go' trial no group differences were found, indicating no substantially different inhibitory control in individuals with ASD than in TD-individuals. The aberrant neural activation during the 'go' cue, suggests less reactivity and thus hyposensitivity towards the non-social cue. However, ASD-participants and TD-participants did not differ in reaction time in both studies during the experimental trials (Kohls et al., 2011; Kohls

et al., 2013) and did not differ in accuracy in one study (Kohls et al., 2013). Kohls et al. (2011) found ASD-participants were less accurate than NT-participants. But they were less accurate in all trials (non-social, social and neutral trials). Studies that used this experimental paradigm and focused on the reward processing of social stimuli in ASD-individuals found no clear evidence for a hyposensitivity in ASD as well. Although Shafritz et al. (2015) did find hyposensitivity towards the social stimulus in ASD, this diminished sensitivity towards social stimuli during go/no-go tasks was not found in most other studies (Pankert et al., 2014; Dermurie et al., 2016; Kohls et al., 2011; Kohls et al., 2013; Kohls et al., 2014).

Besides the types of experimental paradigm described above, also types of measurement were investigated in the current systematic review. Differences were found between measurement types and their outcomes concerning reward sensitivity towards non-social stimuli in ASD-diagnosed individuals. In percentage terms, studies using EEG data showed less evidence for altered neuronal activation, thus reward hyposensitivity, than studies using fMRI data. EEG measures a broader somewhat general level of neural activation, less specific per brain region than fMRI measurements do. As aforementioned, the reward system is a complex network composed of specific brain areas and neural connections between these areas. Some of these brain areas lie quite on the surface, such as cortical areas. However, some important subcortical structures of this network lie deeper, such as components of the basal ganglia (e.g. nucleus accumbens and caudate nucleus) (Sherman et al., 2018). Possibly, EEG instruments are not sufficient enough to accurately measure the activation of specific (deeper lying) reward circuitry related brain areas. Although the fMRI studies show ambiguous results concerning brain activation, they did find some evidence for hypo-activation in parts of the reward circuitry in non-social reward conditions. Perhaps the differences in brain activity measured, might be due to

the methodological differences (e.g. non-social reward type, participant characteristics, experimental paradigms). For instance, the experimental paradigms surely all aim to trigger the reward system during the experimental trials. Nevertheless, it might be possible that these paradigms trigger this circuitry in slightly different ways resulting in different states of activation.

Overall the results of the behavioural responses are less robust than the results of the physiological responses. Individuals diagnosed with ASD seemed to perform even accurate and with the same speed as TD-individuals. The most convincing finding is the choice for smaller immediate reward over a larger but later reward, as previously described. Other choices that ASD-individuals made show perhaps an interesting trend. Damiano et al. (2012) showed that ASD-participants choose the hard tasks more often than TD-participants, regardless of reward magnitude or probability of succeeding. Also, Watson et al. (2015) showed that ASD-participants were even willing to forgo a monetary reward for a high interest stimulus. These choices might not directly indicate a hyposensitivity towards non-social stimuli in general. It might be possible that certain specific types of stimuli/reward are more triggering than others (e.g. specific personal interests versus monetary stimuli or social stimuli). Biological responses might also indicate this pattern. Where reduced brain activity was found during the monetary trial but not during the trial where an object of interest was presented (Dichter et al., 2012a), and more brain activity was found in ASD than in controls when presenting a video clip of a personal interest (Kohls et al., 2018) or when presenting photos of primary rewards such as food (Cascio et al., 2012). Although small, these results might indicate altered non-social reward processing might be more domain specific than general. And could possibly give some insight in

mechanisms of other key characteristics of ASD as well, such as restricted interests. Future research might focus on the reward processing of specific non-social domains.

Limitations

The findings of this systematic review should be seen in the light of some limitations. Firstly, a remarkable amount of different types of experimental paradigms and measurement types were used in the included studies (e.g. modified incentive delay, guessing task, 'go/no go' paradigms, EEG, fMRI, Reaction Time, Choice). Moreover, the studies used multiple distinct sets of combinations of these experimental paradigms and measurement types. These differences could contribute to the inconsistencies that were found in the outcomes of the studies. These inconsistent findings are not only seen in studies investigating non-social reward processing, but also in studies focussing on social reward processing (Bottini, 2018). Making it hard to draw general, straight and comprehensive conclusions about (non-)social reward sensitivity in ASD-individuals.

Next to the differences in measurement types and types of tasks, some notes should be made on the participant characteristics. The participant samples included in the studies lack heterogeneity in age and gender. Namely, the samples used in the studies consisted mostly of male participants with a young age. The overrepresentation of male participants might be due to the population ratio male/female with ASD diagnoses, that is 4-5:1 (Wiśniowiecka-Kowalnik & Nowakowska, 2019). Nevertheless, the homogeneity in age and gender (male and child) in the (experimental) participant samples result in less external validity to female children and male/female adults in the population. An understanding of ASD in different age groups and different types of gender might be important, also for suitable interventions per group. Ergo,

future research should include more females/adults in the participant samples to enhance generalizability.

Additionally, the lack of variety was also seen in the types of non-social reward stimuli that were used in the studies. Despite the fact that 'non-social' is a broad term, meaning all stimuli that are not social, the vast majority of the studies used a monetary reward as a non-social reward stimulus. The outcomes of reward processing during monetary reward trials might therefore not be representative for the reward processing of all non-social stimuli. Moreover, restricted interests is one of the key characteristics in ASD (American Psychiatric Association, 2013). So possibly, money is not much of an interest in people with ASD. For instance, Watson et al. (2005) found ASD-diagnosed participants would even forgo money for a 'high autism interest' picture. In further research, more different types of non-social stimuli should be included for a better understanding of non-social reward processing in ASD.

Finally, an aspect that concerns the procedure for conducting a systematic review. According to the guidelines of PRISMA for performing a systematic review, at least two researchers should independently screen and analyse the titles, abstracts and full texts for inclusion to ensure objective analysis and minimize bias during article selection (Moher et al., 2015). However, due to constraints only one researcher screened the studies for inclusion during the selection procedure.

Implications

The studies included in the current systematic review are inconclusive in their results, it is unclear if the inconsistencies are due to the remarkable amount of differences in methodological approaches. A clear conclusion that ASD-individuals are hyposensitive towards non-social stimuli cannot be drawn. Nevertheless, taken this systematic review and previous

systematic reviews and meta-analyses into account (Bottini, 2018; Clements et al., 2018) there seems to be at least a tendency for a hyposensitivity during reward processing in ASD-individuals in a broader way than the social motivation of autism proposes (Chevallier et al., 2012). Also, some studies suggest a domain related hypo-activation of the reward system in ASD. Thus, the term ‘non-social reward’ might be too broad and has to be specified. Further research might focus on the reward processing of several distinct domains of stimuli.

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Appendix

Table A1

Measurement types, outcome measures, used in the included studies

Measurement Type		Description
Physiological responses	fMRI, BOLD	Activation levels in specific brain areas measured through the increased blood flow towards the activated brain region/structure. BOLD method measures activation through oxygen/carbon dioxide fluctuations in blood in a specific brain area.
	EEG/ERP's: SPN, FRN, p3, alpha and theta	Activation measured through neuronal firing, amplitude analysis, representing state of arousal. Associated with certain events or phases (e.g. stimulus presentation, anticipation, processing).
	Electrodermal Responses	Measurement of arousal through variations in sweat glands activity in the skin, resulting in more or less skin conductance.
Behavioural responses	Accurateness	Performance, amount of correct responses.
	AUC, *k*-variable	Representation of how reward is discounted in a certain period over time (e.g. quickly or slowly).
	Choice	Choosing between options (e.g. preference).
	Reaction Time	Duration of time before an action is performed (e.g. time till pressing a button).

Note: fMRI=functional Magnetic Resonance Imaging, BOLD=Blood Oxygen Level Dependent, EEG=Electroencephalography, ERP=Event-related potential, SPN=Stimulus Preceding Negativity, FRN=Feedback Related Negativity, AUC=Area Under the Curve.