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ORIGINAL INVESTIGATION

Anabolic androgenic steroid dependence is associated with impaired emotion recognition

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Abstract

Rationale Illicit use of anabolic androgenic steroids (AAS) has grown into a serious public health concern throughout the Western World. AAS use is associated with adverse medical, psychological, and social consequences. Around 30% of AAS users develop a dependence syndrome with sustained use despite adverse side effects. AAS dependence is associated with a high frequency of intra- and interpersonal problems, and it is central to identify factors related to the development and maintenance of dependence.

Methods The present study investigated the ability to recognize emotion from biological motion. The emotional biological motion task was administered to male AAS dependent users (AAS dependents; $n = 45$), AAS non-dependent users (AAS non-dependents; $n = 38$) and a comparison-group of non-using weightlifters (non-users; $n = 69$).

Results Multivariate analysis of variance showed a general impairment in emotion recognition in AAS dependents, compared to the non-using weightlifters, whereas no significant impairment was observed in AAS non-dependents. Furthermore, AAS dependents showed impaired recognition of fearful stimuli compared to both AAS non-dependents and non-using weightlifters. The between-group effect remained significant after controlling for Intelligence Quotient (IQ), past 6 months of non-AAS drug use, antisocial personality problems, anxiety, and depression.

Conclusion AAS dependents show impaired emotion recognition from body movement, fear in particular, which could potentially contribute to higher frequency of interpersonal problems and antisocial behaviors in this population.

Keywords Anabolic androgenic steroids · Testosterone · Dependence · Social cognition · Body language · Emotion processing · Emotion recognition

Introduction

Anabolic androgenic steroids (AAS) are synthetic derivatives of testosterone, commonly used to enhance performance and increase muscle mass. Over the last few decades, illicit use of AAS has grown into a serious public health concern throughout the Western World (Kanayama et al. 2008; Sagoe et al. 2014). Epidemiological studies from different countries vary in their prevalence estimates, but a global lifetime prevalence of 3.3% has been reported (Sagoe et al. 2014; Sagoe and Pallesen 2018). AAS easily pass the blood-brain barrier and act on the central nervous system both directly via modulation of intracellular receptors, and indirectly by influencing the function of ligand-gated ion channels and neurotransmitter receptors (Bertozzi et al. 2017). Long-term AAS use is associated with a wide range of adverse medical (de Souza and Hallak 2011; Oskui et al. 2013; Rockhold 1993), psychiatric (Kanayama et al. 2008; Oberlander and Henderson 2012), and cognitive (Heffernan et al. 2015; Kanayama et al. 2013) side effects, in addition to maladaptive behavior (Hall et al. 2005; Kanayama et al. 2010; Miller et al. 2005). The side effects of AAS use are idiosyncratic as some experience few medical

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and psychiatric changes whereas others experience more severe consequences (Kanayama et al. 2010). An accumulation of medical, cognitive, and psychological side effects is commonly found in those fulfilling criteria for AAS-dependence. Around 30% of AAS users develop a dependence syndrome (Kanayama et al. 2009a) characterized by withdrawal symptoms and continued use despite the experience of adverse effects (Brower 2002; Kanayama et al. 2009b). Recent neuroimaging studies have demonstrated that AAS use is associated with structural and functional deviations, and that stronger effects are evident in dependent AAS users (Bjørnebekk et al. 2017; Westlye et al. 2017). AAS dependents appear to be a vulnerable group, reporting more intra- and interpersonal problems compared to AAS non-dependents, and dependence is associated with higher levels of involvement in aggressive and antisocial behaviors (Copeland et al. 1998, 2000; Kanayama et al. 2009c). AAS dependence shares some features with other drugs of abuse (Wood 2008), including brain structural similarities (Hauger et al. submitted manuscript), but the underlying mechanisms of AAS dependence are largely unknown. As with other addictions, it presumably reflects a mixture of premorbid characteristics and consequences of escalated use (Kanayama et al. 2009a). Studies that shed light on these complex connections will be clinically important.

Social cognition is an indispensable aspect of human behavior involving the processes used to analyze, understand, and store information about other persons, oneself, and interpersonal norms (Van Overwalle 2009). Making social cognitive inferences is crucial for successful social interactions because they mediate an understanding of the dispositions and intentions of others, and enables us to predict behavior (Brothers 1990). Evolutionary, extraction of a person's affective state or intention from body movement has been very important for survival (Okruszek 2018), and thus is an ancient social cognitive ability. Humans need minimal information to infer the emotions, intentions, and dispositions of others, and have the ability to extract accurate perceptual information based solely on biological motion (Heberlein et al. 2004; Hubert et al. 2007; Pavlova 2011; Puce and Perrett 2003; Vaskinn et al. 2016). A common method used to examine emotion recognition from biological motion is point-light displays (PLDs), which is considered to be useful for studying emotional processing (Loi et al. 2013; Okruszek 2018). PLDs consist of recordings of a person moving in a dark room with light sources attached to different parts of the body, or to the face (Johansson 1973). Deficits in emotional processing and response have been observed in various psychiatric populations (Leppänen 2006; Loi et al. 2013; Vaskinn et al. 2017; Vaskinn et al. 2016), including substance abuse, where such deficits are thought to contribute to the maintenance of drug addictive behavior (Goldstein and Volkow 2002; Townshend and Duka 2003; Verdejo-García et al. 2006).

Variations in testosterone levels within the normal reference range are associated with variations in mood and behavior (Booth et al. 1999). AAS is commonly administered in a temporal pattern called "cycling" (Pope Jr 1994; Su et al. 1993), with supraphysiological doses exceeding therapeutic levels by 5–100-fold in males (Kanayama et al. 2008, 2013; Su et al. 1993). This administration pattern causes large hormonal fluctuations which presumably elevates the hormonal effects on mood and behavior. Sex hormones appear to play a central role in social-cognitive abilities, possibly explaining the sexual dimorphism that is sometimes found for these abilities, where women outperform men (Baron-Cohen et al. 2005, 2003). Both human (Bos et al. 2010, 2013; Hermans et al. 2006a, b, 2008; van Honk et al. 2005, 2011, 1999) and animal (Aikey et al. 2002) studies have demonstrated that external testosterone administration can alter emotional processing. In particular, altered testosterone levels have been associated with impairment in fear processing (Aikey et al. 2002; Bos et al. 2013; Hermans et al. 2006a; King et al. 2005; van Honk et al. 2005). However, the prolonged effects of high-dose AAS use and dependence on emotion processing remain poorly understood. AAS exposure might affect brain processes and emotional processing temporarily. Still, evidence suggests that severe effects on mental health, brain structure, and cognition are primarily seen after long-term exposure and in AAS dependence (Bjørnebekk et al. 2017; Kanayama et al. 2008, 2013). This might reflect gradual alterations in the neuroendocrine or central nervous system rather than temporal fluctuations in hormonal levels.

The present study examined the ability to recognize emotion from biological motion in AAS users with and without dependence. An Emotional Biological Motion (EmoBio) task was administered to a sample of male AAS dependent, AAS non-dependent, and a comparison-group of non-using weightlifters. In order to illuminate a potential influence of temporal hormonal fluctuations, we tested for associations between emotion recognition accuracy and AAS status (current or previous use). Based on the existing evidence reviewed above, it was anticipated that emotion recognition would be reduced with long-term AAS use, and even more so in AAS dependents. Specifically, differences in fear recognition between the groups were expected.

Materials and methods

Participants and procedure

The study sample consists of adult males involved in heavy strength training ($N = 152$).The participants were either previous or current AAS users reporting at least 1 year of cumulative AAS use (summarizing on-cycle periods) or men who had never used AAS or equivalent doping substances. Participants with long-term AAS use ($n = 83$) were divided into AAS

dependents and AAS non-dependents, based upon a diagnostic tool for the assessment of AAS dependence (Pope Jr et al. 2010). This provided us with the three following groups: (a) AAS non-dependents ($n = 38$), (b) AAS dependents ($n = 45$), and (c) non-users ($n = 69$). Participants were recruited via social media, targeted online forums, and through posters and flyers distributed in selected gyms in Oslo, Norway. Prior to participation, all participants received a brochure with a description of the study, and written informed consent was collected. Participants received NOK 1.000 (≈ $125) as compensation for taking part in the study. The study was conducted in accordance with the Declaration of Helsinki and received ethical approval from the Regional Committee for Medical and Health Research Ethics in South-Eastern Norway (2013/601).

Interview and questionnaires

A semi-structured interview was used to assess relevant background and health information and consumption of pharmaceutical preparations. Additionally, AAS users were interviewed about the history and nature of their AAS use. The interview covered motives behind their usage, age of onset, administration pattern, years of use, length of cycles and number of life-time cycles, side effects, average weekly dosage, where in the cycle they were at the time of assessment, and whether and when they had ceased using AAS. Based on this information, a measure of total lifetime AAS exposure was calculated (lifetime average weekly dose calculated as mg of testosterone equivalent × lifetime weeks of AAS exposure), as has been done by others (Kanayama et al. 2009c; Pope and Katz 2003, 1994). The presence of AAS dependence was assessed by a structured clinical interview in the format of the Structured Clinical Interview for DSM-IV Axis II Disorders (SCID II) (First et al. 1997) by trained study personnel. The interview module is based on the substance-dependence criteria of DSM-IV, but modified to apply to AAS dependence (Pope Jr et al. 2010). Compared to the original SCID II, the AAS interview module takes into account that AAS is not ingested to achieve an immediate "high" of acute intoxication and provides explanatory information on how the other criteria relate to AAS abuse (Kanayama et al. 2009b). Adequate psychometric properties have been found (Pope Jr et al. 2010). The study participants were considered to be AAS dependent if they had a maladaptive pattern of AAS use that leads to clinically significant impairment or distress, manifested by three (or more) of the DSM-IV criteria (Kanayama et al. 2009b). Measures of the past 6-month use of alcohol and illegal drugs, behavioral-, emotional-, and social problems were obtained from the DSM-oriented scales of the Achenbach System of Empirically Based Assessment (ASEBA)–Adult Self-Report (Achenbach et al. 2003). Psychiatrists and psychologist from ten cultures rated these scales as very consistent with categories of the DSM-IV. The scale comprises the following categories: drug and alcohol use, depression, anxiety, somatization, attention deficit/hyperactivity, and avoidant and antisocial personality problems. General intellectual functioning or Intelligence Quotient (IQ) was assessed using the Wechsler Abbreviated Scale of Intelligence (WASI) (Wechsler 1999), and is based on the Vocabulary and Matrix Reasoning subtests.

Table 1 The percentage of urine samples positive for anabolic-androgenic steroids and mean testosterone to epitestosterone ratio in controls, current, and previous AAS users

Group	Analyzed *n* (missing)	AAS positive *n* (%)	T/E ratio	Range
Control	66 (2)	0	1.5 (1.5)	0.10–8.5
AAS current	57 (2)	46 (80.7)	32.9 (42.9)	0.10–225.9
AAS previous	22 (1)	2 (9.1)	2.5 (3.2)	0.6–14.7

T/E testosterone/epitestosterone

Doping analysis

Urine samples were collected during the neuropsychological evaluation and analyzed for AAS and narcotics using gas chromatography and mass spectrometry. This was conducted at the World Anti-Doping Agency-accredited Norwegian Doping Laboratory at Oslo University Hospital. Stimulants were analyzed by liquid chromatography and mass spectrometry. The samples were stored at − 18 °C awaiting analyses. As the half-lives of different AAS compounds vary widely, it is not obvious where a clear boundary between a current and a previous user should be put. The following criteria were used to determine ongoing AAS use: (1) urine samples positive for AAS compounds and/or (2) T/E ratio > 4 (see Table 1). A testosterone to epitestosterone (T/E) ratio > 4 has been applied by the World Anti-Doping Agency as a population-based criteria to follow up for further analyses as such values likely are indicative of testosterone abuse (WADA 2016), although cases of naturally occurring T/E ratios > 4 appear (Mareck et al. 2010).

Emotion biological motion task

We used the Norwegian version (Vaskinn et al. 2016) of the EmoBio task (Heberlein et al. 2004). This is a PLD task (Couture et al. 2010) developed from the stimuli of Heberlein et al. (2004). The EmoBio task comprises 22 short video clips of PLD walkers expressing different emotions: angry, fearful, happy, sad, and neutral (no emotion). Each of the video clips is displayed on a computer screen, and participants indicate which of the emotions is presented by ticking the right box on a piece of paper. A PLD task operationalizes body language reading efficiently in the sense that it eliminates the availability of structural cues such as color or shapes, and thereby enables investigation of pure motion (Okruszek

2018; Pavlova 2011). We adopted a proportional scoring method based on Norwegian norms that used a Norwegian healthy control group (Vaskinn et al. 2016). In the proportional scoring system, a control group serves as a reference category. For instance, where 75% of the control group indicate "angry," 15% indicate "fear," and 10% indicate "happy," an "angry" response receives a score of 1 (75/75), a "fear" response is scored 0.20 (15/75), and a "happy" response receives a score of 0.13 (10/75). When applying this scoring method, a certain degree of variability is accepted as normal. An overall EmoBio score was computed by calculating the average of all items. Similarly, index scores were computed for each emotion subcategory by calculating the average of the corresponding items.

An example of the EmoBio task used: https://youtu.be/mmY6H3Mt8QE.

Statistical analysis

Comparisons of demographic and clinical data between the non-users, the AAS dependents, and the AAS non-dependents were performed using one-way analysis of variance. Two-tailed independent sample *t* tests and chi square test were used to compare characteristics related to AAS use between AAS dependents and AAS non-dependents. The EmoBio data was negatively skewed and was therefore reflected and log-transformed (log10). We used multivariate analysis of variance (MANOVA) to compare the non-users, the AAS dependents, and the AAS non-dependents on the overall EmoBio score and the five emotion subtypes. Differences between means were examined using the Bonferroni post hoc test for multiple group comparisons. To control for the potential influence of confounding variables, we reran the MANOVAs including the following variables into the model (one at a time): IQ value, the ASEBA *T* scores for drug use, and the DSM oriented *T* scores for antisocial personality problems, anxiety and depression. We used a two-way MANOVA to examine possible temporal effects of AAS-exposure on EmoBio performance, by comparing the performance of "current or previous AAS users", and to see if there were any interaction effects between "current or previous AAS use" and AAS group. To investigate potential dose-response effects, a Spearman's rank-order correlation was run to determine the relationship between "total-lifetime-AAS-exposure" and EmoBio performance. Differences between the groups were considered to be significant at an alpha < 0.05. Partial eta-squared (ηp^2) was used as an estimate of effect size. The statistical analyses were conducted using SPSS version 25.0 (IBM corp. 2017).

Results

Demographics

Demographic and other clinical data are presented in Table 2. The three groups did not differ in age, height, or alcohol and cigarette consumption. However, AAS dependents reported using more non-AAS drugs during the previous 6 months.

Table 2 Demographics and other clinical characteristics

Variable	Non-users ($n = 69$) Mean (SD)	Non-dependent ($n = 38$) Mean (SD)	Dependent ($n = 45$) Mean (SD)	Main effect of group *F*
Age (years)	31.77 (9.45)	33.00 (8.27)	33.38 (8.52)	0.508
Height (cm)	180.7 (6.87)	179.88 (5.94)	181.20 (7.66)	0.374
Weight (kg)	90.52 (13.98)	94.09 (12.76)	99.93 (14.01)	5.23[*c]
Education	15.80 (2.73)	14.45 (2.66)	13.82 (2.26)	0.866[*b c]
IQ	112.96 (9.37)	107.95 (11.25)	101.96 (12.16)	14.34[*c d]
Tobacco use T	52.16 (4.06)	53.03 (4.93)	54.36 (4.2)	2.99
Alcohol use T	60.03 (7.04)	57.78 (7.65)	57.68 (7.06)	1.168
Non-AAS drug use T	51.68 (6.78)	54.77 (8.45)	60.06 (15.22)	7.89[*c]
T/E ratio	1.49 (1.47)	19.08 (27.17)	29.87 (45.73)	13.77[*b c]
Depressive T	52.19 (4.82)	54.74 (6.35)	59.67 (9.80)	13.93[*c d]
Anxiety T	50.87 (2.67)	53.06 (5.65)	57.46 (8.54)	16.31[*c d]
Somatic T	53.26 (4.88)	53.13 (4.71)	60.75 (12.41)	12.13[*c d]
Avoidant T	53.02 (3.88)	53.50 (4.52)	57.18 (6.80)	7.58[*c d]
ADHD T	54.33 (4.67)	55.90 (5.88)	60.26 (6.88)	12.12[*c d]
Antisocial T	52.14 (4.39)	57.22 (7.88)	63.92 (9.20)	32.48[*a]

T, T score; T/?E, testosterone/epitestosterone. [*] = $p < .05$. Bonferroni post hoc test: [a] All groups significantly different from one another, [b] AAS non-dependents significantly different from non-users, [c] AAS dependents significantly different from non-users, [d] AAS dependents significantly different from AAS non-dependents

Table 3 Characteristics related to AAS use, and comparison of the two AAS subgroups

	Non-dependent ($n = 38$)		Dependent ($n = 45$)			
Variable	Mean (SD)	Range	Mean (SD)	Range	t	p value
Debut age	23.00 (5.79)	15–38	21.46 (7.35)	12–52	1.06	0.291
Estimated weekly dose	1200.9 (1271.7)	150–7000	1385.1 (854.4)	350–4000	.745	0.459
Total years of use	7.64 (5.19)	1–24	10.35 (5.50)	1.7–30	− 2.29	*0.025**
	n (%)		n (%)		X^2	
Current AAS use	22 (59.5)		28 (63.6)		.148	.700
Physical side effects	28 (75.7)		42 (93.3)		5.08	*0.024**
Psychological side effects	21 (56.8)		41 (91.1)		13.0	*> 0.001**
Cognitive side effects	13 (35.1)		31 (70.4)		13.96	*0.001**

*Significant difference between the groups

The non-users had longer education and higher IQ compared to both AAS groups. There was a statistically significant difference between groups as determined by MANOVA on all the DSM-oriented scales. Bonferroni post hoc test revealed that AAS dependents scored significantly higher on all scales compared to both the AAS non-dependents and the non-users.

Characteristics related to AAS use are displayed in Table 3. Both groups initiated AAS use on average when in their early 20s. There were no significant differences in average weekly intake of AAS (mg/week). However, AAS dependents had used AAS for more years ($M = 10.3$, SD = 5.5) than AAS non-dependents ($M = 7.7$, SD = 5.2), t (80) = − 2.29, p = 0.025. In all, 63.6% of AAS dependents were current AAS users, compared to 59.5% of the AAS non-dependents. The majority of the AAS dependents reported some physical (93.3%), psychological (91.1%), and cognitive (70.4%) side effects of AAS—significantly higher (ps < 0.025) proportions compared to the AAS non-dependents.

Comparative performance on the EmoBio task

Tables 4 and Fig. 1 show mean scores and comparative analyses of the performance of the controls, AAS dependents, and AAS nondependents on the EmoBio task. There were significant between-group differences for the comparisons on the overall EmoBio score [F (2, 149) = 4.45, $p = 0.013$, $\eta p^2 = 0.06$]. The Bonferroni post hoc test showed that AAS dependents ($M = 0.84$) scored significantly lower ($p = 0.014$), compared to the non-users ($M = 0.88$), whereas the AAS non-dependents ($M = 0.88$), did not differ ($p = 1.0$) from the non-users Fig. 1.

For the EmoBio subscales, a significant between-group difference was observed for fear recognition [F (2, 149) = 4.32, $p = 0.015$, $\eta p^2 = 0.06$]. The Bonferroni post hoc test showed that AAS dependents ($M = 0.75$) performed significantly worse ($p = 0.040$) compared to the non-users (M = 0.87), and compared to AAS non-dependents ($M = 0.89$), ($p = 0.029$). This finding was robust, as the between-group effect remained significant with medium effect size after controlling for each of the included confounders: IQ [F (2, 147) = 4.13, p = 0.018, $\eta p^2 = 0.05$], depression [F (2, 149) = 3.95, p = 0.022, $\eta p^2 = 0.06$], anxiety [F (2, 149) = 3.95, $p = 0.022$, $\eta p^2 = 0.06$], antisocial personality problems [F (2, 149) = 3.27, $p = 0.041$, $\eta p^2 = 0.05$], and past 6 months of non-AAS drug use [F (2, 149) = 3.65, $p = 0.029$, $\eta p^2 = 0.06$]

Table 4 Emotional biological motion test scores and statistics

		Non-user ($n = 69$)	Non-dependent ($n = 38$)	Dependent ($n = 45$)	Main effect of group		
Emotion †	Range	Mean (SD)	Mean (SD)	Mean (SD)	$F^{\S}$	p	ηp^2
Overall	0.56–1.0	0.88 (0.07)	0.88 (0.08)	0.84 (0.10)	4.45	*0.013*[c]	0.06
Happy	0.40–1.0	0.91 (0.11)	0.90 (0.12)	0.89 (0.14)	0.45	.637	0.01
Fearful	0.01–1.0	0.87 (0.17)	0.89 (0.11)	0.75 (0.28)	4.32	*0.015*[cd]	0.06
Angry	0.28–1.0	0.84 (0.18)	0.83 (0.20)	0.79 (0.18)	1.21	.300	0.02
Sad	0.48–1.0	0.90 (0.14)	0.88 (0.20)	0.86 (0.16)	2.03	.136	0.03
Neutral	0.29–1.0	0.90 (0.16)	0.90 (0.15)	0.88 (0.15)	0.48	.620	0.01

† Emotional biological motion. § Log.Bonferroni post hoc test: [a] All groups significantly different from one another, [b] AAS non-dependents significantly different from non-users, [c] AAS dependents significantly different from non-users, [d] AAS dependents significantly different from AAS non-dependents

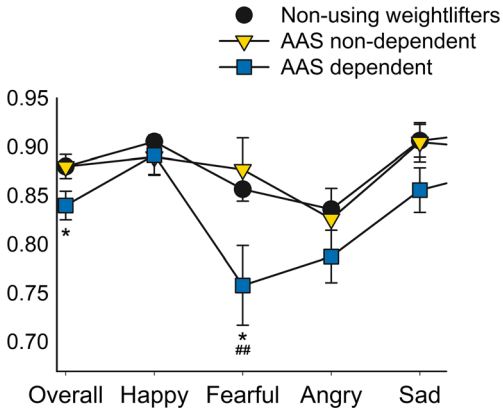

Fig. 1 Emotional Biological Motion test scores for non-using weightlifters, AAS-dependents and AAS non-dependents. Error bars correspond to standard error of mean. *X*- axis, EmoBio subscales, *Y*-axis, †EmoBio score. §Log. *AAS dependents significantly different from non-using weightlifters, ##AAS dependents significantly different from AAS non-dependents

(see Table 5). No significant group differences were seen for the other emotions. There was a small negative correlation between "total-lifetime-AAS-exposure" and fear recognition (r_s (79) = − 0.236, $p = 0.036$).

There were no significant differences between current and previous AAS users on the overall EmoBio score [F (1, 61) = 0.018, $p = 0.895$, $\eta p^2 = 0.000$], nor on the fear recognition subscale [F (1, 61) = 0.520, $p = 0.473$, $\eta p^2 = 0.008$]. Moreover, there were no statistically significant interactions between current and previous AAS use and AAS group (AAS dependent, AAS non-dependent) on overall EmoBio performance [F (1, 61) = 0.024, $p = 0.877$, $\eta p^2 = 0.000$] or on the fear recognition subscale [F (1, 61) = 0.054, $p = 0.816$, $\eta p^2 = 0.001$].

Discussion

The present study investigated the ability to recognize emotional states from body movement in a large sample of dependent and non-dependent AAS users and non-using weightlifters. The findings indicate that AAS dependents have reduced emotion recognition from body movement, fear in particular. Possible implications of the findings are discussed below.

Compared to the Norwegian norm group (Vaskinn et al. 2016), our study sample had similar scores although the AAS dependents scored markedly lower on the fear subscale. In our study sample, significant between-group differences were also observed for fear recognition where AAS dependents performed poorer compared to both AAS non-dependents and the non-users. There was no significant difference between the AAS non-dependents and the non-users on any of the EmoBio subscales which indicates that emotion recognition impairments are related to the characteristics of the AAS-dependent group. This finding of reduced fear recognition was robust, as the between-group effect remained significant with medium effect size after controlling for IQ, past 6 months of non-AAS drug use, antisocial personality problems, anxiety, and depression. There was also a small, but significant correlation between total lifetime AAS exposure and fear recognition. Together, these findings provide some support that impaired fear recognition could be related to long-term high-dose AAS use and dependence. This is in accordance with previous reports stating that severe effects on mental health, brain structure, and cognition are primarily seen after long-term exposure and in AAS dependence (Bjørnebekk et al. 2017; Kanayama et al. 2008, 2013; Pope

Table 5 Emotional biological motion test statistics, controlling for confounders

	Main effect of group (adj IQ)			Main effect of group (adj 6 m drugs)			Main effect of group (adj depression)			Main effect of group (adj anxiety)			Main effect of group (adj antisocial)		
Emotion†	$F^{\S}$	p	ηp^2	$F^{\S}$	p	ηp^2	$F^{\S}$	p	ηp^2	$F^{\S}$	p	ηp^2	$F^{\S}$	p	ηp^2
Overall	2.90	.058	0.04	2.53	.083	0.04	1.59	.207	0.02	1.57	.213	0.02	1.29	.279	0.02
Happy	0.18	.839	0.00	0.31	.737	0.01	0.56	.573	0.01	0.55	.581	0.01	0.52	.593	0.01
Fearful	4.13	*0.018*[cd]	0.05	3.65	*0.029*[d]	0.06	3.95	*0.022*[d]	0.06	3.95	*0.022*[d]	0.06	3.27	*0.041*[d]	0.05
Angry	0.10	.908	0.00	0.41	.663	0.01	0.53	.589	0.01	0.21	.811	0.00	0.17	.842	0.00
Sad	2.89	.059	0.04	2.42	.093	0.04	1.57	.212	0.02	2.24	.111	0.03	1.47	.233	0.02
Neutral	0.86	.427	0.01	0.38	.688	0.01	0.03	.973	0.00	0.11	.897	0.00	0.08	.918	0.00

† Emotional biological motion. § Log

Adj IQ, adjusted for intelligence quotient (IQ)

Adj 6 m drugs, adjusted for past 6 months of non-AAS drug use (ASEBA Adult Self-Report)

Adj depression, adjusted for ASEBA depression *T* score

Adj anxiety, Adjusted for ASEBA anxiety *T* score

Adj antisocial, Adjusted for ASEBA antisocial *T* score

Bonferroni post hoc test: [a] All groups significantly different from one another, [b] AAS non-dependents significantly different from non-users, [c] AAS dependents significantly different from non-users, [d] AAS dependents significantly different from AAS non-dependents

Jr et al. 2013). Impairment in fear recognition has been associated with antisocial or psychopathic tendencies (Birbaumer et al. 2005; Blair 2006; López et al. 2013). In line with this, AAS dependents scored higher on the DSM-oriented antisocial personality problem scale, with a mean score close to the clinical range. When we controlled for antisocial personality problems in the analysis, the effect of reduced fear recognition remained, indicating that it does not just reflect an effect of sociopathy, but is seemingly related to long-term AAS use and dependence. Associations between AAS dependence and antisocial tendencies have also been reported in other studies (Kanayama et al. 2018; Miller et al. 2005). Conceivably, the higher levels of involvement in aggressive and antisocial behaviors associated with AAS dependence (Kanayama et al. 2009c) could reflect a lower ability to recognize submission cues such as fearful body language. In an overlapping sample, our group recently reported aberrations in functional brain connectivity organization involving the amygdala in AAS users, where the connectivity was further reduced with increased lifetime use (Westlye et al. 2017). Aberration in amygdala connectivity could underpin the observed impairment in fear recognition of AAS dependents, as the amygdala has a central role in emotion processing and reactivity, fear in particular (Adolphs 2002; Blair 2006; Ochsner and Gross 2008; Yildirim and Derksen 2012) and is among the brain regions with the highest androgen receptor mRNA density (Menard and Harlan 1993; Michael et al. 1995; Simerly et al. 1990).

In addition, AAS dependents performed significantly poorer on the overall EmoBio score compared to the non-users, whereas no difference was seen in AAS non-dependents. However, the effect did not survive adjusting for IQ, past 6 months of non-AAS drug use, anxiety, and depression, suggesting that in addition to long-term high-dose AAS use, other factors associated with AAS dependence may be related to general emotion recognition. Reduced emotional processing ability has been found in several other psychiatric populations using the PLD tasks (Leppänen 2006; Loi et al. 2013; Vaskinn et al. 2017, 2016). As such, it is plausible that the observed lower accuracy in emotional recognition ability of AAS dependents is part of a more complex problem picture. This is in accordance with theoretical considerations and empirical evidence suggesting that emotional processing and response are caused by a complex interaction between hormonal effects, social context, and individual characteristics (Bos et al. 2012; Keverne et al. 1996; Welker et al. 2015). Consistent with this, the AAS dependents scored higher on all the DSM scales, had lower education and IQ, had higher past 6-month consumption of illegal drugs, and reported more intra- and interpersonal problems. The majority of the AAS dependents also reported physical, psychological, and cognitive side effects of AAS and continued use despite experiencing these side effects. This coincides with previous findings demonstrating that AAS dependents differ markedly from both AAS non-dependents and non-users on a number of measures, such as the Structured Clinical Interview for DSM-IV (Kanayama et al. 2009c). Several contextual factors, including early-life stress (Pechtel and Pizzagalli 2011; Veenema 2009) may increase the vulnerability to the adverse effects of hormonal fluctuations. It has been suggested that early-life stress can create imbalance in hormonal systems, especially oxytocin and testosterone systems, which can alter the brain's sensitivity to these hormones and affect later social-emotional behaviors (van Honk et al. 2015).

There was no significant association between emotion recognition and AAS status (current or previous use). However, other studies have demonstrated that acute testosterone administration can alter emotional processing (Bos et al. 2012; Osório et al. 2018), fear recognition in particular (Bos et al. 2012; Van Honk and Schutter 2007; van Honk et al. 2005). In relation to this, it has been hypothesized that testosterone may promote social aggression by reducing recognition of threat such as fear, anger, and disgust (Van Honk and Schutter 2007). To our knowledge, this is the first study investigating the association between long-term high-dose AAS use and emotion recognition. The supraphysiological AAS doses used by our sample are not comparable with the typically low testosterone doses administered in experimental studies, where the participants often are females. Therefore, it is not possible to directly compare across studies where different methods have been applied. Studying emotional processing of AAS users using a within-subject design at different time points in the usage cycle (during on- and off-cycles) could enhance our understanding of how AAS induced hormonal fluctuations influences emotional processing.

Limitations

Some limitations of the present study should be considered when interpreting the results. The cross-sectional design does not allow claims regarding causality. It is not clear whether the observed differences in emotion recognition were present prior to AAS initiation, or if it is connected to high-dose long-term AAS use. However, the two alternatives may not be mutually exclusive but rather reflect a mixture of premorbid characteristics and consequences of escalated AAS use as discussed in a recent review by Piacentino et al. (2015). Regardless of causal direction, it is an important aspect to consider clinically since emotion recognition is crucial for adaptive social functioning. Second, we did not have serum testosterone levels, making it harder to investigate the relationship between testosterone levels and emotion recognition. Third, only males participated in the present study. It is unclear if the present findings are applicable to females, notwithstanding evidence of AAS use as a preponderantly

male phenomenon (Sagoe et al. 2014). Further, the information presented in PLD is limited. It has been suggested that the information provided by body motion is of foremost importance when evaluating a person's emotions or intentions from long distance, when viewing conditions are suboptimal (Okruszek 2018; Yovel and O'Toole 2016). Therefore, it could be argued that performance on PLD tasks is not relevant for most daily social situations. However, studies show that performance on the EmoBio task predicts measures of functioning in different clinical populations (Engelstad et al. 2017; Olbert et al. 2013; Vaskinn et al. 2017). An important topic for future research is to ascertain whether our findings can be replicated with other methods, such as facial emotion recognition.

In summary, we found impairments in emotion recognition from body movement in AAS dependents, particularly for the recognition of fear. It seems that AAS dependents are a vulnerable population where impaired recognition of fearful stimuli might be one of many factors leading to a higher frequency of interpersonal problems and antisocial behavior (Copeland et al. 1998; Kanayama et al. 2009a, c). The complexity of symptoms accompanying AAS dependence is important to consider clinically (Brower 2002), where an interdisciplinary focus is needed in order to provide optimal treatment. The present study provides further insight into the psychosocial outcomes of long-term AAS use and dependence, particularly emotion processing, which future investigations can build on.

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Compliance with ethical standards

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

Disclaimer The founding organizations had no role in the design or conduct of the study; in the collection, analysis, or interpretation of data; or in the preparation, review, or approval of the manuscript.

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