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# Anabolic-androgenic steroids and the risk of imprisonment

Thea Christoffersen[a,*], Jon Trærup Andersen[a,b], Kim Peder Dalhoff[a,b], Henrik Horwitz[a,b]

[a] Department of Clinical Pharmacology, Bispebjerg and Frederiksberg Hospital, Bispebjerg Bakke 23, 2400 Copenhagen NV, Denmark
[b] Department of Clinical Medicine, University of Copenhagen, Blegdamsvej 9, 2100 Copenhagen Ø, Denmark

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ABSTRACT

*Background:* The use of Anabolic-Androgenic Steroids (AAS) has been associated with increased aggressiveness and violent behavior. We therefore investigated the proposed correlation between the use of AAS and criminality while controlling for important socio-economics covariates and for psychiatric comorbidity.

*Methods:* The primary endpoints were prison sentences, and time to first prison sentence. A retrospective matched cohort study design consisting of 545 males, who tested positive for AAS in Danish gyms during the period January 3, 2006 to January 31, 2017. They were matched with 5450 randomly chosen male controls. Data were cross-referenced with national register information on education, employment status, substance abuse and psychiatric comorbidity. In addition, 638 males sanctioned because they rejected to participate in the doping control and 6380 controls were used as a replication cohort.

*Results:* Already at baseline, 20.6% of the AAS users had a previous prison sentence whereas the rate was 3.7% in the control cohort ($p < 0.0001$). During the follow-up period the cumulative prevalence increased to 29.5% and 4.9%, respectively (unadjusted HR 9.15, 95% CI 6.33–13.20). The associations remained highly significant after controlling for socio-economic factors, drug abuse and psychiatric comorbidity. The results could be replicated in a similar cohort.

*Conclusion:* Our study shows that AAS users have a 9-fold increased risk of being convicted of a crime compared to matched controls, randomly chosen from the general population. This association could not be explained by common socioeconomic factors or by psychiatric comorbidity.

## 1. Introduction

Anabolic-Androgenic Steroids (AAS) are a group of hormones that include the natural male hormone testosterone and chemically synthesized derivates thereof. These hormones have various degrees of anabolic and masculinizing properties. Initially, the AASs were developed for clinical use, e.g. for muscle wasting or hypogonadal diseases (Shahidi, 2001) but gained quickly popularity as performance-enhancing drugs in sports and have been used systematically as doping in sports since the 1950s (Franke and Berendonk, 1997).

In the 1980s Western culture became increasingly obsessed with male muscularity and subsequently, AAS use began to spread from elite athletics to the general male community (Hartgens and Kuipers, 2004; Kanayama et al., 2008).

Today, the clear majority of AAS users are recreational exercisers (Ip et al., 2011; Parkinson and Evans, 2006). Predominantly, it is a male phenomenon and among males in the Scandinavian countries the prevalence of AAS use is estimated to be 1.8–2.9% (Nilsson, 2001; Singhammer, 2013).

Use of AAS has been associated with a wide range of health consequences and psychiatric side effects such as increased aggressiveness, hostility and mood swings (Hall et al., 2005; Horwitz et al., 2018; Klötz et al., 2010). Further, an association between use of AAS and increased criminality has been suggested as a consequence of the increase in aggressive and hostile behavior. In a retrospective cohort study of 241 individuals, who were tested positive for AAS, Klötz and colleagues found that the risk of being convicted for weapon offences or fraud was higher among AAS users compared to the negative controls (n = 1199) (Klötz et al., 2006). Data from a minor, well-conducted Swedish study support the suggested association between crime and AAS use. The authors examined data from – and interviewed 36 individuals who sought help at a psychiatric addiction clinic due to suspected AAS adverse effects. They found that criminal activity, especially violent crimes and weapons offences, increased for almost 70% of the individuals after having started drug use, and in particular for individuals, who started the drug abuse with AAS (Skårberg et al., 2010).

* Corresponding author.
*E-mail addresses:* thea.christoffersen@regionh.dk (T. Christoffersen), jon.thor.traerup.andersen@regionh.dk (J.T. Andersen), kim.peder.dalhoff@regionh.dk (K.P. Dalhoff), henrik.horwitz@regionh.dk (H. Horwitz).

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Thus, the results from the studies above indicate an association. However, due to methodological challenges, *i.e.* the risk of misclassification bias and absence of a control group, respectively, the findings must be interpreted with caution. Further, the association is poorly examined in the Danish population.

We therefore set out to investigate the proposed correlation between crime and AAS use in a larger cohort of AAS users and controls in Denmark. Secondly, we aimed to investigate whether an association between criminal behavior and AAS use could be explained by socioeconomic factors such as education, employment, substance abuse or by psychiatric comorbidity.

## 2. Materials and methods

### 2.1. Primary endpoint

The primary endpoints of this study were incident (*de novo*) cases of prison sentences, and time to first prison sentence.

### 2.2. Study design

We used a retrospective matched cohort study design and compared the incidence and prevalence of prison sentences among AAS users with that of matched controls from the general Danish population.

### 2.3. Cohort

#### 2.3.1. The antidoping program

Over the last decade, Anti Doping Denmark has been engaged in a collective preventative response to doping among recreational athletes. In 2006 they established a collaboration with Danish commercial gyms and fitness centres to initiate a doping control program. The legal basis of this collaboration is formulated in the document "The initiative on integrity in sports" (Ministry of Education and Culture, 2015).

Today, Anti Doping Denmark conducts 1000 inspections annually in 342 collaborating gyms across Denmark, covering approximately 80% of all Danish gym members. The doping controls have primarily been targeted at persons visually suspected of AAS use, *i.e.* muscular men and women who engage in weightlifting. If the persons were tested positive for AAS or if they declined to provide a urine sample for testing, they would receive a doping sanction, resulting in a two-year suspension of membership of all of the collaborating gym (Horwitz et al., 2018).

#### 2.3.2. AAS-user cohort

During the period from January 3, 2006 to March 18, 2018 1219 individuals received a doping sanction. Only 19 females were sanctioned during the period, and hence we have chosen to restrict our further analysis to males. Of these 1200 males, 1189 were Danish citizens and were included in this study. Of these 1189 persons, 545 were sanctioned because AAS traces were found in the urine sample provided, and their data are the primary focus of this study. All 545 were sanctioned before December 31, 2017.

#### 2.3.3. Control cohort

As previously described (6) we randomly selected a control cohort consisting of ten controls from the general population per AAS user, matched by age, gender and date.

### 2.4. Registries, endpoints, and confounders

All Danish residents are assigned a unique personal identification number (CPR-number), which is used in all national registers and in all contacts with the health care system and the state (Pedersen, 2011). We linked the study subjects' CPR-numbers with the Danish Civil Registration System, the Danish Central Crime Register, the DREAM database, The Danish National Registry of Patients, and The Danish Psychiatric Central Research Registry. Subjects were followed until December 31, 2017 or when they deceased or migrated from Denmark. Below is a description of the applied registries and how we defined our covariates and endpoints.

#### 2.4.1. Civil registration

The Danish Civil Register System keeps records of current and historical information on all residents living in Denmark. The information includes gender, vital status, place and date of birth, place of residence, date of emigration, immigration or disappearance, and information about parents, siblings, spouses and for women information about children (Pedersen, 2011).

#### 2.4.2. Prison sentences

The Danish Central Crime Register has information about all sentences in Denmark since 1978 (Greve et al., 2006). We retrieved data on prison sentences related to this cohort during the period from January 1, 1995 until December 31, 2017. The different types of crimes were divided into six categories according to the guidelines of Statistics Denmark (Statistics Denmark, 2018): (i) prison sentences due to violation of the law on road traffic; (ii) drug related crimes; (iii) violation of the weapon law; (iv) crimes of violence; (v) property crime: rubbery, burglary, theft, and fraud (vi) and finally sentences which did not fit in to the aforementioned categories were categorized as "Other". Originally, we also planned to investigate the prevalence of sexual crime, but due to few observations this category had to be omitted, and thus coded as "Other".

#### 2.4.3. Employment status

The DREAM database was established in 1991 and covers information on all Danish residents, who have received social benefits (transfer income) and further it covers data on employment status. Data are updated weekly (Due Madsen and Sørensen, 2018). The employment status at baseline was divided into four categories: self-supporting (working), short-term sickness (sickness benefits), long-term sickness or disability (including disability pension, Flex-jobs (long-term disabled with partial working capacity)), unemployment benefits (social security benefits).

#### 2.4.4. Drug abuse and psychiatric comorbidity

The Danish National Register of Patients and The Danish Psychiatric Central Research Registry contain information on all somatic and psychiatric hospital contacts in Demark (Lynge et al., 2011; Mors et al., 2011). We used diagnoses of poisoning by narcotics (ICD-10: T40 + T43) or mental disorders related to the use of psychoactive substance (ICD-10:F1) up to ten year prior to baseline as a proxy for drug abuse (World Health Organization, 2010). Furthermore, we grouped disorders within ICD-10 group F, except F1, as other psychiatric diagnoses.

#### 2.4.5. Education

Information about the highest attained level of education of all subjects was retrieved from Statistics Denmark based on data from the Danish Education Registers (Jensen and Rasmussen, 2011). Level of education at baseline was divided into four groups based on length of education: (i) 10 years or less, (ii) 10–12 years, (iii) 12–15 years, or (iv) 15 years.

#### 2.4.6. Origin

Statistics Denmark also holds information on country of origin and have defined following three categories: (i) Persons of Danish origin, (ii) immigrants, and (iii) descendants of immigrants. According to Statistics Denmark an immigrant is a person born outside Denmark, where none of the parents were of Danish origin. Descendants of immigrants are defined as persons born in Denmark, where none of the parents had a Danish citizenship. Thus, a child of immigrants where one

of the parents had received a Danish citizenship is regarded as a person of Danish origin (Statistics Denmark, 2019).

### 2.5. Statistics

We used ordinary test statistics as applicable. Thus, we employed the *t*-test for normally distributed continuous variables, and for categorical variables we used a chi-square table test.

#### 2.5.1. Time to event analysis

Data interpretation was primarily based on the incident cases, since we argue that these figures have the highest probability of reflecting the causal relationship. Therefore, we used time to event analysis.

#### 2.5.2. Univariable model

We used the Kaplan-Meier estimator to calculate and visualize time to first prison sentence, and in order to obtain hazard ratios we used a Cox proportional hazard regression model. We ignored death as a competing risk, due to the few incident cases of death (Horwitz et al., 2018). Observation time was calculated from index date (*i.e.* date of doping sanction and date of enrolment for the controls) and until time of first prison sentence or death/migration. Persons were left censored if they had a prison sentence at baseline.

In the same manner we analyzed the risk of conviction within the different domains of crime. Persons were left censored if they had a prison sentence within that domain at baseline.

Furthermore, we tabulated cumulative prevalence of prison sentences at baseline and end of follow-up and compared the two groups with a chi square table test.

#### 2.5.3. Multivariable model

We also used a Cox proportional hazards regression model to adjust for the following confounders: Age, origin, employment status, education, drug abuse, and psychiatric diagnoses. Persons were left censored if they had a prison sentence at baseline.

As the extent of missing data for the AAS - and control cohort was limited, we did not impute data.

#### 2.5.4. Missing data

Missing data were rare, see Table 1. Thus, a complete dataset could be gathered for 94.6% of the control cohort, and 96.5% of the AAS user cohort. The primary reason for missing data were related to missing information on education and this was primarily a problem for individuals categorized as “immigrants”. See Supplementary material.

#### 2.5.5. Sensitivity analysis

To investigate the validity of our estimates we ran the same analyses in the replication cohort. Since missing values were primarily related to individuals categorized as immigrants, we also conducted the multivariable analysis for individuals characterized as being of Danish origin.

#### 2.5.6. Replication cohort

Of the 644 males who were sanctioned because they declined to deliver a urine sample, 638 received their doping sanction before December 31, 2017, and they were included in the replication cohort. There is a substantial suspicion the persons were using AAS, since they were informed that refusing to participate in the doping control would lead to a doping sanction, and secondly we have previously shown that they present the same prevalence of adverse effects as the AAS positive (Horwitz et al., 2018). The results from the replication cohort are presented in supplementary material*.

All statistics were calculated in SAS 9.4, and all hazard ratios are presented with 95% confidence intervals.

**Table 1**
Baseline characteristics.

| | | AAS user (n = 545) | Control (n = 5450) | *P* Value |
|---|---|---|---|---|
| Age/years | Mean/SD | 26.19 (6.31) | 26.19 (6.34) | |
| Length of education in months | Mean/SD | 135.18 (24.76) | 142.86 (28.76) | < 0.0001[a] |
| Education groups | | 2.20 | 5.05 | |
| missing | % | | | |
| 10 years or less | % | 48.81 | 35.50 | < 0.0001[b] |
| 10 to 12 years | % | 9.91 | 21.98 | |
| 12 to 15 years | % | 36.51 | 24.64 | |
| 15 years or more | % | 2.57 | 12.83 | |
| Country of origin | | 85.50 | 84.31 | 0.22[b] |
| Danish | % | | | |
| Immigrant | % | 10.64 | 12.70 | |
| Descendant of immigrants | % | 3.85 | 2.99 | |
| Occupational status | | 1.65 | 1.05 | |
| missing | % | | | |
| self supporting | % | 78.90 | 85.89 | < 0.0001[b] |
| sick leave-temporarily | % | 2.39 | 1.69 | |
| Disability benefits | % | 2.20 | 2.33 | |
| Unemployed | % | 14.86 | 9.05 | |
| previous prison sentence | % | 20.55 | 3.65 | < 0.0001[b] |
| A diagnosis of drug abuse | % | 10.28 | 4.92 | < 0.0001[b] |
| Other psychiatric diagnoses | % | 9.72 | 7.63 | 0.08[b] |
| Complete data | % | 96.51 | 94.64 | 0.06[b] |

[a] P value obtained from two-sample t-test.
[b] P value obtained from ordinary chi square table test.

### 2.6. Ethics

The present study was approved by the Danish National Board of Health (FSEID-00003570), and the Danish Data Protection Agency (2012-58-0004/BFH-2017-105/05949). Further, the study has an approval from Statistics Denmark (dstfse-706925). Retrospective register studies do not require ethical permission in Denmark. Our findings are reported in accordance with the STROBE criteria (von Elm et al., 2007).

## 3. Results

### 3.1. Basic characteristics

We included 545 AAS doping sanctioned males (the AAS cohort) and compared them with 5450 matched male controls. The average age at time of the doping sanction was 26.2 years (SD 6.3 years), and age at enrolment in the control cohort was equivalent (26.2 years with SD 6.3 years). Their baseline characteristics are shown in Table 1. In general, AAS users had a shorter length of education, a higher percentage were living on social benefits, and they were more likely to have a diagnosis of drug abuse, but other psychiatric diagnoses were comparable to that of healthy peers.

The Danish Registry of Crime was updated up until December 31, 2017, and we therefore discontinued follow-up at that date. Thus, the follow-up period was 7.1 years (SD 2.9) in average in the AAS cohort, and 7.0 (SD 3.0) in the control cohort ($p = 0.52$).

### 3.2. Crime

The use of AAS was strongly associated with criminal behavior, and during the period 1995–2018, 161 AAS users had served prison time due to 481 law offences. The reasons for imprisonment are found in Table 2.

Already at baseline (*i.e.* time of doping sanction) 20.6% of the AAS

**Table 2**
Distribution of prison sentences.1995–2018.

| | AAS user (n = 545) | Control (n = 5450) |
|---|---|---|
| Individuals with a prison sentence | 161 (29.5%) | 267 (4.9%) |
| Number of prison sentences | 481 | 749 |
| Length of prison sentences/days (Median IQR) | 90 (40-210) | 70 (30-180) |
| Property crime (i.e. theft, burglary, robbery) | 27.9% | 30.8% |
| Violation of the traffic law | 5.6% | 8.7% |
| Violation of the law on narcotics | 2.9% | 4.7% |
| Violent crime | 41.2% | 39.1% |
| Violation of the weapon law | 2.1% | 1.7% |
| Other | 20.4% | 15.0% |

Explanation: During the period from 1995 to 2018, a total of 481 and 749 prison sentences have been giving to the individuals comprising the AAS cohort and the control cohort, respectively, including cases of multiple sentences to the same individual. The percentages below refer to the distribution of total number of prison sentences among the six crime categories.

users had a previous prison sentence whereas the rate was 3.7% in the control cohort ($p < 0.0001$), during the follow-up period the cumulative prevalence increased to 29.5% and 4.9%, respectively (Table 3) (HR 9.15, 95% CI 6.33–13.20). This indicates that AAS use is a strong risk factor of criminal behavior, and this can also be seen in the Kaplan-Meier in Fig. 1, which depicts time to first prison sentence. In general, AAS users have a high risk of conviction within all the different domains of crime. However, it is worth noting that when we completed follow-up, 18.5% of AAS users had been imprisoned due to violent crimes. For further details please see Table 3.

### 3.3. Multivariable analysis

We also investigated whether the high risk of getting involved in criminal activities, could be explained by a range of socioeconomic factors. But after adjusting for age, origin, history of drug abuse, educational length, occupational status, and psychiatric comorbidity, the association decreased slightly, but remained highly significant with a 7-fold higher risk of prison sentences compared to the control group (HR 7.17 95% CI 4.89–10.52). Please see supplementary material.

### 3.4. Sensitivity - and replication analysis

Neither sensitivity nor replication analyses altered the general results or conclusions. Please see supplementary material*.

## 4. Discussion

We performed a retrospective nationwide matched cohort study analyzing the association between use of AAS and conviction of a prison sentence. We found a strong association between use of AAS and prison sentences, but whether AAS causes this anti-social behavior or it is a symptom of such is less clear. However, it is indeed very difficult to study the causality between AAS use and crime, as it is a challenge to design and conduct ideal observational studies of doping and drug abuse due to the illicit nature of these substances. Randomized clinical trials are hampered by ethical issues given the fact that there is no registered indication for the use of supraphysiologic doses and by the fact that these substances are mainly illegally obtained. For the same reasons there are no public registries of AAS users and a large, reliable and representative sample is therefore difficult to obtain. Further, the selection of a control group is not straightforward. If AAS users and non-users are identified by questionnaires there is a substantial risk of reporting bias since AAS are illicit drugs. Conversely, if AAS users are identified by testing blood/urine samples and are compared to those

**Table 3**
Time to first prison sentence, within different domains of crime.

| Law offense | baseline AAS user | baseline control | *P* Value[a] | Follow-up AAS-users | Follow-up controls | *P* Value[a] | Hazard ratio | *P* Value[b] |
|---|---|---|---|---|---|---|---|---|
| Property crime (i.e. theft, burglary, robbery) | 8.07% | 1.54% | < .0001 | 11.01% | 2.15% | < .0001 | 5.12 (2.82-9.29) | < .0001 |
| Violation of the traffic law | 0.92% | 0.42% | 0.11 | 2.57% | 0.70% | < .0001 | 5.98 (2.62-13.66) | < .0001 |
| Violation of the law on narcotics | 1.47% | 0.26% | < .0001 | 2.02% | 0.51% | < .0001 | 2.15 (0.62-7.49) | 0.2285 |
| Violent crime | 13.58% | 2.02% | < .0001 | 18.53% | 2.72% | < .0001 | 8.24 (5.03-13.49) | < .0001 |
| Violation of the weapon law | 0.55% | 0.11% | 0.011 | 1.47% | 0.22% | < .0001 | 8.32 (2.54-27.27) | 0.0005 |
| Other | 6.97% | 0.79% | < .0001 | 12.11% | 1.34% | < .0001 | 10.1 (6.04-16.91) | < .0001 |
| Any prison sentence | 20.55% | 3.65% | < .0001 | 29.54% | 4.90% | < .0001 | 9.15 (6.33-13.2) | < .0001 |

Explanation: Already at baseline (*i.e.* time of doping sanction) 20.6% of the AAS users had a previous prison sentence whereas the rate was 3.7% in the control cohort ($p < 0.0001$), during the follow-up period the cumulative prevalence increased to 29.5% and 4.9%, respectively. Thus, the hazard of being convicted was 9.15 times higher for AAS users than the controls.

[a] P-value obtained from ordinary chi square table test.

[b] P-value obtained for the hazard ratio (Wald test).

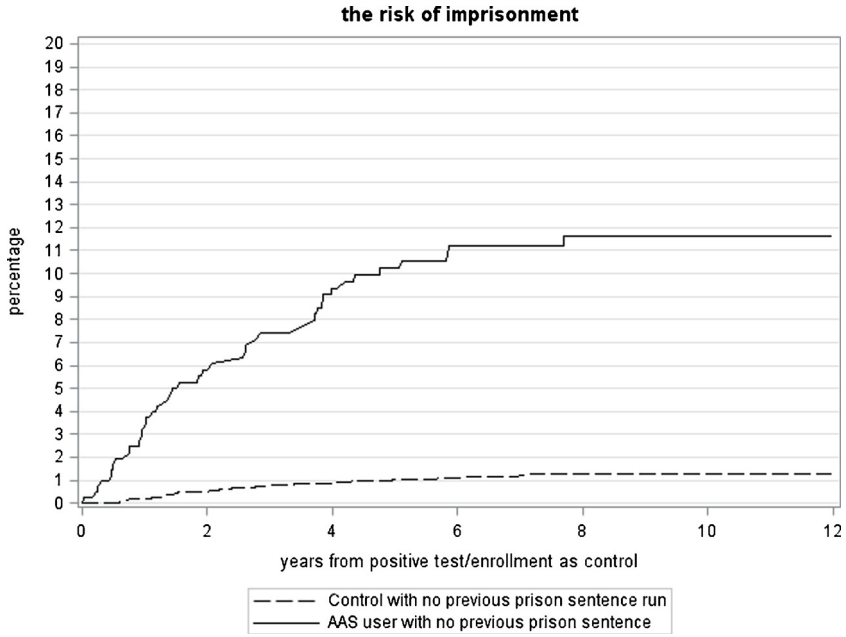


**Fig. 1.** Time to prison sentence.
Fig. 1 shows that AAS use is a strong risk factor for imprisonment. Hazard ratio 9.15 (6.33–13.2).

who test negative from the same weightlifting milieu, there is a great risk of having unidentified AAS users, who are temporarily in an off-cycle, in the comparison group. Finally, if the AAS users are compared to a random selection of controls, there is a potential risk of unmeasured confounders. Ideally, the control cohort in an observational study would consist of individuals from the weightlifting milieu who *repeatedly* were tested negative for AAS use and at the same time were matched on age, educational length, occupational status, origin etc. However, such comparison group is indeed very difficult to establish.

AAS cross the blood-brain barrier and are expected to have certain CNS effects (Bjørnebekk et al., 2017). Su et al. investigated the short-term effects of AAS on mood and behavior in 20 healthy volunteers, and reported that high doses of AAS increased self-confidence, forgetfulness, distractibility, mood swings, and violent feelings (Su et al., 1993). Chronic use of AAS has been associated with amygdala enlargement, elevated glutamate-glutamine levels and a poorer visuospatial cognitive function (Carrillo et al., 2009; Kaufman et al., 2015). Bjørnebekk and colleagues compared the brains of AAS -using and clean weightlifters with magnetic resonance imaging and found that AAS use was associated cortical thinning (Bjørnebekk et al., 2017). These neural alterations might explain the impaired impulse control, extreme mood swings and increased aggressiveness that have been associated with AAS use (Kouri et al., 1995; Perry et al., 2003). Occasionally, this aggressiveness and impaired impulse control may trigger violent behavior in certain individuals (Klötz et al., 2010; Lundholm et al., 2015; Thiblin and Pärlklo, 2002). Our results support the above, as our AAS positive cohort had an 8-fold higher risk of being convicted for violent crimes compared to the control cohort.

The finding that AAS abuse and risk-taking behavior is associated with crime is probably not all that surprising, although previous research on the issue has been conflicting. As previously mentioned, Klötz et al. (Klötz et al., 2006) conducted a register-based study on individuals referred to the Swedish Doping Laboratory. They compared 241 subjects who tested positive for AAS with 1,199 subjects who tested negative and reported that the conviction rate for weapons offences or fraud was higher in the AAS positive group. In contrast, they did not find a significant difference regarding violent crimes or crimes against property. However, as the authors states, the study findings must be interpreted with some reservations as some misclassification was likely to have occurred, due to the probability of unidentified AAS users in the AAS-negative control group, as well as a risk of selection bias since most of the study subjects were referred from other medical centers, including drug abuse centers.

A recent large Swedish cross-sectional register study of 10,365 male twins (Lundholm et al., 2015) reports a strong association between self-reported AAS use and conviction of a violent crime, which, however, lost statistical power when adjusting for other drug abuse. However, as the non-responders (40%) more often were male, criminally convicted, treated for psychiatric conditions and less educated, underestimation of the true association might have occurred. Further, misclassification due to self-report data is likely.

Beaver and co-workers examined the association between AAS use and violent delinquency in a nationally representative survey of US adolescents and found that the self-reported AAS users reported a small but significant greater involvement in serious violent behavior. An association that remained significant after adjusting for polysubstance use and previous violent behavior (Beaver et al., 2008).

### 4.1. Strength and limitations

The main weakness of the present study is the observational design. Some misclassification cannot be excluded because the control cohort might include unidentified AAS users. We do not know the exact prevalence of AAS use in Denmark but based on the literature 1.8–2.9 % of the general male population have used AAS (Nilsson, 2001; Singhammer, 2013). This would lead to a minor underestimation of the risk of prison sentences related to AAS use. Conversely, some AAS users may not have been captured by the doping controls as the individual inspected could be in an off-cycle period and thus tested negative and further, some AAS users may not have the bodybuilder physique and hence not been a target for doping control.

Other limitations need considerations. First, we cannot exclude that unaccounted confounders to some extent explain the results. We had access to important covariates such as educational length, occupational status, origin and psychiatric diagnoses and after adjusting for these the associations remained strong and highly significant. The registries contain limited information on more personal habits, such as recreational drug abuse. Furthermore, psychiatric disorders are still taboo

subjects, and patients may be reluctant to seek help. This will affect our confounder control for psychiatric co-morbidity and substance abuse. The control cohort may differ from the AAS cohort in other aspects than the above mentioned, since our AAS-user cohort all attended commercial gyms or fitness centers, whereas the control cohort represent the general male population in Denmark. However, as previously discussed the selected matched control cohort is assessed to pose the best available comparator. Finally, we had no information on the duration of AAS exposure, which left us unable to draw conclusions about dose-response relationship.

A main strength is national design; our cohort is obtained from Danish fitness centers all over Denmark, whereas most comparable study samples are drawn from the prison or healthcare system, which we believe reduce selection bias and increase generalizability. Furthermore, recall bias is eliminated since information was recorded prospectively and not based on questionnaires or interviews. Finally, our replication analysis shows that our associations are reliable and robust.

## 5. Conclusions

Our study shows that AAS users have a 9-fold higher risk of being convicted of a crime compared to matched controls, randomly chosen in the general population. This association was confirmed in a replication cohort and could furthermore not be explained by common socioeconomic factors or psychiatric comorbidity. Whether AAS use causes this anti-social behavior or it is a symptom of such still has to be determined.

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## Contributors

TC, JTA, KD and HH formulated the research project. TC drafted the manuscript. HH performed the statistical analysis. HH, JTA and KD provided critical revisions. All authors assisted with the writing of the manuscript and approved the final version for publication.

## Declaration of Competing Interest

Thea Christoffersen and Jon Trærup Andersen have no conflicts of interest. Kim Peder Dalhoff is a member of the Board of Anti Doping Denmark. Henrik Horwitz has received a research grant from Anti Doping Denmark.

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## References

Beaver, K.M., Vaughn, M.G., Delisi, M., Wright, J.P., 2008. Anabolic-androgenic steroid use and involvement in violent behavior in a nationally representative sample of young adult males in the United States. Am. J. Public Health 98, 2185–2187. https://doi.org/10.2105/AJPH.2008.137018.

Ministry of Education and Culture, 2015. Act on the Promotion of Integrity in Sports. https://www.finlex.fi/fi/laki/kaannokset/2015/en20150390_20150390.pdf.

Bjørnebekk, A., Walhovd, K.B., Jørstad, M.L., Due-Tønnessen, P., Hullstein, I.R., Fjell, A.M., 2017. Structural brain imaging of long-term anabolic-androgenic steroid users and nonusing weightlifters. Biol. Psychiatry 82, 294–302. https://doi.org/10.1016/j.biopsych.2016.06.017.

Carrillo, M., Ricci, L.A., Melloni, R.H., 2009. Adolescent anabolic androgenic steroids reorganize the glutamatergic neural circuitry in the hypothalamus. Brain Res. 1249, 118–127. https://doi.org/10.1016/j.brainres.10.053.

Due Madsen, A., Sørensen, M.L., 2018. Effects of Trade and Market Integration in a Small Open Economy - a Dynamic CGE Approach. Accessed November 9, 2018. http://www.dreammodel.dk/pdf/D2002_01.pdf.

von Elm, E., Altman, D.G., Egger, M., Pocock, S.J., Gøtzsche, P.C., Vandenbroucke, J.P., STROBE Initiative, 2007. The strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: guidelines for reporting observational studies. Lancet 370, 1453–1457. https://doi.org/10.1016/S0140-6736(07)61602-X.

Franke, W.W., Berendonk, B., 1997. Hormonal doping and androgenization of athletes: a secret program of the German Democratic Republic government. Clin. Chem. 43, 1262–1279.

Greve, V., Høyer, G., Spencer, M., 2006. The Principal Danish Criminal Acts: The Criminal Code, The Corrections Act, The Administration of Justice Act, 3rd ed. DJØF Publishing, Denmark.

Hall, Ryan C.W., Hall, Richard C.W., Chapman, M.J., 2005. Psychiatric complications of anabolic steroid abuse. Psychosomatics 46, 285–290. https://doi.org/10.1176/appi.psy.46.4.285.

Hartgens, F., Kuipers, H., 2004. Effects of androgenic-anabolic steroids in athletes. Sports Med. 34, 513–554.

Horwitz, H., Andersen, J.T., Dalhoff, K.P., 2018. Health consequences of androgenic anabolic steroid use. J. Intern. Med. 285, 333–340. https://doi.org/10.1111/joim.12850.

World Health Organization, 2010. International Statistical Classification of Diseases and Related Health Problems (10th Revision). Retrieved from https://icd.who.int/browse10/2016/en Accessed January 28, 2019. .

Ip, E.J., Barnett, M.J., Tenerowicz, M.J., Perry, P.J., 2011. The Anabolic 500 survey: characteristics of male users versus nonusers of anabolic-androgenic steroids for strength training. Pharmacotherapy 31, 757–766. https://doi.org/10.1592/phco.31.8.757.

Jensen, V.M., Rasmussen, A.W., 2011. Danish education registers. Scand. J. Public Health 39, 91–94. https://doi.org/10.1177/1403494810394715.

Kanayama, G., Hudson, J.I., Pope, H.G., 2008. Long-term psychiatric and medical consequences of anabolic-androgenic steroid abuse: a looming public health concern? Drug Alcohol Depend. 98, 1–12. https://doi.org/10.1016/j.drugalcdep.2008.05.004.

Kaufman, M.J., Janes, A.C., Hudson, J.I., Brennan, B.P., Kanayama, G., Kerrigan, A.R., Jensen, J.E., Pope Jr, H.G., 2015. Brain and cognition abnormalities in long-term anabolic-androgenic steroid users. Drug Alcohol Depend. 152, 47–56. https://doi.org/10.1016/j.drugalcdep.2015.04.023.

Klötz, F., Garle, M., Granath, F., Thiblin, I., 2006. Criminality among individuals testing positive for the presence of anabolic androgenic steroids. Arch. Gen. Psychiatry 63, 1274–1279. https://doi.org/10.1001/archpsyc.63.11.1274.

Klötz, F., Petersson, A., Hoffman, O., Thiblin, I., 2010. The significance of anabolic androgenic steroids in a Swedish prison population. Compr. Psychiatry 51, 312–318. https://doi.org/10.1016/j.comppsych.2009.05.007.

Kouri, E.M., Lukas, S.E., Pope, H.G., Oliva, P.S., 1995. Increased aggressive responding in male volunteers following the administration of gradually increasing doses of testosterone cypionate. Drug Alcohol Depend. 40, 73–79.

Lundholm, L., Frisell, T., Lichtenstein, P., Långström, N., 2015. Anabolic androgenic steroids and violent offending: confounding by polysubstance abuse among 10,365 general population men. Addiction 110, 100–108. https://doi.org/10.1111/add.12715.

Lynge, E., Sandegaard, J.L., Rebolj, M., 2011. The danish national patient register. Scand. J. Public Health 39, 30–33. https://doi.org/10.1177/1403494811401482.

Mors, O., Perto, G.P., Mortensen, P.B., 2011. The danish psychiatric central research register. Scand. J. Public Health 39, 54–57. https://doi.org/10.1177/1403494810395825.

Nilsson, S., 2001. The prevalence of the use of androgenic anabolic steroids by adolescents in a county of Sweden. Eur. J. Public Health 11, 195–197. https://doi.org/10.1093/eurpub/11.2.195.

Parkinson, A.B., Evans, N.A., 2006. Anabolic androgenic steroids: a survey of 500 users. Med. Sci. Sports Exerc. 38, 644–651. https://doi.org/10.1249/01.mss.0000210194.56834.5d.

Pedersen, C.B., 2011. The danish civil registration system. Scand. J. Public Health 39, 22–25. https://doi.org/10.1177/1403494810387965.

Perry, P.J., Kutscher, E.C., Lund, B.C., Yates, W.R., Holman, T.L., Demers, L., 2003. Measures of aggression and mood changes in male weightlifters with and without androgenic anabolic steroid use. J. Forensic Sci. 48, 646–651.

Shahidi, N.T., 2001. A review of the chemistry, biological action, and clinical applications of anabolic-androgenic steroids. Clin. Ther. 23, 1355–1390.

Singhammer, J., 2013. Attitudes toward anabolic-androgenic steroids among non-competing athletes in various types of sports – a cross-sectional study. Sport Sci. Rev. 22, 109–128. https://doi.org/10.2478/ssr-2013-0006.

Skårberg, K., Nyberg, F., Engström, I., 2010. Is there an association between the use of anabolic-androgenic steroids and criminality? Eur. Addict. Res. 16, 213–219. https://doi.org/10.1159/000320286.

Statistics Denmark, https://www.dst.dk/da/Statistik/dokumentation/Times/forebyggelsesregistret/ietype. Accessed January 28, 2019.

Statistics Denmark, https://www.dst.dk/da/TilSalg/Forskningsservice/Dokumentation/hoejkvalitetsvariable/kriminalitet—indsaettelser/ind-ger7#. Accessed November 9, 2018.

Su, T.P., Pagliaro, M., Schmidt, P.J., Pickar, D., Wolkowitz, O., Rubinow, D.R., 1993. Neuropsychiatric effects of anabolic steroids in male normal volunteers. JAMA 269, 2760–2764.

Thiblin, I., Pärlklo, T., 2002. Anabolic androgenic steroids and violence. Acta Psychiatr. Scand. S125–S128.