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ORIGINAL ARTICLE

Interoceptive awareness in patients with attention-deficit/hyperactivity disorder (ADHD)

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Abstract

Attention-deficit/hyperactivity disorder (ADHD) is a neuropsychiatric disorder normally diagnosed in childhood and persisting into adulthood in up to two-thirds of the patients. Its core symptoms comprise inattention and hyperactive–impulsive behaviours. Several studies suggest that patients with ADHD show alterations in self-regulation and self-monitoring. So far, it has not been described whether these deficits also affect the awareness of one's own bodily signals, that is, interoceptive awareness. To investigate possible alterations in interoceptive awareness, 14 adult patients with ADHD and 16 healthy controls performed a heartbeat detection task, in which they had to count their heartbeat without any external help (e.g. visualization on a screen). As an indicator of the individual interoceptive awareness ability, a score based on the comparison between recorded and counted heart beats was calculated. Our results showed that patients with ADHD performed significantly worse on this task than controls, which indicates that they were less aware of internal bodily signals while additionally experiencing deficits in regulating and monitoring their own (overt) behaviours.

Keywords ADHD · Interoception · Interoceptive awareness · Self-regulation

This article is dedicated to the loving memory of Katrin Kutscheidt, who was killed in a road accident while attending the SFN conference 2015 in Chicago, USA. This article is based on her first unfinished draft which was later finalized by the co-authors.

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Introduction

Adult attention-deficit/hyperactivity disorder (ADHD) has a prevalence of about 0.5–3%, with percentage differences depending on the countries investigated and the applied diagnostic systems (Fayyad et al. 2017; Giacobini et al. 2018). Whereas children with ADHD often display inattention, impulsiveness, and overt symptoms of motor hyperactivity, adult patients with ADHD report suffering from an attention deficit combined with impulsiveness and inner restlessness (Wender et al. 2001).

Neuropsychologically, Barkley (1997) described ADHD as a major deficit in behavioural inhibition affecting four executive functions. These are working memory, internalization of speech, reconstitution, and self-regulation. Self-regulation therein refers to the regulation of affect, motivation, and arousal. Dysfunctional inhibition has been shown to elicit inappropriate impulsive and risky behaviours, that is, less self-regulated behaviour (e.g. Ramos Olazagasti et al. 2013; Richards et al. 2006). Henceforth, therapeutic approaches also aim to improve self-regulation skills to better adapt the respective behaviour (e.g. Mitchell et al. 2017).

Self-monitoring, which is the observation and recording of one's own behaviour, can be considered one step in successful self-regulation. Self-monitoring skills were thus shown to be positively associated with task-focussed behaviour, appropriate behaviour or academic accuracy (Axelrod et al. 2009; Reid et al. 2005). These data indicate that children and adults with ADHD can benefit from training such monitoring skills. Closely related to self-monitoring is a more basic construct called interoceptive awareness. Interoception refers to the perception of signals coming from within one's own body—these can be feelings and physiological states such as hunger or thirst, but also one's own breathing or heartbeat frequency (Cameron 2001). Interoceptive awareness is usually measured by heartbeat detection tasks, in which the participants' perceived heartbeats are compared to objectively measured heartbeats.

To adapt and consequently reduce impulsive behaviour and specific bodily states, they need to be first identified by the person itself. Effective self-regulation builds on appropriate self-monitoring of behaviour, which may be related to a better functioning of interoceptive awareness of bodily signals—meaning that, in reverse, deficient interoceptive awareness may play an important role in patients with ADHD. However, to the best of our knowledge, it is unclear how insufficient self-monitoring skills in adult patients with ADHD are associated with reduced conscious interoceptive awareness. So far, no interoceptive awareness studies have investigated patients with ADHD. Interoceptive awareness studies in other mental disorders reported lower interoceptive awareness in patients with depression (Pollatos et al. 2009) and anorexia nervosa (Pollatos et al. 2008), while anxiety seemed to be related to higher interoceptive awareness (Pollatos et al. 2009).

In the present study, we employed a heartbeat detection task to investigate interoceptive awareness in adult patients with ADHD and a healthy control group. We hypothesized that adult ADHD is associated with reduced interoceptive awareness.

Methods

Study population

Sixteen adult patients with ADHD were recruited via the outpatient clinic of the Department of Psychiatry and Psychotherapy, University of Tuebingen, as well as public notices. All of them had a pre-existing ADHD diagnosis. Two patients had to be excluded: one had a current ADHD Self-Rating Scale (ADHD-SB) score below the cut-off of 18, and the other seemed to measure their pulse during the counting phase of the heartbeat detection task by pressing their thumb against their index finger. Thus, 14 patients (7 female; mean age 29.36 ± 10.59 years) were included in the final analysis. Eight patients were medicated with methylphenidate; the rest were unmedicated. Additionally, 16 healthy control participants were recruited from the local area via public notices (9 female; mean age 26.38 ± 5.34 years). They were comparable to the patients regarding age and gender (see Table 1).

Course of the study

The study consisted of an online assessment and a laboratory heartbeat detection task. Participation in both parts was reimbursed with 10 EUR for 60 min. The study was approved by the ethics committee of the University Hospital Tuebingen, and all procedures were in accordance with the latest version of the Declaration of Helsinki.

Online assessment

Before the actual laboratory experiment, the participants received an online link (SoSciSurvey) via e-mail for filling in questionnaires, which took about 25 min. The questionnaire battery included the following ADHD questionnaires: the Barratt Impulsiveness Scale (Hartmann et al. 2011), the Adult ADHD Self-Report Scale (ASRS) (Meule et al. 2015), the ADHD Self-Rating Scale (ADHS-SB) (Rösler et al. 2008), and the short form of the Wender Utah Rating Scale (WURS-K) measuring childhood symptoms of ADHD (Rösler et al. 2008). To characterize the sample regarding comorbid symptoms, the State-Trait Anxiety Inventory (STAI) (Laux et al. 1981), the Beck Depression Inventory II (BDI-II) (Hautzinger et al. 2006), the Borderline Symptom List (BSL) (Bohus et al. 2009), and the Eating Disorder Examination-Questionnaire (EDE-Q) (Hilbert et al. 2007) were applied.

Heartbeat detection task

After giving written informed consent, completing a verbal IQ test (Multiple Choice Vocabulary Test, MWT-B) (Lehrl 1999) and a questionnaire about their state anxiety (STAI state) (Laux et al. 1981), the participants underwent the heartbeat detection task. Electrocardiographic (ECG) electrodes were placed on the participants' right and left wrist with a ground electrode attached to the forearm. One-lead bipolar ECG based on Einthoven I (Einthoven 1901) was recorded using a Brain Products ExG 16-channel amplifier with a frequency of 5000 Hz. Participants were instructed via text on a computer screen and could ask questions whenever something remained unclear. One practice counting phase of 15 s was performed before the actual experiment,

Table 1 Sample characteristics

Variable	Controls ($n=16$)		Patients ($n=14$)		Statistics (Mann–Whitney *U*-tests)		
	M	SD	*M*	SD	*U*	*Z*	*p*
General characteristics							
Age	26.38	5.34	29.36	10.59	105.5	−.271	.786
Verbal IQ (MWT-B)	111.13	9.88	110.50	16.81	50	−.412	.681
ADHD characteristics							
ASRS	18.94	5.39	50.36	7.38	0	−4.669	<.001**
WURS-K	10.06	6.97	37.64	14.63	18	−3.912	<.001**
ADHS-SB	8.88	4.23	33.69	5.79	0	−4.497	<.001**
Barratt Impulsiveness Scale	56.63	8.50	83.79	8.77	2.5	−4.559	<.001**
Comorbid characteristics							
BDI-II	4.25	5.50	10.57	8.26	54	−2.429	.015*
BSL	5.56	7.32	18.21	11.01	22.5	−3.735	<.001**
STAI state	37.56	11.27	36.83	8.31	89	−.325	.745
STAI trait	36.94	10.00	46.93	8.61	49	−2.623	.009**
EDE-Q	.86	.91	.95	.92	99	−.541	.589

Due to missing questionnaire items in the patient group: $n=13$ for the ADHS-SB, $n=12$ for the STAI state

*$p<.05$; **$p<.01$

ADHS-SB ADHD Self-Rating Scale, *ASRS* ADHD Self-Report Scale, *BDI-II* Beck Depression Inventory II, *BSL* Borderline Symptom List, *EDE-Q* Eating Disorder Examination-Questionnaire, *MWT-B* Multiple Choice Vocabulary Test, *STAI* State-Trait Anxiety Inventory, *WURS-K* Wender Utah Rating Scale

which was then comprised of 11 subsequent experimental counting phases. These phases varied in duration between 30 and 90 s—in steps of 6 s (Pollatos et al. 2005)—and were pseudorandomized across participants.

Each counting phase was preceded by a blank screen of 3000 ms to prepare participants. A 700 ms fixation cross, followed by a start signal (beep), indicated the beginning of the counting phase which ended with a stop signal (second beep). Participants were instructed to only count their heartbeat between the start and stop signals, and after each phase, they specified the number of counted heartbeats via a keyboard. In the ECG signal, start and stop markers were set corresponding to the start and stop beeps. The whole procedure, including placing the electrodes, usually lasted about 35 min.

Data analysis

ECG data were preprocessed with BrainVision Analyzer 2.0 and Kubios HRV and then analyzed with Matlab 2012b and IBM SPSS Statistics 22. Data were down-sampled to 500 Hz (BrainVision Analyzer 2.0) and processed with Kubios HRV, which automatically detects R-waves (i.e. the highest upward deflections in the ECG) and saves their time-points. ECG data were visually inspected, and R-wave markers were set manually whenever they were not automatically detected. The heartbeats during each interval were counted based on time-points of R-waves. The number of recorded beats was then compared to the number of counted beats. An individual score for each person was finally calculated based on the following formula (Schandry 1981), in which the resulting score between 0 (worst) and 1 (best) indicates the individual's interoceptive awareness ability (IA—interoceptive awareness, *n*—number of intervals).

$$IA = \frac{1}{n}\sum_{i=1}^{n}\left(1 - \frac{(|\text{recorded beats} - \text{counted beats}|)}{\text{recorded beats}}\right)$$

As data were not normally distributed, only nonparametric tests were used for data analysis. Statistics for between-group comparisons were calculated with Mann–Whitney *U*-tests, and relationships between variables were calculated using Spearman's Rho rank correlations.

Results

Sample characteristics are shown in Table 1. Groups were similar in age and IQ. They differed significantly in all four questionnaires assessing ADHD characteristics, in depressive symptomatology, borderline symptomatology, and trait anxiety, but not in state anxiety or eating disorder symptomatology.

While the mean interoceptive awareness score in the control group was .71 (SD = .17), it was .55 (SD = .15) in the patients with ADHD, indicating a significant group difference ($U=58$, $Z=-2.245$, $p=.025$; Fig. 1). In addition, we also computed interoceptive awareness scores for short intervals only (30–54 s) to exclude influences of potential working memory deficits in the ADHD group. However, the results remained virtually unchanged (controls: $M=.70$, SD = .17, ADHD: $M=.54$, SD = .16; $U=58$, $Z=-2.245$, $p=.025$). The mean actual heart rate (beats per minute) also differed significantly between controls ($M=67.15$, SD = 8.91) and patients ($M=82.88$, SD = 13.64; $U=33$, $Z=-3.284$, $p=.001$).

Referring to the previous literature on interoceptive awareness differences in various clinical groups, we also calculated correlations between interoceptive awareness and the questionnaire data (see Table 2). No significant correlations were found in the patient group. In the control group, significant negative correlations were found between interoceptive awareness and the BSL score and the STAI trait score, respectively.

As some patients were on medication, an additional exploratory comparison was made within the patient group. Interoceptive awareness scores from medicated ($n=8$, $M=.51$, SD = .17) and unmedicated patients ($n=6$, $M=.60$, SD = .12) revealed no sub-group differences, which was also confirmed by a Mann–Whitney U-Test ($U=17$, $Z=.904$, $p=.366$). Actual heart rate was also not influenced by medication status (ADHD medicated: $M=82.98$, SD = 15.04, ADHD unmedicated: $M=82.76$, SD = 12.91; $U=23.0$, $Z=-.129$, $p=.897$).

Taking into account that patients with ADHD show impairments in time perception (Hartmann et al. 2011; Wender et al. 2001), we investigated whether patients and controls over- or underestimated their heartbeats. To this end, we subtracted the counted heartbeats from the recorded heartbeats trial-wise and calculated the percentage of underestimation (positive difference). While the control group underestimated their heartbeat in 94.89% of cases, patients always underestimated the number of heartbeats during the test interval (100%). This difference was significant (Fisher exact probability test: $p=.004$).

Table 2 Rank correlation analyses of interoceptive awareness scores with questionnaire data

Correlation of interoceptive awareness score with	Controls ($n=16$)		Patients ($n=14$)	
	Rho	*p*	Rho	*p*
ADHD characteristics				
ASRS	.270	.312	−.025	.933
WURS-K	−.169	.530	.418	.137
ADHS-SB	.260	.331	.185	.545
Barratt Impulsiveness Scale	.306	.250	.143	.625
Comorbid characteristics				
BDI-II	−.419	.107	−.209	.473
BSL	−.641	.007**	−.203	.486
STAI state	−.419	.107	−.452	.140
STAI trait	−.524	.037*	−.048	.869
EDE-Q	−.124	.648	−.099	.737

Due to missing questionnaire items in the patient group: $n=13$ for the ADHS-SB, $n=12$ for the STAI state

$^*p<.05$; $^{**}p<.01$

ADHS-SB ADHD Self-Rating Scale, *ASRS* ADHD Self-Report Scale, *BDI-II* Beck Depression Inventory II, *BSL* Borderline Symptom List, *EDE-Q* Eating Disorder Examination-Questionnaire, *STAI* State-Trait Anxiety Inventory, *WURS-K* Wender Utah Rating Scale

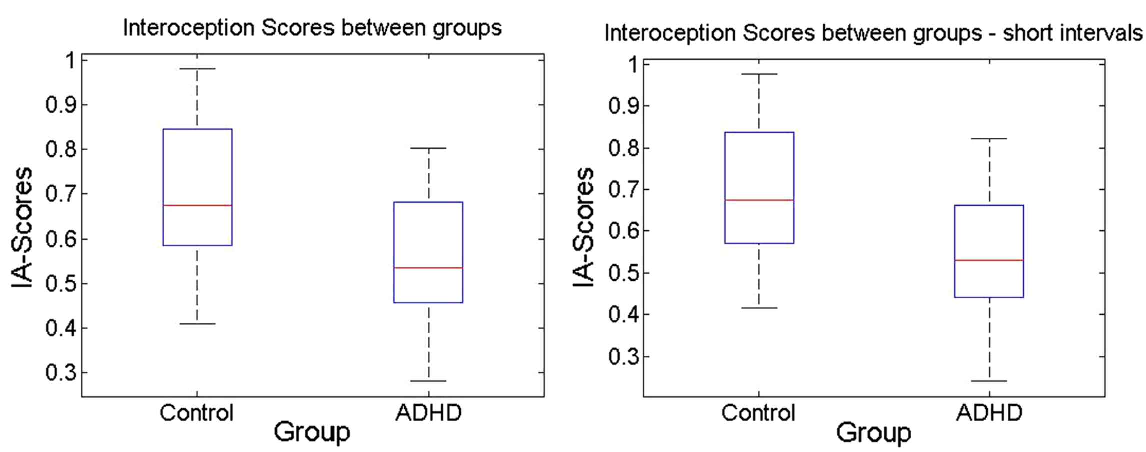

Fig. 1 The panels show the box plots of the interoceptive awareness scores for each group, the left panel for all intervals, the right panel for short counting intervals only. The red line marks the median

Discussion

Using a heartbeat detection task, we found a significant difference in interoceptive awareness between adult patients with ADHD and a healthy control group, with patients displaying lower scores, which means that they performed worse than controls. This is, to the best of our knowledge, the first study to show an impaired interoceptive awareness in adult patients with ADHD.

The mean interoceptive awareness score of our control group (.71) was comparable with previous studies in healthy subjects (Matthias et al. 2009; Pollatos et al. 2008, 2009), indicating that the group difference was not driven by an uncharacteristically high interoceptive awareness in the controls. When one assumes interoceptive awareness to be closely related to or preceding self-monitoring, our finding is in accordance with previous studies reporting an impaired self-monitoring in ADHD (Westby and Cutler 1994). It is also in line with studies that found alterations in the processing of and adaptation to response errors (Ehlis et al. 2018; Herrmann et al. 2010; Schachar et al. 2004; Wiersema et al. 2005). Additionally, our findings corroborate a study showing that impaired post-error adaptation (i.e. disturbed self-monitoring and subsequent regulation of behaviour) was correlated with low interoceptive awareness in healthy subjects (Sueyoshi et al. 2014). If this holds true for patient samples, improving interoceptive awareness (see below) could improve behavioural regulation. Pollatos et al. (2005) found that participants responding with higher emotional arousal towards IAPS pictures also had higher interoceptive awareness, which could indicate an impact of interoceptive awareness on emotional self-regulation. Patients with ADHD generally suffer from emotional dysregulation (for a review, see Shaw et al. 2014) and show deficits in detecting emotional facial (Singh et al. 1998) and vocal expressions (Bisch et al. 2016). Based on these more general affective findings, a decreased interoceptive awareness could be expected in ADHD, which is in accordance with our results.

The finding that interoceptive awareness is impaired in adult ADHD may actually—if replicated in larger samples—have implications for new therapeutic approaches. As stated above, self-monitoring and self-regulation trainings have been successfully applied in the past (Axelrod et al. 2009; Mitchell et al. 2017; Reid et al. 2005). Hence, specific training of the more basic interoceptive awareness level could be a promising idea. Starting from basic processes, hierarchically organized steps could be taken: from interoceptive awareness to self-monitoring to self-regulation. Such trainings could add to the effects of already established therapeutic approaches. An interoceptive awareness training could be conceptualized comparable to biofeedback trainings, where patients with ADHD learn to regulate their own physiological signals in a standardized setting (e.g. Barth et al. 2016, 2017; Hudak et al. 2017). Here, in a multiple session training, they would learn to improve their performance in a heartbeat detection task by receiving feedback after each trial, for example, by showing how many heartbeats they missed or detected incorrectly. An easy application at home is imaginable, as costs for measuring heartbeat are rather low. Smartphone applications can be used; game-based features can be implemented ("How well can you count your heartbeat?"). As the crucial factors for biofeedback or neurofeedback (Heinrich et al. 2007) are not fully understood, several implications regarding interoceptive awareness are possible. On the one hand, the effect on interoceptive awareness could mediate some of the effects of bio- or neurofeedback; on the other hand, interoceptive awareness could serve as a predictor for bio- or neurofeedback training outcomes. Open questions remain, for example regarding the actual consciousness of the biological signals in interoceptive awareness trainings and bio- or neurofeedback trainings, respectively.

Regarding a potential impact of common comorbidities of ADHD, previous studies point towards associations between interoceptive awareness and depression (Pollatos et al. 2009), eating disorders (Pollatos et al. 2008) or panic disorder (Ehlers and Breuer 1996; Pollatos et al. 2009), which hinder strong conclusions. For our ADHD sample, we found significant group differences for most of the psychometric variables except for eating disorder symptomatology and state anxiety (STAI). This means that ADHD—besides displaying to-be-expected increased scores in ADHD symptoms—was associated with increased depressive and trait anxiety scores. However, as these symptoms were uncorrelated with interoceptive awareness in the ADHD group, we consider the group difference in interoceptive awareness to be mainly due to the ADHD diagnosis, rather than merely the result of comorbid symptoms.

Limitations

Several limiting factors in our study should be taken into account. First, the sample size is rather low, which only allows to investigate general effects. Measuring a larger sample of patients would allow to differentiate between different ADHD presentations (i.e. diagnostical subtypes). In that way, it might be possible to draw conclusions about differences in interoceptive awareness between the predominantly hyperactive and the predominantly inattentive presentation type.

Second, even though our main results did not differ between shorter and longer intervals, follow-up studies should measure working memory (e.g. Ehlis et al. 2008) to investigate its influence on interoceptive awareness.

Third, many of our patients with ADHD took methylphenidate, which can result in a generally increased heart rate. However, although patients had a significantly higher heart rate, there was no influence of medication on it. Medication also did not influence interoceptive awareness.

Fourth, there is evidence—mostly based on time reproduction tasks—that ADHD is related to impaired time interval perception (e.g. Hartmann et al. 2011; Noreika et al. 2013). Thereby, patients with ADHD tend to overestimate time intervals, which fit nicely to their impulsive and impatient behaviour. If patients have a faster inner clock (Noreika et al. 2013), potential biases might arise, which should be investigated in more detail. Still, it is not clear whether counting heartbeats is influenced by an altered inner clock.

Conclusions

Adult patients with ADHD show an impaired interoceptive awareness in addition to the already described deficits in self-monitoring and self-regulation. This finding could have important implications for therapeutic strategy options in the future.

Compliance with ethical standards

Conflict of interest The authors declare that they do not have any conflicts of interest.

Human and animal rights All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

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