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ORIGINAL PAPER

Interpretation of ambiguous facial affect in adults with attention-deficit/hyperactivity disorder

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Abstract
In addition to impairments in cognitive functioning, attention-deficit/hyperactivity disorder (ADHD) is associated with deficits in interpersonal functioning as well which are assumed to stem from a distorted perception or interpretation of affective information. While previous research suggests that the decoding of negatively valenced facial stimuli is impaired, less is known about the potential interpretation biases in ADHD which are linked to other externalizing psychopathologies. The present study investigated interpretation biases in adults with ADHD ($N=65$) and controls ($N=49$) using ambiguous facial stimuli (angry/happy, angry/fearful, fearful/happy blends) with different proportions of each emotion. Participants indicated the dominant emotion and rated the perceived intensity of each image. While impaired processing of fearful expressions was evident in the ADHD group, the results of the current study do not provide support for an interpretation bias in adults with ADHD. These findings suggest that interpretation biases may be restricted to aggressive psychopathology and cannot be generalized to individuals with ADHD.

Keywords ADHD · Hostile attribution bias · Ambiguous faces · Social cognition

Introduction

Attention-deficit/hyperactivity disorder (ADHD) is defined by symptoms of inattention and/or hyperactivity-impulsivity [1] that are maintained into adulthood in 40–60% of affected individuals [2–5]. In addition to impairments in cognitive functioning, individuals with ADHD also show serious deficits in various interpersonal functioning domains. For instance, children with ADHD tend to have fewer friends, are rejected more often, and are less popular among their peers [6–8]. Interpersonal problems are also reported by adults with ADHD who experience difficulties in forming and maintaining close personal relationships [9–15]. Furthermore, parents with ADHD are also more likely to display negative parent–child interactions and maladaptive parenting techniques [13].

The ability to understand others' mental and emotional states is essential for successful social interactions and relies heavily on the correct identification and appropriate interpretation of the available social cues, such as nonverbal information. According to an influential theory, social information processing comprises multiple consecutive processing stages, with encoding and interpretation of social cues constituting early stages that are crucial for the understanding of social interactions [16, 17]. Therefore, a compromised ability to accurately encode and interpret facial cues is assumed to impair proper adjustment or inhibition of inappropriate behaviors [18] and may thus explain the poor social interaction skills in individuals with ADHD [19]. Indeed, several studies have reported medium to large impairments in facial affect recognition when comparing healthy controls (HC) with children [20–26], adolescents [27, 28], and adults with ADHD [19, 29–32]. Most of these studies found an impaired encoding of facial cues signaling socially relevant negative feedback, i.e., fearful, sad, or angry facial expressions. Interestingly, the same recognition deficits for negative social cues have also been reported in

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other externalizing disorders, such as antisocial personality disorder (ASPD) and psychopathy [33–35].

Apart from the mere ability to accurately encode social cues, a biased interpretation is another source of potential social information processing distortions that can result in interpersonal difficulties. Situations or signals that contain ambiguity, which is often the case during social interactions, are assumed to be particularly vulnerable for such interpretation biases [36]. For instance, many previous studies have shown that antisocial and violent individuals have a tendency to ascribe hostile intent to others when being confronted with ambiguous social scenes, previously coined as the hostile attribution bias [HAB; 37, 38], and that the magnitude of this bias predicts reactive aggressive behavior [16, 39]. During social interactions, facial expressions represent a class of important cues with a high potential for ambiguity and are therefore also vulnerable to interpretation biases [40–42]. For instance, individuals with ASPD have been reported to systematically misinterpret ambiguous facial cues as hostile [36, 42] and similar tendencies have been documented in community samples scoring high on aggressiveness [for an overview, see 43]. One of these recent studies from our work group investigated the HAB for ambiguous facial cues in a sample of antisocial violent offenders using pictures of blended emotional faces in three continuous dimensions (angry/happy, angry/fearful, and fearful/happy) and five distinct intensity levels [42]. The results showed that individuals with ASPD made significantly more 'angry' endorsements for ambiguous (50/50) 'angry/happy' as well as 'angry/fearful' categories and exhibited a tendency to overrate the perceived intensity of anger, which is indicative of a HAB.

Notably, ADHD and ASPD have a large symptomatic overlap (e.g., rule-breaking, aggressive and hostile behavior tendencies) and are highly comorbid [8]. Given that recognition deficits for negative facial expressions have been documented in both disorders, it is feasible that similar mechanisms may underlie interpersonal difficulties within the broader category of externalizing disorder spectrum [19]. However, while numerous studies investigated antisocial and psychopathic populations, investigations of interpretation biases in ADHD are scarce. Existing studies that did tackle the HAB in individuals with ADHD relied exclusively on vignettes displaying ambiguous situations (e.g., two peers walk by, while whispering and laughing). In these studies, children [44] and adolescents [45] with ADHD relative to HC showed similar rates of hostile attributions in their interpretations. However, it is possible that the attribution of others' intentions in ambiguous situations and the interpretation of ambiguous facial affect may represent two different facets of a HAB [36]. Thus, despite a lack of evidence for a broader bias to correctly assess contextual cues, this does not exclude the possibility that individuals with ADHD may exhibit a biased processing of more subtle and immediate nonverbal cues, i.e., facial affect. No previous study to date has tackled this issue in patients with ADHD and it remains unresolved whether individuals with ADHD exhibit a HAB in the interpretation of facial affect similar to that reported for aggressive populations [36, 42]. This knowledge is highly relevant, as the delineation of the exact mechanisms underlying the social information processing impairments have the potential to shed light on their specificity and to inform the development of new intervention methods tailored to these impairments [46].

In the current study, we examined for the first time interpretation biases in adults with ADHD using ambiguous facial expressions. Here, we used an experimental paradigm with ambiguous facial stimuli previously validated on aggressive and anxious clinical populations [40, 42]. Based on previous methods, we used stimuli that were blends between angry/happy, angry/fearful and fearful/happy expressions, containing different proportions (90/10, 70/30, 50/50, 30/70, 10/90) of each emotion. We presented the participants with these distinct blends, asking them to indicate the most dominant emotion (angry, fearful or happy) and to rate the perceived intensity of each image. We expected that if adults with ADHD exhibit HAB, this should be evident in more 'angry' endorsements and enhanced intensity ratings for both the ambiguous (50/50) 'angry/happy' and the 'angry/fearful' stimulus sets in the ADHD vs. the HC group.

Materials and methods

Participants

Participants were recruited via an internet advertisement on our department's homepage and via advertisements in local newspapers. The data reported in the current study was collected within the context of a larger intervention study with adult ADHD patients; however, no training or therapy had occurred prior to the experiment. Interested individuals were invited to participate in the study, signed a written informed consent, and filled out a number of self-report surveys assessing demographical information and self-reported dimensional severity of ADHD. The ADHD diagnosis according to DSM-IV was confirmed with the ADHD Self-Rating Scale [ADHD-SB; 47, score $\geq$ 15], the Wender Utah Rating Scale for Adults [WURS-K; 48, score $\geq$ 30], and the Wender-Reimherr-Interview [WRI; 49]. Participants in the ADHD group who suffered from current substance abuse/dependence, bipolar, antisocial personality, psychotic, or a neurological disorder (e.g., epilepsy) were excluded from participation. Participants with no current psychopathology were recruited as a HC group. The age criterion in both groups was between 18 and 60 years. Seven participants were excluded from the ADHD and two from the HC group due to the fulfillment of psychopathology exclusion criteria or high error-rates (> 2 *SD*). Thus, a total of 114 participants were included in the final sample with 65 adults, aged 19–57, in the ADHD group and 49 HC, aged 19–60 years. Twelve participants from the ADHD group were currently treated with ADHD-relevant medication (methylphenidate) and 10 received antidepressants (selective serotonin reuptake inhibitors, serotonin norepinephrine reuptake inhibitors, dopamine norepinephrine reuptake inhibitors). Comorbid diagnoses in the ADHD group included depression ($N=37$), anxiety ($N=15$) and eating disorders ($N=1$). All participants received monetary compensation for participation. The study was approved by the university's ethics review board and was conducted in accordance with the Declaration of Helsinki.

Clinical measures

For the ADHD diagnostics, the Homburger ADHD Scales for Adults [HASE; 50] were utilized. This procedure contains German versions of the WRI, a semi-structured interview addressing psychopathologic characteristics relevant for adult ADHD; the WURS-K, which retrospectively addresses ADHD symptoms during childhood; and the ADHD-SB to assess current self-reported ADHD symptoms. The Mini International Neuropsychiatric Interview [MINI; 51] was administered to assess comorbid disorders for a differentiated diagnostic evaluation. Verbal and nonverbal intelligence were estimated by administering a computerized version of the Vocabulary Test [Wortschatztest, WST; 52] and the Wiener Matrizen Test 2 [WMT-2; 53].

Ambivalence task

Stimuli

Images of affective expressions (angry, happy and fearful) of three male models (code 5, 7, 30) were selected from the Radboud Faces Database based on the accuracy of emotional expressions [54]. All images (421 × 500 pixels) were cropped and subsequently blended (FantaMorph software, Abrosoft, Beijing, China) with each other to create three continuous dimensions (angry/happy, angry/fearful, and fearful/happy). For each dimension, we created five distinct intensity levels containing different proportions of each blended emotion (e.g., a 90% angry and 10% happy, a 70% angry and 30% happy, a 50% angry and 50% happy (maximal ambiguity), a 30% angry and 70% happy, and a 10% angry and 90% happy blend for the 'angry/happy' dimension; Fig. 1). Therefore, the stimulus material for the experiment consisted of 45 distinct images (3 model identities × 3 emotional expressions x 5 intensity levels). For the practice trials, 15 additional stimuli (3 emotional expressions × 5 intensity levels) of one male model (code 15) were created in the same manner and were not used in the proper experiment.

Procedure

The experiment was run on a 22-inch TFT LCD monitor at 1680 × 1050 resolution at a viewing distance of about 50 cm. All images were displayed centered against a gray background. Stimulus presentation and data collection were controlled by Presentation version 16.5 (Neurobehavioral Systems, California, US). Participants completed 15 practice trials and began the experimental task with a total of 180 trials (3 models × 3 emotions × 5 intensity levels × 4 repetitions), which were pseudo-randomized across emotions and intensity ratios (i.e., no more than two identical consecutive trials in a row). Each trial started with a fixation cross presented for 1000 ms and was replaced by a face stimulus (500 ms). Participants were then asked to identify the subjectively predominant emotional expression depicted by the stimulus (happy, angry, fearful) on a forced-choice task (open-ended response time) by logging their response via a corresponding button. Subsequently, participants rated the intensity level of the emotion identified in the previous trial on a rating scale ranging between zero (not present at all) and 10 (full-blown emotion). The intertrial interval was randomly selected to be 1000 or 1500 ms long.

Statistical analysis

All statistical analyses were performed using SPSS version 22.0 for Windows (IBM SPSS Statistics, IBM Corporation, Armonk, NY). Demographic and clinical variables between groups were compared with t tests for continuous variables and χ^2-tests for frequencies. To investigate the HAB in the categorization task, sum scores were computed for each participant, morph ratio, and emotional dimension, indicating the number of 'angry' (for the angry/happy and angry/fearful dimensions) and 'fearful' endorsements (for the fearful/happy dimension). These sum scores were then entered in three separate 5 (Morph ratio: 90/10, 70/30, 50/50, 30/70, 10/90) x 2 (Group: ADHD vs. HC) repeated measures analyses of variance (ANOVAs) for each emotional dimension (angry/happy, angry/fearful, fearful/happy) [40, 42].

To examine the general pattern of the participants' perceived intensity ratings, mean subjective intensity ratings were computed for correct responses (e.g., for an angry-happy morph, both 'angry' and 'happy' responses would be included, while 'fearful' is not part of the blend and would, therefore, be excluded from further analysis). These mean ratings were entered into three separate 5 (Morph ratio) x

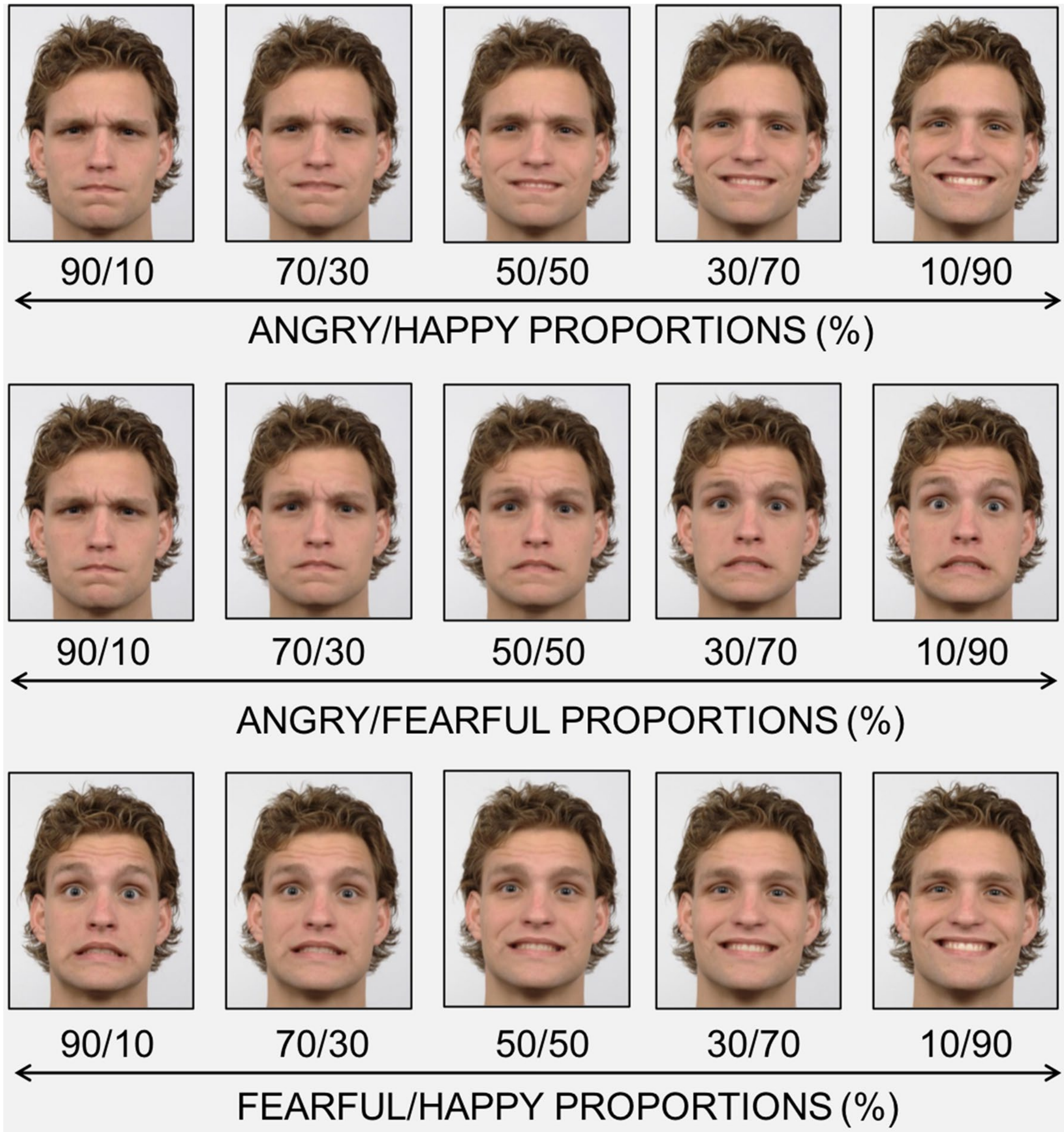

Fig. 1 Example of stimulus material. Faces depicting angry, fearful and happy expressions were blended together and parametrically varied to create stimulus material varying in ambiguity

2 (Group) repeated measures ANOVAs and conducted for each emotional dimension.

To investigate whether an interpretative bias in ADHD may also be reflected in perceived intensity ratings, three independent samples *t* tests were computed for the trials with maximum ambiguity (50/50 morphs) in which the participants inferred a hostile ('angry' endorsements for the angry/happy and angry/fearful) or negative ('fearful' endorsements for the fearful/happy dimension) interpretation.

For the analysis of overall accuracy in the categorization task, the percentage of correct responses across all morph ratios were computed for each emotional dimension and participant and entered into a 3 (Emotional dimension) x 2 (Group) repeated measures ANOVA.

Two-sided *t* tests were used for all post-hoc analyses which were Bonferroni-corrected. For all analyses, *p*-values lower than 0.05 were considered significant; effect sizes are presented as partial η^2.

Table 1 Demographic and clinical characteristics

	ADHD (N=65)	HC (N=49)	Statistics
Demographics			
Gender, female n (%)	29 (44.62)	29 (59.18)	$X^2_{(1)}=2.37$; n.s
Age, in years	38.35 (10.42)	35.00 (11.13)	$t\,(112)=1.65$; n.s
WST	106.62 (9.86)	109.57 (9.93)	$t\,(112)=1.58$; n.s
WMT-2	91.00 (17.06)	89.20 (16.14)	$t\,(112)=0.57$; n.s
ADHD rating scales			
WURS-K	44.43 (10.63)	8.84 (6.64)	$t\,(112)=20.59$; $p<.001$
ADHD-SB			
Total score	33.88 (6.31)	5.98 (4.00)	$t\,(112)=27.10$; $p<.001$
Inattention	18.35 (3.16)	3.67 (2.54)	$t\,(112)=26.65$; $p<.001$
Hyperactivity	8.51 (3.14)	1.27 (1.43)	$t\,(112)=15.02$; $p<.001$
Impulsiveness	7.02 (2.63)	1.04 (1.27)	$t\,(112)=14.64$; $p<.001$

The data represented in the table refers to means and standard deviations for each measure (in parentheses)

ADHD attention-deficit/hyperactivity disorder, *ADHD-SB* ADHD self-rating scale, *HC* healthy controls, *WMT-2* Wiener Matrizen Test 2, *WST* Wortschatztest, *WURS-K* Wender Utah rating scale for adults

Results

Participants

Participants did not differ with regard to sex, age, and verbal/nonverbal intelligence (Table 1). Compared to HC, the ADHD group exhibited significantly higher scores on all measures of ADHD symptomatology (total scores and subscales). Most participants from the ADHD group fulfilled the categorical diagnosis of ADHD combined subtype in the WRI (9 participants with inattentive subtype).

Ambivalence task

Interpretation bias

For the 'angry/happy' dimension, this analysis yielded a significant main effect of Morph ratio, $F(2.82, 315.92)=1655.16$, $p<.001$, $\eta_p^2=0.94$, which was further qualified by a significant Morph ratio x Group interaction, $F(2.82, 315.92)=3.70$, $p=.014$, $\eta_p^2=0.03$ (all other ps > 0.10). Separately computed t tests revealed that adults with ADHD compared to HC made less 'angry' responses under the conditions of maximal ambiguity on a statistical trend level (50% angry/50% happy: $t(112)=1.86$, $p=.065$; all other ps > 0.10). For the 'angry/fearful' dimension, there were significant main effects of Morph ratio, $F(2.98, 334.14)=1271.19$, $p<.001$, $\eta_p^2=0.92$, and Group, $F(1, 112)=4.89$, $p=.029$, $\eta_p^2=0.04$, which were further qualified by a significant Morph ratio x Group interaction, $F(2.98, 334.14)=3.96$, $p=.009$, $\eta_p^2=0.03$. Separately computed t tests revealed that adults with ADHD compared to HC made significantly more 'angry' responses for 50% angry/50% fearful, $t(112)=2.43$, $p=.017$, 30% angry/70% fearful, $t(112)=2.84$, $p=.005$, and 10% angry/90% fearful, $t(112)=2.97$, $p=.004$ (all other ps > 0.10). Finally, for the 'fearful/happy' dimension, analysis yielded significant main effects of Morph ratio, $F(2.95, 330.38)=1310.48$, $p<.001$, $\eta_p^2=0.92$, and Group, $F(1, 112)=9.62$, $p=.002$, $\eta_p^2=0.08$, which were further qualified by a significant Morph ratio x Group interaction, $F(2.95, 330.38)=3.86$, $p=.010$, $\eta_p^2=0.03$. Separately computed t tests revealed that adults with ADHD compared to HC made significantly less 'fearful' responses under conditions of 50% fearful/50% happy, $t(112)=2.73$, $p=.007$, 70% fearful/30% happy, $t(112)=2.87$, $p=.005$, and 90% fearful/10% happy, $t(112)=3.17$, $p=.002$ (all other ps > 0.10)[1] (Fig. 2 a–c).

Perceived intensity ratings

For the 'angry/happy' dimension, only a significant main effect of Morph ratio, $F(2.82, 316.22)=143.02$, $p<.001$, $\eta_p^2=0.56$ emerged (all other ps > 0.10). For the 'angry/fearful' dimension, the analysis yielded a significant main effect of Morph ratio, $F(2.56, 287.12)=143.42$, $p<.001$, $\eta_p^2=0.56$, which was further qualified by a significant Morph ratio x Group interaction, $F(2.56, 287.12)=3.97$, $p=.012$, $\eta_p^2=0.03$ (all other ps > 0.10). Separately computed t-tests revealed that adults with ADHD compared to HC exhibited marginal significantly reduced intensity levels under the condition of 10% angry/90% fearful, $t(112)=1.72$, $p=.088$ (all other ps > 0.10). Finally, for the 'fearful/happy' dimension, only a significant main effect of

[1] Additional analyses of the interpretation bias and perceived intensity ratings which excluded all patients with ADHD-relevant medication from the data set revealed the same main and interaction effects.

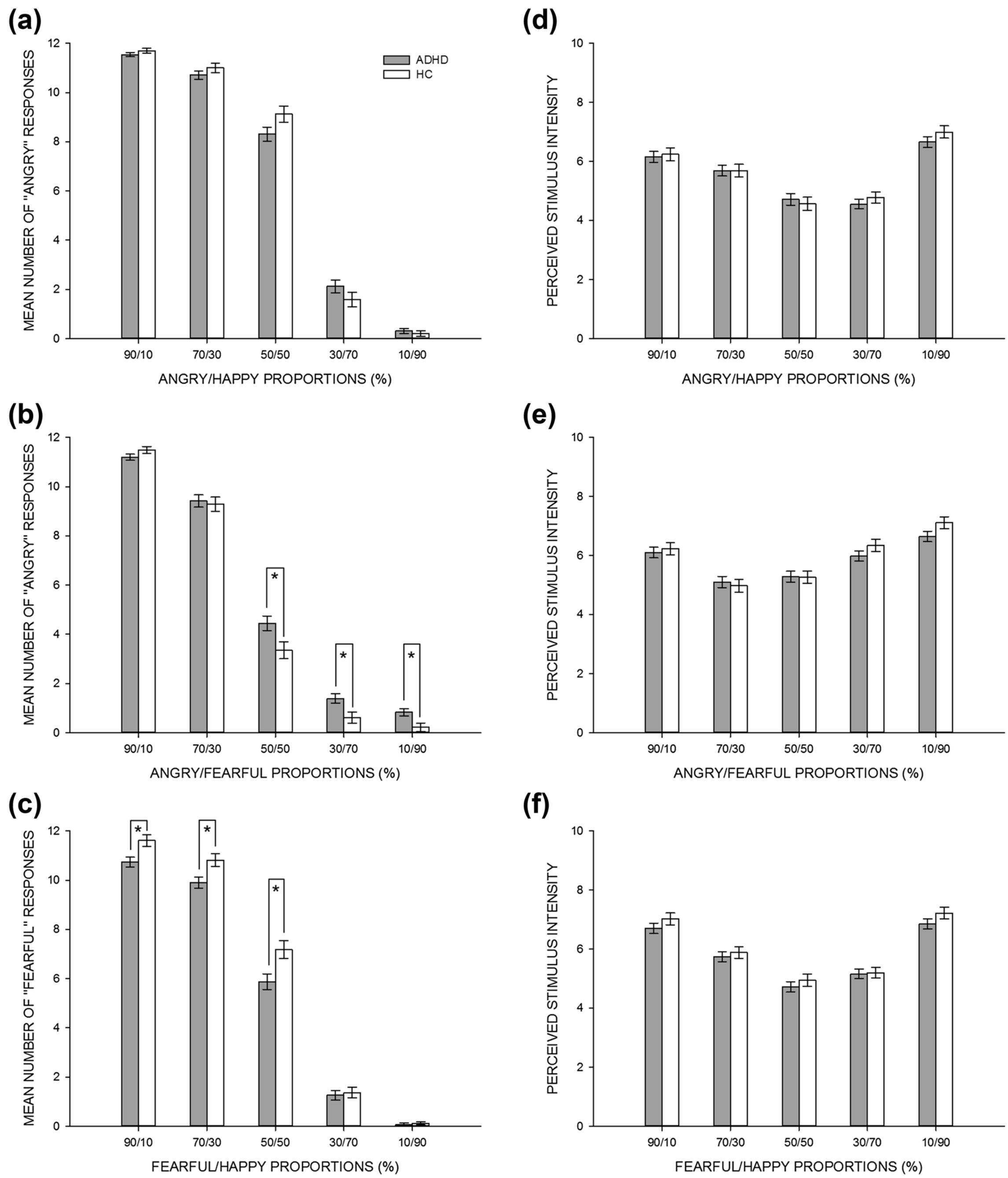

Fig. 2 **a–c** Results illustrate the mean number of responses and standard deviations for each emotional dimension; maximal number of responses: $N = 12$. **e–f** Means and standard deviations of the intensity ratings for each emotional dimension; rating scale: 0 (not present at all) to 10 (full-blown emotion). Bars indicate standard errors of mean. $^*p < .05$

Morph ratio, $F(3.01, 336.93) = 179.53$, $p < .001$, $\eta_p^2 = 0.62$, emerged (all other *p*s > 0.10)1 (Fig. 2 d–f).

Finally, the paired-samples *t* tests for the ambiguous intensity levels in which the participants inferred a negative ('angry' for the angry/happy and angry/fearful or a 'fearful' on the fearful/happy dimension) interpretation did not reveal significant differences between groups on the 'fearful/happy' (ADHD: $M = 4.90$, $SD = 1.60$ vs. HC: $M = 5.10$, $SD = 1.70$, $t(112) = 0.61$, $p > .10$), the 'angry/fearful' (ADHD: $M = 5.00$, $SD = 1.61$ vs. HC: $M = 4.82$, $SD = 1.84$, $t(105) = 0.52$, $p > .10$), or the 'angry/happy' (ADHD: $M = 5.10$, $SD = 1.64$ vs. HC: $M = 4.80$, $SD = 1.68$, $t(112) = 0.95$, $p > .10$) dimension.

Accuracy

Overall accuracy was very high in both groups (fearful/happy: ADHD: $M = 94.00\%$, $SD = 3.70$ vs. HC: $M = 96.70\%$, $SD = 8.30$; angry/fearful: ADHD: $M = 98.50\%$, $SD = 3.62$ vs. HC: $M = 99.52\%$, $SD = 1.00$; angry/happy: ADHD: $M = 94.54\%$, $SD = 5.60$ vs. HC: $M = 95.20\%$, $SD = 4.75$). Despite slightly lower accuracy rates in the ADHD group, $F(1, 112) = 8.14$, $p = .005$, $\eta_p^2 = 0.07$, there was no evidence for an interaction between emotional dimension and group, $F(1.71, 191.37) = 1.91$, $p = .157$, $\eta_p^2 = 0.02$.

Discussion

The present study aimed to investigate the HAB in adults with ADHD using an experimental paradigm with ambiguous facial expressions. We hypothesized that a HAB should be reflected in a larger number of 'angry' endorsements for the 'angry/fearful' and the 'angry/happy' blends at maximum ambiguity and that the endorsements should also be associated with an enhanced perceived stimulus intensity. Contrary to our expectations, the results did not reveal that ADHD participants made more 'angry' endorsements and higher intensity ratings for the 'angry/happy' as well as the 'angry/fearful' ambiguous (50/50) stimulus sets. Therefore, these results do not provide support for a HAB in the interpretation of ambiguous facial affect in adults with ADHD. Instead, we observed an attenuated number of 'fearful' endorsements in 'angry/fearful' and 'fearful/happy' blends in the ADHD group, which was largely pervasive across different intensity levels, possibly indicating a disturbed processing of fearful expressions.

Although we did find indication for enhanced number of 'angry' endorsements in the 'angry/fearful' dimension, this tendency was (a) pervasive across all morph levels and not restricted to ambiguous 50/50 mixtures and (b) not evident for 'angry/happy' morphs. Taken together, this data pattern does not indicate a HAB; instead the enhanced number of 'angry' endorsements for the 'angry/fearful' dimension is likely rooted in an impaired recognition of fearful expressions. Our null findings are in accordance with previous studies that used vignettes with ambiguous situations and found no evidence for a HAB in ADHD [44, 45]. This is the first study to date to investigate biased processing in facial affect in ADHD using an experimental paradigm which previously revealed a HAB in populations with ASPD [42], but not in generalized social phobia [40]. Our data thus adds to the existing evidence and supports the notion that different mechanisms may underlie interpersonal difficulties within the category of externalizing spectrum disorders. Importantly, these findings suggest that the HAB may be restricted to aggressive psychopathology and cannot be generalized to individuals with ADHD [44].

An unexpected finding in the present study is that compared to HC, adults with ADHD made significantly less 'fearful' responses within the 'angry/fearful' and 'fearful/happy' stimulus sets. Importantly, this effect was pervasive across nearly all morph proportions and across both types of fearful blends (angry/fearful and fearful/happy). Thus, these results can be interpreted as further evidence for an impaired processing of fearful facial expressions in ADHD. Congruent with previous studies, fear seems to be the most impaired facial affect category in individuals with ADHD [19–22, 25–30]. In sum, our findings and previous research suggest that the social information processing in ADHD is predominantly impaired at the perceptual encoding stage of particularly fearful expressions, while the interpretation is not compromised. One possible explanation is that this stems from a perceptual impairment, which is also supported by studies that provide evidence for neuronal disruptions in the early processing of fearful facial expressions in individuals with ADHD [28, 55]. Notably, in these studies, early event-related potential components (e.g., P120, P300, N400) were reduced in response to fearful facial expressions in individuals with ADHD [28, 55], whereas evidence for changes in amygdala activation patterns in face of fearful expressions in ADHD is mixed [56–58]. Furthermore, the impaired ability to categorize fear in ADHD may also stem from impairments in ascribing verbal labels [59]. In future research, more electrophysiological and neurobiological studies are needed to explore the neuronal mechanisms underlying the processing deficit of fearful facial expressions in individuals with ADHD. However, it should also be noted, that fear is generally the expression that is recognized the worst in HC [60, 61], so the fear recognition deficit might also be due to task difficulty. Future studies employing a control task with non-social stimuli are needed to show whether this impairment is specific to emotional stimuli.

The current study is the first to investigate interpretation biases for affective facial expressions in adults with ADHD. Despite its' strengths, such as the naturalistic stimulus material and the large ADHD sample size, the current study also has some limitations worth noting. For one, a small proportion of our ADHD sample was not naive to ADHD-relevant medication. To date, previous studies showed only an influence of methylphenidate on facial affect recognition in ADHD which was evident in an alleviation [28] or a complete remission [57, 62, 63 but see 63] of the observed perceptual impairments. Although additional analyses which excluded all patients with ADHD-relevant medication from the current data set revealed the same results, the small proportion of the medicated patients prevents us from drawing any conclusions about the influence of methylphenidate and provides an interesting avenue for future research. Another concern is that a part of our ADHD sample suffered from comorbid disorders (e.g., depression, anxiety, or eating disorders) that could influence the facial affect recognition. However, the sample of the present study is fairly common with regard to comorbid disorders, as previous research has repeatedly demonstrated that ADHD patients show generally high comorbidity rates [e.g., 64, 65]. This pattern is quite typical considering that ADHD is a developmental disorder and that affected individuals often have a long history of unmanaged symptoms. Furthermore, the stimulus material was restricted to male facial expressions. However, previous studies showed that in both genders especially negative emotional expressions of male faces receive prioritized processing compared to other facial expressions [66]. Therefore, it can be assumed that an inclusion of female faces would not change the results.

In summary, the results of the current study indicate that adults with ADHD show no HAB in the interpretation of ambiguous facial affect. Instead, the present findings support the existing evidence documenting a fear recognition deficit in the ADHD group. However, to date, it remains unclear whether adults with ADHD would benefit from specific treatment programs [46] that aim to enhance the sensitivity to social distress cues. Therefore, potential treatment effects and their associations with improvements in basic social interaction skills should be explored in future studies.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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