CHAPTER 3
Social reward processing in children with ADHD
A systematic literature review
ABSTRACT

Objective: Like individuals with autism spectrum disorder (ASD), individuals with attention-deficit/hyperactivity disorder (ADHD) often experience difficulties in social functioning. Although research indicates aberrant processing of tangible rewards in ADHD, less is known about social reward processing in ADHD. Therefore, the aim of this study was to gain insight into social reward processing in individuals with ADHD.

Methods: The literature was systematically searched for studies examining social reward processing in individuals with ADHD in comparison to typically developing controls (TDCs) and ASD. Six studies conducted in children were included and reviewed.

Results: In general, the included studies demonstrated that social rewards increase motivation, task performance, and (reward-related) neural responsiveness in children with ADHD. Most studies found intact social reward processing in ADHD and only a few studies found hyperresponsiveness to social rewards in ADHD relative to TDCs (two out of five studies concerning task performance and one out of one study with regard to neural responsiveness) and ASD (one out of one study concerning temporal discounting and one out of one study with regard to neural responsiveness).

Conclusion: There is limited research on social reward processing in ADHD. Although the findings on social reward processing in ADHD are inconsistent, studies indicate rather hyperresponsiveness than hyporesponsiveness to social rewards in ADHD, which is contrary to findings in ASD.
INTRODUCTION

Attention-deficit/hyperactivity disorder (ADHD) is a neurodevelopmental disorder (American Psychiatric Association, 2013) with an estimated prevalence of 5 to 7% in children (Polanczyk et al., 2007; Thomas et al., 2015; Willcutt, 2012). Although the core symptoms of ADHD are inattention, hyperactivity, and impulsivity (American Psychiatric Association, 2013), many individuals with ADHD experience difficulties in social functioning (for reviews, see Hoza, 2007; Kok et al., 2016; Nijmeijer et al., 2007; Ros & Graziano, 2018). For example, in comparison to same-age peers, children with ADHD are less socially preferred, and more often socially isolated and rejected by peers (Hinshaw, 2002; Hoza et al., 2005). Furthermore, children with ADHD have fewer and less enduring reciprocal friendships, which are often of lower quality (Hoza et al., 2005; Normand et al., 2013, 2011). These difficulties may be due to the core symptoms of ADHD, which pose difficulties in social situations, such as intrusive and inattentive behaviors and comorbid externalizing behaviors (Nijmeijer et al., 2007). These behaviors increase the risk for peer rejection (particularly in girls with ADHD), which may start a negative spiral of fewer positive social interactions leading to impaired development of social skills (Kok et al., 2016; Mikami & Hinshaw, 2003). It is, therefore, not surprising that ADHD has recently been associated with deficient social cognition, including emotion recognition and theory of mind (Bora & Pantelis, 2018). According to meta-analytic findings (Bora & Pantelis, 2018), individuals with ADHD show an intermediate pattern of social cognition somewhere between typically developing individuals and autism spectrum disorder (ASD). ADHD and ASD often co-occur (see review of Leitner, 2014) and share various behavioral (e.g., hyperactivity), cognitive (e.g., executive dysfunction), and neurobiological (e.g., fronto-striatal dysfunction) characteristics (for reviews, see Rommelse et al., 2011; Taurines et al., 2012), complicating a differential diagnosis.

Several theories suggest aberrant reward processing to be one of the underlying mechanisms of ADHD as well as ASD. The social motivation theory of ASD (Chevallier et al., 2012) assumes an early-onset reduced social interest in children with ASD, expressed as diminished social orienting (i.e., paying attention to social signals), social reward sensitivity, and social maintaining (i.e., the desire to maintain social bonds over sustained periods of time). These motivational deficits are supposed to have downstream effects on the development of social cognition and social skills. However, a recent meta-analytic study (Bottini, 2018) has found mixed support for the social motivation theory of ASD. Although there is evidence for aberrant social reward processing in ASD, deficiencies are often present during non-social reward processing as well, indicating a more general reward sensitivity deficit in ASD. Moreover, Bottini (2018) suggests that specific components of reward processing (e.g., learning) may be disrupted in ASD. Whereas the social motivation theory of ASD emphasizes reduced interest with regard to the social domain, theoretical models of ADHD focus on aberrant sensitivity to reinforcement (e.g., reward and response cost) in general without distinguishing between different types of incentives (see reviews of Luman et al., 2005, 2010). Studies on reward processing in ADHD have predominantly made use of tangible rewards, whereas social rewards (e.g., verbal praise, smiling face, cooperation, and competition) are most common in daily life, for
example when parenting and teaching children. Therefore, in the present literature review, we systematically examine social reward processing in ADHD and compare these findings with previous review findings on social reward processing in ASD (Bottini, 2018).

Social reward processing shows large similarities with non-social reward processing (e.g., food and money; Bhanji & Delgado, 2014; Daniel & Pollmann, 2014; Krach, Paulus, Bodden, & Kircher, 2010; Lin, Adolphs, & Rangel, 2012; Rademacher et al., 2015). Reward processing is not a single construct but consists of different components, including ‘wanting’, ‘liking’, and ‘learning’ (Berridge & Robinson, 2003; Berridge et al., 2009). ‘Wanting’ (or ‘incentive salience’) refers to the motivational aspect of reward and occurs during the anticipation of reward. ‘Liking’, by contrast, reflects the hedonic experience during the consummation of reward. Finally, learning is the acquisition of information about predictive relationships between stimuli and actions and occurs throughout the reward cycle. These components of reward processing are associated with different neurobiological substrates (see reviews of Berridge et al., 2009; Kohls, Chevallier, Troiani, & Schultz, 2012). For example, the ventral striatum plays a central role in reward processing, particularly in ‘wanting’. ‘Liking’, on the other hand, is predominantly associated with activation of the ventromedial prefrontal cortex, especially the orbitofrontal cortex. In addition, category-specific reward brain areas have been observed (Grabenhorst & Rolls, 2011; Rademacher et al., 2009). Social approval, for example, predominantly activates the amygdala, whereas monetary reward consumption strongly relates to activation of the thalamus (Rademacher et al., 2009). The dopamine system has been found to play an important role in reward processing (Berridge & Robinson, 2003; Berridge et al., 2009; Kohls et al., 2012). However, dopamine seems most important for ‘wanting’, whereas opioid neuropeptides are mainly associated with ‘liking’. There is growing evidence that oxytocin supports reward processing with regard to social stimuli (Rademacher et al., 2015). Although the reward components are psychologically and neurobiologically dissociable, most studies using behavioral outcome measures do not allow disentangling these components because both ‘wanting’ and ‘liking’ contribute to task performance.

Multiple theoretical models provide a neurobiological explanation for altered reward processing in ADHD (see review of Luman et al., 2010). Some of these theories focus on neurochemical deficits, i.e., dysfunction of the dopamine system (Sagvolden et al., 2005; Tripp & Wickens, 2008). Others assume that deficiency in the activation of brain reward pathways plays a significant role (Nigg & Casey, 2005; Sonuga-Barke, 2002, 2003). For example, the dual pathway model attributes aberrant reinforcement in ADHD to abnormalities in the mesolimbic fronto-ventral striatal circuits (Sonuga-Barke, 2002, 2003). The theoretical models all include behavioral predictions for altered reinforcement in ADHD, which have primarily been tested by utilizing tangible rewards.

Research has shown several patterns of aberrant reward processing in ADHD, although the findings being mixed (Luman et al., 2005, 2010). Firstly, individuals with ADHD often show steeper temporal discounting of rewards as reflected by a preference for small, immediate rewards over larger, delayed rewards (see meta-analytic review of Jackson & Mackillop, 2016). This delay aversion
is supported by findings of decreased activation of the ventral striatum during the anticipation of rewards in individuals with ADHD (see meta-analytic review of Plichta & Scheres, 2014). Secondly, there is evidence that ADHD is associated with increased risk-taking. Several studies using gambling tasks indicate that individuals with ADHD are more likely to favor large but risky rewards over small but more probable rewards (see review of Groen, Gaastra, Lewis-Evans, & Tucha, 2013). Thirdly, individuals with ADHD often show less efficient or slower reward-based learning than healthy controls (Frank et al., 2007; Groen et al., 2008; Luman, Van Meel, et al., 2008; Thoma et al., 2018). Fourthly, compared to healthy controls, individuals with ADHD seem to benefit more from rewards, i.e., cognitive task performance of individuals with ADHD is often more improved when reward is added (Luman et al., 2005). In accordance with this finding, ADHD has been found to be associated with altered psychophysiological responses when no rewards are used but normal psychophysiological responses when rewards are added (Luman, Oosterlaan, Hyde, Van Meel, & Sergeant, 2007), particularly when these rewards are delivered immediately and consequently (Groen, Tucha, Wijers, & Althaus, 2013). These findings suggest that individuals with ADHD have a low level of intrinsic motivation and depend more on external motivation.

The present study
In the present study, we perform a systematic literature review on social reward processing in individuals with ADHD. Social rewards are of particular importance in daily life, for example in behavioral parenting programs and classroom interventions. Considering the overlap between ADHD and ASD, individuals with ADHD are not only compared with typically developing controls (TDCs) but also with individuals with ASD. This direct comparison between ADHD and ASD may provide more insight into the overlapping and discriminating characteristics of both disorders.

METHODS
This systematic review followed the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA). For this review, no protocol was registered.

Selection criteria
Studies were included in the review when they met the following selection criteria: (a) the study was published in English in an academic journal, (b) participants were diagnosed with ADHD, (c) a group of TDCs was included, and (d) at least one of the outcome measures reflected social reward processing. Criterion (d) required participants to be exposed to a social stimulus, which was not combined with or could not be exchanged for a material reward. Studies examining potential downstream consequences of reduced social interest, such as deficits in social cognition (e.g., face processing) and social skills, were excluded.
Search procedure
The electronic databases PsycInfo, Scopus, and Web of Science were searched for studies meeting the selection criteria. The final search was performed in August, 2018. The key terms ADHD and attention deficit hyperactivity disorder were combined with the terms social and motivat*, reward*, reinforce*, and incentive*. Titles and abstracts of the initial records were screened, after which full-text articles were assessed for eligibility.

Coding of studies
The first author coded the characteristics of the studies, including sample size, diagnostic information, medication use, sex, age, full-scale IQ, research instrument (i.e., paradigm and questionnaire), reward type, type of social reward, and outcome measure. The type of outcome measure was categorized into different aspects of reward processing: reward effects on task performance, temporal discounting, self-reported ‘wanting’ and ‘liking’, and neural reward responsiveness. We reported the results of the studies in different ways: (a) group differences (ADHD versus TDC/ASD) in a reward condition (group main effect), (b) effects of reward relative to non-reward in individuals with ADHD (reward main effect), (c) the interaction between reward type (i.e., reward versus non-reward) and group (ADHD versus TDC/ASD), and (d) whether a study provided evidence for altered reward processing in ADHD for at least one outcome measure (e.g., accuracy, response time). If studies provided the required data (i.e., means and standard deviations), Cohen’s $d$ was computed as effect size for reward and group effects. A positive effect size indicated higher temporal discounting, task performance, or neural activation in the reward condition in ADHD as compared to TDC/ASD (group effect) or a positive effect of rewards as compared to non-reward in ADHD (reward effect). An effect was considered meaningful when the study reported a statistically significant effect ($p < .05$) or the computed effect size was large ($d \geq 0.80$; Cohen, 1988).

RESULTS
Appendix 3.1 shows an overview of the literature search. The electronic databases search resulted in 996 records meeting the search terms. After removing duplicates ($k = 296$), screening titles and abstracts ($k = 700$), and reading full-text articles ($k = 46$), six studies fulfilled the criteria to be included in this review.

Characteristics of studies
The included studies have been published between 2008 and inclusive 2016 and performed by three different research groups. See Appendix 3.2 for an overview of the characteristics of these studies.

Participants.
Participants across studies consisted of 661 children and adolescents (195 ADHD, 277 TDC, 173
ASD, 16 ADHD+ASD). None of the studies examined adults. Five studies included an ASD group, with one of these five studies also including a comorbid group of children with both ADHD and ASD. Participants with ADHD all met DSM-IV (American Psychiatric Association, 1994) or DSM-IV-TR (American Psychiatric Association, 2000) criteria of ADHD. All diagnoses were confirmed using diagnostic interviews. The number of participants with ADHD per study ranged from 16 to 72 ($M = 32.5$ participants, $SD = 21.1$). Of these participants, 30.8% were classified as the predominantly inattentive subtype, 4.6% as the predominantly hyperactive/impulsive subtype, and 64.6% as the combined subtype. The ADHD samples predominantly existed of males ($M = 88.1\%$, $SD = 13.5$) with three studies including only males. Mean age of the participants with ADHD was 11.8 years ($SD = 1.6$). All studies assessed participants’ full scale IQ using subtests of the Wechsler Intelligence Scale for Children third edition (WISC-III; Wechsler, 1991). The average full scale IQ of participants with ADHD was 101.4 ($SD = 3.2$). Within studies, the ADHD group was comparable concerning age, sex, and IQ to the other groups. Participants on stimulant medication discontinued medication for at least 24 ($k = 4$) or 48 hours ($k = 2$) before testing.

**Rewards.**

All studies compared a social reward condition with a non-reward and/or non-social reward condition. Five studies used a non-reward condition in which participants could not gain a reward. Four of these studies included also a monetary reward condition. The only study not using a non-reward condition, provided multiple types of rewards in comparison to social rewards, including (hypothetical) money, activities, materials, and food.

The studies operationalized social rewards in different ways. Five studies used pictures representing social rewards. Two of these studies showed pictograms with an interaction between two persons and written compliments with points depicted on top. Stronger compliments accompanied by more points reflected larger social rewards. Two other studies operationalized a social reward as a photograph of a positively expressed face. Another study using a temporal discounting task showed various pictures representing different (hypothetical) social rewards, including compliments by meaningful persons, medals that could be won, and smiling faces. Based on the subjective ratings of the social rewards, five social rewards were selected for each participant. Instead of pictures, one study used (hypothetical) peer competition as social motivation condition.

**Paradigms and questionnaires.**

Table 3.1 provides a brief description of the used paradigms. Five studies administered a cognitive control task in which the participant had to correctly respond (and in some studies sometimes had to inhibit a response) to a target stimulus. One study used another kind of paradigm, i.e., a temporal discounting task. In addition to the paradigms, two studies used subjective rating questionnaires to assess participants’ ‘wanting’ and ‘liking’ of different types of rewards.
Outcome measures.

Five studies examined the effects of social rewards on task performance (e.g., accuracy, response time). Two of these studies also described self-reported social ‘wanting’ and liking. One study combined the behavioral and self-report measures with a neurobiological measure, i.e., functional magnetic resonance imaging (fMRI). Finally, one study examined social reward processing in terms of temporal discounting.

Findings of studies

Table 3.2 presents a summary of the findings of the studies.

Effects of rewards on task performance.

Five studies examined the effects of social rewards on task performance in participants with ADHD (Demurie, Roeyers, Baeyens, & Sonuga-Barke, 2011; Demurie, Roeyers, Wiersema, & Sonuga-Barke, 2016; Geurts, Luman, & van Meel, 2008; Kohls, Herpertz-Dahlmann, & Konrad, 2009; Kohls et al., 2014).

Two studies found evidence for hyperresponsiveness to social rewards in ADHD (Geurts et al., 2008; Kohls et al., 2009). Geurts et al. (2008) compared children with ADHD, ASD and TDCs in their performance on a Flanker task during a neutral and social motivation condition (hypothetical peer competition). The results showed faster response times across groups in the social motivation
Table 3.2. Overview of results of studies.

<table>
<thead>
<tr>
<th>Outcome measure</th>
<th>Group main effect</th>
<th>Reward main effect</th>
<th>Reward x Group interaction effect</th>
<th>Summary reward processing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Study</td>
<td>ADHD vs TDC</td>
<td>ADHD vs ASD</td>
<td>ADHD vs TDC</td>
<td>ADHD vs TDC</td>
</tr>
<tr>
<td>DeMurie et al., 2013</td>
<td>SR: ns (d = 0.26)</td>
<td>MR: + (d = 0.45)</td>
<td>SR: N/A</td>
<td>MR: N/A</td>
</tr>
<tr>
<td>Task performance</td>
<td>DeMurie et al., 2011</td>
<td>SR: − (RT correct [d = −0.66]); ns (accuracy [d = −0.32])</td>
<td>SR: + (accuracy [d = 0.31], RT correct [d = 0.38])</td>
<td>SR vs NR: ns (accuracy, RT correct)</td>
</tr>
<tr>
<td></td>
<td>DeMurie et al., 2016</td>
<td>MR: ns (no-go errors, go errors, RT go, SD-RT go)</td>
<td>MR: + (go errors, RT go, SD-RT go)</td>
<td>MR vs NR: ns (go errors, RT go, SD-RT go)</td>
</tr>
<tr>
<td>Geerts et al., 2008</td>
<td>MR: − (RT correct); ns (errors)</td>
<td>SR: − (RT correct); ns (errors)</td>
<td>SR: + (errors, RT correct)</td>
<td>MR vs NR: ns (errors, RT correct)</td>
</tr>
<tr>
<td>Kohls et al., 2009</td>
<td>SR: − (no-go errors [d = 0.97]); ns (RT go [d = −0.35], RT no-go errors [d = −0.04])</td>
<td>N/A</td>
<td>SR: + (no-go errors [d = 1.74], RT go [d = −0.02], ns (RT go, RT no-go errors)</td>
<td>N/A</td>
</tr>
<tr>
<td>Kohls et al., 2014</td>
<td>MR: − (no-go errors [d = 0.43], RT go [d = −0.54], RT no-go errors [d = 0.07])</td>
<td>MR: + (no-go errors [d = 1.90], RT no-go errors [d = 0.60], RT go [d = −0.10])</td>
<td>MR: + (RT no-go errors); − (RT go); ns (no-go errors)</td>
<td>MR: −/+ MR: N/A</td>
</tr>
<tr>
<td>Kohls et al., 2014</td>
<td>MR: + (go accuracy [d = −0.59], no-go accuracy [d = −0.19], RT go [d = −0.88])</td>
<td>MR: + (go accuracy [d = −0.26], no-go accuracy [d = −0.30], RT go [d = −0.43])</td>
<td>MR: + (go accuracy, no-go accuracy, RT go)</td>
<td>MR vs NR: ns (go accuracy, no-go accuracy, RT go)</td>
</tr>
<tr>
<td>Self-reported ‘wanting’ and ‘liking’</td>
<td>DeMurie et al., 2011</td>
<td>SR: ns</td>
<td>MR: ns</td>
<td>MR: + (d = 0.89)</td>
</tr>
<tr>
<td>Kohls et al., 2014</td>
<td>MR: ns (d = −0.59)</td>
<td>MR: + (d = 1.27)</td>
<td>MR vs NR: ns</td>
<td>MR vs NR: N/A</td>
</tr>
<tr>
<td>Kohls et al., 2014</td>
<td>MR: − (mPFC)</td>
<td>MR: + (mPFC)</td>
<td>MR vs NR: N/A</td>
<td>MR vs NR: N/A</td>
</tr>
<tr>
<td>Neural responsiveness</td>
<td>Kohls et al., 2014 (using fMRI)</td>
<td>SR: + (n/mPFC)</td>
<td>SR: + (ventral striatum)</td>
<td>MR vs NR: N/A</td>
</tr>
<tr>
<td>Kohls et al., 2014</td>
<td>MR: ns (d = −0.63)</td>
<td>MR: + (d = 0.06)</td>
<td>MR vs NR: N/A</td>
<td>MR vs NR: N/A</td>
</tr>
</tbody>
</table>

Note. ADHD = attention-deficit/hyperactivity disorder; ASD = autism spectrum disorder; mPFC = medial prefrontal cortex; MR = monetary reward; N/A = not applicable/reported; NR = non-reward; RT = response time; TDC = typically developing control; SR = social reward; vs = versus.

a (+) = relative to non-reward, reward resulted in higher task performance/self-ratings of ‘wanting’ and ‘liking’/neural activation in ADHD versus TDC/ASD (p < .05 or d ≥ 0.80) (+) = higher temporal discounting/task performance/neural activation in ADHD vs TDC/ASD (p < .05 or d ≥ 0.80); ns = no significant group difference.
b (+) = reward hyperresponsiveness to reward vs non-reward in ADHD vs TDC/ASD (p < .05); (+) = relative to non-reward, reward resulted in lower task performance in ADHD (p < .05 or d ≤ −0.80); ns = no significant differences between reward and non-reward in ADHD.
c (+) = hyperresponsiveness to reward vs non-reward in ADHD vs TDC/ASD (p < .05); (+) = reward hyperresponsiveness in ADHD vs TDC/ASD; ns = no significant group differences in reward processing.
d (+) = relative to non-reward, reward resulted in higher task performance/self-ratings of ‘wanting’ and ‘liking’/neural activation in ADHD (p < .05 or d ≥ 0.80); (+) = reward hyperresponsiveness in ADHD vs TDC/ASD; ns = no significant group differences in reward processing.
condition as compared to the neutral condition. Social motivation significantly increased accuracy in children with ADHD as compared to TDCs, and normalized their level of accuracy. No group differences were found with the children with ASD. These results were corroborated by Kohls et al. (2009), who used social (facial stimuli) and monetary rewards to motivate children with ADHD and TDCs during the performance of a go/no-go task. Social and monetary rewards improved response inhibition accuracy for both groups. The effect of social rewards was larger for participants with ADHD than for TDCs, whereas the effect of monetary rewards did not significantly differ between the groups. No group differences were found for response times. These two studies indicate hyperresponsiveness to social rewards in children with ADHD; one study indicating that this is specific for ADHD and not for ASD, and one study indicating that this is specific for social rewards and not for monetary rewards.

Three studies did not find support for altered social reward sensitivity in ADHD (Demurie et al., 2011, 2016; Kohls et al., 2014). DeMurie et al. (2011) found that children with ADHD, ASD, and TDCs all benefited to the same extent when social (pictogram of interaction with compliments and points) or monetary rewards could be won during an incentive delay task. Furthermore, participants with ADHD and participants with ASD showed shorter response times for monetary than social rewards, whereas response times for TDCs did not significantly differ between both types of reward. In line with these findings, DeMurie et al. (2016) demonstrated that social (pictogram of interaction with compliments and points) and monetary rewards had positive effects on the performance during an incentive delay go/no-go task of children with ADHD, ASD, ADHD+ASD, and TDCs. Overall, task performance was better for monetary than social rewards, irrespectively of group. In accordance with this finding, Kohls et al. (2014) found differences with regard to reward type. Whereas social rewards (facial stimuli) did not influence performance significantly during a cued incentive go/no-go task of participants with ADHD, ASD, and TDCs, monetary rewards had a positive impact on the ‘go’ hit rates, irrespectively of group.

**Temporal discounting.**

One study examined temporal discounting of social rewards in children with ADHD (Demurie, Roeyers, Baeyens, & Sonuga-Barke, 2013) and found steeper monetary temporal discounting in children with ADHD as compared to TDCs but no significant differences between both groups with regard to temporal discounting of social rewards. Furthermore, both groups discounted social rewards to a higher rate than monetary rewards. With regard to participants with ASD, the computed effect size ($d = 0.98$) indicated steeper temporal discounting of social rewards in ADHD as compared to ASD.

**Self-reported ‘wanting’ and ‘liking’.**

Two studies included self-report measures of social ‘wanting’ and ‘liking’ (Demurie et al., 2011; Kohls et al., 2014). DeMurie et al. (2011) observed no significant differences in subjective values
of written compliments nor in money between children with ADHD, ASD, and TDCs. These results were supported by Kohls et al. (2014), who found that self-ratings of reward value and motivation for a social (facial stimuli) and monetary reward condition were not significantly different for participants with ADHD, ASD, and TDCs. All groups showed the highest ratings for the monetary reward condition, followed by the social reward and non-reward condition respectively. The results of these two studies indicate intact social ‘wanting’ and ‘liking’ in children with ADHD as well as children with ASD.

**Neural reward responsiveness.**

One study examined neural social responsiveness in children and adolescents with ADHD (Kohls et al., 2014). Kohls et al. (2014) used fMRI and observed a stronger reward circuitry (including the ventral striatum) activation in response to social (facial stimuli) and monetary rewards as compared to non-reward in participants with ADHD. Relative to ASD and TDCs, ADHD was associated with medial prefrontal hyperactivation when social reward was at stake. With regard to monetary reward, participants with ADHD demonstrated fronto-parietal hypoactivation relative to TDCs and ventral striatal hyperactivation relative to ASD. In conclusion, this study indicates neural hyperresponsiveness to social rewards in children and adolescents with ADHD. This hyperresponsiveness is specific for ADHD and not for ASD and specific for social rewards and not for monetary rewards.

**DISCUSSION**

In this systematic literature review, we examined social reward processing in individuals with ADHD. Overall, the (limited number of) studies indicate that children with ADHD can be motivated by social rewards. Relative to non-reward, social rewards are associated with higher self-rated ‘wanting’ and ‘liking’, improvement of task performance, and stronger neural responsiveness in reward-related brain areas (e.g., ventral striatum). These findings also apply to monetary reward. Like TDCs, children with ADHD seem to benefit somewhat more from monetary rewards than social rewards. However, the evidence is inconsistent. Across and within studies, there is variability in the effects of one reward type above another, which may relate to various factors, such as the specific rewards used (e.g., written compliments, facial expressions), the outcome measure (e.g., accuracy, response time), and sample characteristics (e.g., age, comorbidity). Moreover, there may be individual variation in the preference for specific rewards.

There is slight evidence for intact social reward processing in ADHD in terms of self-reported ‘wanting’ and ‘liking’ (two out of two studies) and temporal discounting (one out of one study) of social rewards. Studies on the impact of social rewards on task performance show inconsistent results; a small majority of studies indicate typical effects of social rewards on task performance in ADHD (three out of five studies), whereas other studies suggest hyperresponsiveness to social rewards in ADHD, particularly for accuracy performances (two out of five studies). Evidence for hyperresponsiveness to social rewards in ADHD is also found with regard to neural responsiveness.
(one out of one study). Kohls et al. (2014) found medial prefrontal hyperactivation during social reward conditions. As activation of the medial prefrontal cortex has been mainly associated with the consummation component of reward (Berridge et al., 2009; Kohls et al., 2012), this finding may suggest that children with ADHD experience more pleasure from social rewards than TDCs (however, participants with ADHD did not indicate that they found the social feedback stimuli more rewarding than TDCs). This neural hyperresponsiveness to social rewards may express as impulsive and intrusive behavior in social contexts and may serve as a compensatory reaction to frequently experienced peer rejection (Kohls et al., 2014). Our findings imply that alterations in social reward processing in ADHD may be neurobiologically evident but may not always express behaviorally in an experimental setting. Unfortunately, firm conclusions cannot be drawn yet as only one study included neurobiological measures of social reward processing in ADHD.

The question arises whether these findings are specific for social rewards and do not apply to monetary rewards as well. Except for one study (showing steeper monetary temporal discounting in ADHD), all included studies demonstrating intact social reward processing in ADHD also indicate intact monetary reward processing. The studies suggesting hyperresponsiveness to social rewards in ADHD, show mixed results regarding monetary reward processing; one study showing contrary effects of monetary rewards (i.e., opposite effects for different performance measures), one study indicating hyperresponsiveness to monetary rewards, and one study not using monetary reward at all. In summary, the results on reward processing in ADHD are inconclusive with regard to the specificity of reward type. This finding is not surprising as a previous review of studies mainly using tangible rewards also points to inconsistencies in the literature (Luman et al., 2005). It is unclear which factors contribute to these discrepancies. However, comorbid disorders (e.g., oppositional defiant disorder and conduct disorder) are likely to be important confounders.

A second objective of our review was to compare the findings on ADHD with current and previous findings regarding social reward processing in ASD. The present review shows only very limited evidence for differences in social reward processing between ADHD and ASD. Relative to ASD, ADHD is associated with neural hyperresponsiveness to social rewards (one out of one study) and steeper temporal discounting of social rewards (one out of one study). No significant differences between both disorders are found with regard to self-reported ‘wanting’ and ‘liking’ of social rewards (two out of two studies) and social reward effects on task performance (four out of four studies). These findings imply that ADHD and ASD can be difficult to differentiate based on self-report and behavioral measures of social reward processing. However, both disorders may differ neurobiologically in social reward processing. More specifically, Kohls et al. (2014) found medial prefrontal hyperactivation under social reward conditions in ADHD as compared to ASD, suggesting that children with ADHD like social rewards more than children with ASD (which was, however, not expressed as higher self-ratings of reward value). Differences between both disorders were not limited to social rewards but also found for monetary rewards. Relative to ASD, ADHD was associated with ventral striatal hyperactivation under monetary reward conditions, suggesting
that children with ADHD are more motivated by money than those with ASD (again, this was not confirmed using self-ratings of motivation). Thus, there is some evidence that, relative to ASD, ADHD is associated with neural hyperresponsiveness to rewards in general.

Although the present review indicates that ADHD and ASD cannot be conclusively discriminated on social reward processing, evidence across studies suggests differences between both disorders in social reward processing. Our review implies rather social reward hyperresponsiveness than hyporesponsiveness in ADHD. By contrast, the social motivation theory of ASD assumes hyporesponsiveness to social reward in ASD (Chevallier et al., 2012). In a recent literature review, Bottini (2018) also concluded that, although not specific for social rewards, individuals with ASD generally show hyporesponsiveness to social rewards. These deficits in social reward processing in ASD may relate to specific components of reward. For example, there is good evidence for aberrant social reward ‘wanting’ in ASD but inconclusive evidence for disruptions in social reward ‘liking’ (see reviews of Bottini, 2018; Kohls et al., 2012). Unfortunately, the task performance measures in our review could not be used to disentangle these reward components and to derive conclusions about potential deficiencies in specific reward components in ADHD. Furthermore, behavioral manifestations of social interest involve not only social reward sensitivity but also social orienting (i.e., paying attention to social signals) and social maintaining (i.e., the desire to maintain social bonds over sustained periods of time; Chevallier et al., 2012). Possibly, ADHD and ASD differ with regard to these other aspects of social interest.

Limitations and future research
There are several limitations regarding this literature review and the included studies. Only six studies on social reward processing in ADHD were available. These studies have been performed by merely three research groups. Some studies used small sample sizes and overall, the findings of the studies were inconsistent, diminishing the reliability and firmness of our conclusions. It is striking that such little research on social reward processing in ADHD has been performed considering that ADHD has been associated with altered reward processing (Luman et al., 2005, 2010) as well as deficits in social functioning (Hoza, 2007; Kok et al., 2016; Nijmeijer et al., 2007; Ros & Graziano, 2018). Notably, most included studies examined social reward processing in ADHD in relation to ASD. The small number of studies did not allow for identifying potential confounders that could explain the inconsistencies in findings. Furthermore, it was not possible to make statements about specific theoretical models of ADHD. Therefore, future research is necessary to get more insight into social reward processing in ADHD.

The included studies predominantly focused on the impact of social rewards on task performance, particularly cognitive control. However, ADHD has also been associated with aberrant reward-based learning (Frank et al., 2007; Groen et al., 2008; Luman, Van Meel, et al., 2008; Thoma et al., 2018). As both learning and social rewards are important aspects in the educational setting, future research may focus on this component of social reward processing in ADHD as well. Moreover, it may be
important to design studies that allow for disentangling the reward components ‘wanting’ and ‘liking’. Few studies have examined self-reported social ‘wanting’ and ‘liking’, temporal discounting of social rewards, and the neurobiological underpinnings of social reward processing in ADHD. As the current review indicates neural functional abnormalities in response to social rewards in ADHD, future research may focus not only on behavioral measures of social reward processing in ADHD but also on the neurobiology underlying social reward processing in ADHD.

The majority of included studies operationalized a social reward as a static picture. The ecological validity of these simple stimuli can be disputed as real social interaction is complex (Risko et al., 2012). For future research, therefore, more ecologically valid social reward stimuli, such as video clips, are recommended. Moreover, some studies added collectible points to the social reward to have a quantifiable measure (Demurie et al., 2011, 2016). However, points may be regarded as a non-social reward and may have strengthened the social reward.

All of the included studies focused on children and none on adults with ADHD. One study used a sample consisting of children and adolescents and performed analyses across these age groups (Kohls et al., 2014). Because the reward circuitry encounters important structural and functional changes during development, particularly during adolescence, it appears necessary to examine reward processing in ADHD separately for children, adolescents, and adults (Fareri, Martin, & Delgado, 2008; Kappel et al., 2015; Padmanabhan, Geier, Ordaz, Teslovich, & Luna, 2011). Our review findings, therefore, are not necessarily generalizable to adolescents and adults with ADHD. Furthermore, all ADHD samples had a mean IQ of about 100 (average). Relative to TDCs, ADHD has been associated with a lower intellectual ability (Frazier, Demaree, & Youngstrom, 2004). Moreover, there is evidence for a relationship between IQ and cortical development, which differs between ADHD and TDCs (de Zeeuw et al., 2012), questioning the generalizability of our review findings to the whole ADHD population. Another limitation concerns potential sex differences in social reward processing in ADHD. The studies in this review included predominantly boys with ADHD. Future research may examine social reward processing in girls with ADHD as well. Although Kohls et al. (2009) found no significant association between ADHD subtype and social reward effects, future research may consider potential ADHD subtype differences in social reward responsiveness. Finally, the use of stimulant medication may influence reward sensitivity. Although all studies discontinued stimulant medication for at least 24 hours before testing, long-term treatment with stimulant medication may have effects on striatal dopamine transporter availability (Wang et al., 2013), influencing reward sensitivity.

**Implications**

Our review findings indicate that social as well as monetary rewards have positive effects on the motivation and task performance of children with ADHD. As social rewards in real life may be more valuable than static pictures as used in experimental studies, the findings are very promising for behavioral interventions in the educational and home setting. For example, teachers and parents
may not only rely on tangible rewards but also use praise, a smile, cooperation, or competition to motivate children with ADHD. The findings further imply that the impact of social rewards is equal to or even stronger for children with ADHD than for TDCs. However, it may be important to consider individual reward preferences and to alternate between different types of rewards (Zentall, 2005).

There is limited evidence for differences in social reward processing between ADHD and ASD from studies comparing ADHD and ASD directly, which may be the result of a lack of ecologically valid rewards. However, review studies point rather to social reward hyperresponsiveness in ADHD and social reward hyporesponsiveness in ASD. These findings may suggest that difficulties in social functioning in both disorders derive from different sources. For example, strong valuation of social rewards may result in impulsive and intrusive social behavior in children with ADHD, whereas reduced social interest may cause the social impairments in ASD. However, future research is necessary to gain more insight into social reward processing in both disorders.
APPENDIX 3.1: FLOW DIAGRAM OF LITERATURE SEARCH

PRISMA 2009 Flow Diagram

Records identified through database searching
(k = 996) → Additional records identified through other sources
(k = 0) → Records after duplicates removed
(k = 700) → Records screened
(k = 700) → Records excluded
(k = 654) → Full-text articles assessed for eligibility
(k = 40) → Full-text articles excluded, with reasons
(k = 40) → Studies included in qualitative synthesis
(k = 6) → Studies included in quantitative synthesis
(meta-analysis)
(k = 0)

## APPENDIX 3.2: CHARACTERISTICS OF STUDIES

<table>
<thead>
<tr>
<th>Study</th>
<th>n (subtypes)</th>
<th>Diagnosis</th>
<th>Medication</th>
<th>% of males</th>
<th>Age in years: M (SD)</th>
<th>FSIQ (SD)</th>
<th>Paradigm/questionnaire</th>
<th>Reward type</th>
<th>Social reward</th>
<th>Outcome measure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demurie et al., 2013</td>
<td>72 ADHD (21 I, 4 H, 47 C) 69 ASD 130 TDC</td>
<td>DSM-IV-TR DISC-IV</td>
<td>≥24 hours abstinence (n = 52)</td>
<td>75.0</td>
<td>11.8 (1.9)</td>
<td>WISC-III: 102.1 (13.6)</td>
<td>Temporal discounting task</td>
<td>Social; Monetary; Activities; Material; Edible</td>
<td>Picture of praise, e.g., compliments by meaningful persons, medals that could be won, smiling faces</td>
<td>Rate of temporal discounting</td>
</tr>
<tr>
<td>Demurie et al., 2011</td>
<td>35 ADHD (11 I, 1 H, 23 C) 31 ASD 40 TDC</td>
<td>DSM-IV-TR DISC-IV</td>
<td>≥24 hours abstinence (n = 28)</td>
<td>71.4</td>
<td>12.5 (2.1)</td>
<td>WISC-III: 104.7 (14.9)</td>
<td>Incentive delay task; Motivation rating scale</td>
<td>Social; Monetary; No reward</td>
<td>Pictogram of interaction with thumbs up, written compliment, and points</td>
<td>Task performance; Subjective motivation ratings</td>
</tr>
<tr>
<td>Demurie et al., 2016</td>
<td>34 ADHD (10 I, 4 H, 20 C) 36 ASD 41 TDC</td>
<td>DSM-IV-TR DISC-IV</td>
<td>≥24 hours abstinence (n = 22)</td>
<td>82.4</td>
<td>11.5 (1.8)</td>
<td>WISC-III: 101.8 (11.6)</td>
<td>Incentive delay go/no-go task</td>
<td>Social; Monetary; No reward</td>
<td>Pictogram of interaction with thumbs up, written compliment, and points</td>
<td>Task performance</td>
</tr>
<tr>
<td>Geurts et al., 2008</td>
<td>22 ADHD (8 I, 14 C) 22 ASD 33 TDC</td>
<td>DSM-IV-TR DISC-IV DBD</td>
<td>≥24 hours abstinence</td>
<td>100.0</td>
<td>9.9 (1.5)</td>
<td>WISC-III: 98.2 (13.0)</td>
<td>Flanker task</td>
<td>Social; No reward</td>
<td>(Hypothetical) peer competition</td>
<td>Task performance</td>
</tr>
<tr>
<td>Kohls et al., 2009</td>
<td>16 ADHD (7 I, 9 C) 16 TDC</td>
<td>DSM-IV K-DIPS CBCL FBB-HKS</td>
<td>≥48 hours abstinence</td>
<td>100.0</td>
<td>10.7 (1.6)</td>
<td>WISC-III: 97.1 (14.2)</td>
<td>Incentive go/no-go task</td>
<td>Social; Monetary; No reward</td>
<td>Photograph with positively expressed face</td>
<td>Task performance</td>
</tr>
<tr>
<td>Kohls et al., 2014</td>
<td>16 ADHD (3 I, 13 C) 15 ASD 17 TDC</td>
<td>DSM-IV ICD-10 K-SADS-PL FBB-HKS</td>
<td>≥48 hours abstinence (n = 9)</td>
<td>100.0</td>
<td>14.5 (2.6)</td>
<td>WISC-III: 104.6 (13.0)</td>
<td>Cued incentive go/no-go task; Motivation rating scale</td>
<td>Social; Monetary; No reward</td>
<td>Photograph with positively expressed face</td>
<td>Task performance; fMRI; Subjective motivation ratings</td>
</tr>
</tbody>
</table>

**Note.** ADHD = attention-deficit/hyperactivity disorder; ASD = autism spectrum disorder; C = combined subtype; CBCL = Child Behavior Checklist; DBD = Disruptive Behavior Disorder rating scale; DISC = Diagnostic Interview Scale for Children; DSM = Diagnostic and Statistical Manual; FBB-HKS = German version of the hyperkinetic disorder questionnaire for external evaluation; fMRI = functional Magnetic Resonance Imaging; FSIQ = full scale intelligence quotient; H = hyperactive/impulsive subtype; I = inattentive subtype; ICD = International Classification of Diseases; K-DIPS = Interview for Psychiatric Disorders in Children and Adolescents; K-SADS-PL = Schedule for Affective Disorders and Schizophrenia for School Aged Children; TDC = typically developing control; WISC = Wechsler Intelligence Scale for Children.