# Investigating Consequences on Hormone Levels of Gaming for Girls at Nine to Ten Years Old

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### Abstract

Video games have become a huge part of people's lives. Thereby, the negative effects of gaming are of interest. This study investigated associations between gaming time and hormone levels. The examined hormones were testosterone as well as DHEA, the prohormone to testosterone, and estradiol, a hormone produced from testosterone. Data regarding children at 9-10 years old were taken from the Adolescent Brain Cognitive Development. It was analyzed, using a multiple linear regression model. The regression shows DHEA levels are negatively affected by an increase in gaming time for girls, but not for boys. Neither testosterone, or estradiol levels were affected by gaming time. However, the results of DHEA suggest there is a connection between gaming and hormones. Thereby, future studies should be done to investigate the details of the effect. This subject could in the future explain gaming time affect on the brain and help tackle eventual negative effects.

## Acknowledgements

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## 1 Introduction

In modern society, gaming is one of the widest entertainment genres around the world. Since it takes up a generous part of people's lives, the negative effects of gaming is interesting, for example, studies have shown that gaming can result in increased aggression, negative academic results, and social isolation [1]. Behavior and sex hormone secretion is strongly connected to brain functions which makes it interesting to investigate the effects of gaming time on the brain, and further, the effects on hormone levels.

### 1.1 Insula

The insula cortex is a brain region that is positioned in the deep lateral sulcus. The main functions of the region are sensory processing, emotion processing, and high levels of cognition. After processing information, the insula integrates information between cognitive, visual, affective, and sensorimotor networks. [2]

### 1.2 Hormones

Hormones are signaling molecules that can regulate the human body, such as physiological behaviors and the anatomy of the brain. A subgroup of hormones is sex hormones, they play an important role in maturation, three examples of sex hormones are dehydroepiandrosterone, testosterone, and estradiol. [3]

### 1.2.1 Dehydroepiandrosterone

Dehydroepiandrosterone (DHEA) is produced in the adrenal glands [4], and can be altered from cholesterol [5]. The production can be affected by factors such as race, sex, insulin, and insulin-like growth factors [6]. DHEA is a prohormone, a precursor hormone, which alters into testosterone [5]. It can not be directly aromatized into testosterone. Instead, it is metabolized by the enzyme 3S-HSD to androstenedione which can be dehydrated into testosterone.

#### 1.2.2 Testosterone

Testosterone is a steroid hormone [7] that produces in boys' testicles and in girls' adrenal glands [8]. In general, the steroid hormone increases muscle- and skeleton mass [8]. An increase in testosterone levels results in a thinner grey matter in these areas for girls and a thicker area for boys [9].

#### 1.2.3 Estradiol

Estradiol is an estrogen, a type of steroid hormone that is derived from testosterone [10]. Estradiol can also affect an individual's blood pressure regulation, mood, cognitive function, pain, opioid sensitivity, and motor coordination [10].

### 1.3 Puberty

Puberty is a period that starts around 10 years for girls and 11.5 years for boys [11]. Multiple changes occur in the body during the period, for example, fat is redistributed, growth spurt, and sexual dimorphic enhancement. These changes are affected by nutrition and general health. [12]

The brain changes during puberty through an increase in the volume of white matter and a decrease the in grey matter [11]. This development is affected by genes, sex, DNA from the mother, and sex hormones [10]. Studies have shown that there is a connection between an increase in the level of sex hormones and cortical thickness [10]. The study was made on people in the age span of 4 to 22 of both sexes [10].

The Pubertal Development Scale, created in 1988 by Peterson, Crockett, Richards, and Boxer is a scale that divided puberty into twenty stages. Both sexes were asked about their growth, body hair, and skin. The boys in specific were asked about changes in their voice and the growth of facial hair. The girls were asked about menstruation and the growth of breasts. The pages the adolescents were asked to fill in are in appendix 7, 8, 5, and 6. [13]

## 1.4 Multiple Linear Regression

In a linear regression

$$y \alpha x$$
 (1)

which y dependent on one variable. [14]

In a multiple linear regression,

$$y \alpha x_1, x_2, x_3, \dots x_n \tag{2}$$

the dependent variable, y is proportions to multiple independent variables,  $x_1, x_2, x_3, ... x_n$ . Observe, independent variable  $x_2$  is not a function of the variable  $x_1$ . Equation 2 shows the proportions. [14]

Multiple linear regression is based on the equation

$$y_{i} = \beta_{0} + \beta_{1}X_{i1} + \beta_{2}X_{i2} + \dots + \beta_{p}X_{ip} + \epsilon_{i}$$
(3)

The variables are explained in List 1.4.1. [14]

### 1.4.1 List of Variables

- $\beta_0$  is the constant
- p is the number of independent variables.
- The number of dependent variables is i = 1, ..., n, for every separate model.
- $\beta_{1,2,3,\dots,p}$  is the coefficient for each independent variable.

•  $\epsilon_i$  is a residual term for the  $i^{th}$ . For  $\epsilon$  to be valid in the equation, the mean value of every residual term is equal to zero. [14]

The statistical certainty of a results is classified, according to the p-value. It is measured on a scale from 0 to 1 where a number under 0.05 is defined as significant.

### 1.5 Aim of the Study

The aim of the study is to see if there is an association between gaming and hormone levels, gaming and insula, and the insula and DHEA levels It could explain the change in behavior and further help tackle eventual negative effects of video gaming.

## 2 Method

To investigate changes in brain structure, data from magnetic resonance imaging (MRI) scans were used. The machine construct three-dimensional images showing the anatomy of a brain. Further information regarding the MRI-scans can be viewed in the appendix A. The data was retrieved from the Adolescent Brain Cognitive Development (ABCD) study which gathers information from 21 different sites across the United States. The participants in the study were between 9 and 10 years old. The number of participants was (N=6005), girls (n=3121), and boys (n=2884). The gathered data was approved by the National Institute of Mental Health Data Archive, United States (NIMH).

### 2.1 Processing of Data

To investigate if gaming affects sex hormone levels (pg/ml), factors that are known to affect hormone levels were included in the models. Since multiple linear regressions were done with sex hormones as variables, models were done for both sex included (BG) the sexes separated. A participant was excluded if the information on one of the variables was missing. The model was constructed in python using the website colab.

#### 2.1.1 Independent variables

Multiple independent variables were included in the models, "Gaming and Hormone Levels", "Surface Area of the Insula and DHEA Levels2, and "Gaming and Surface Area of the Insula".

- Age was measured in months. The participants were between 107 months and 132 months.
- Sex of an individual was one independent variable.
- The site of scans was numbered 1 to 21.
- SES is the background of a participant, their socioeconomic status, parents' education, etc.
- Puberty score, measured by the Pubertal Development Scale was one independent variable.

#### 2.1.2 Gaming and Hormone Levels

The first multiple linear regression model examined an association between gaming time and hormone levels. Gaming time was an additional independent variable in the model. The model was run for each hormone: DHEA, testosterone, and estradiol, separately as the dependent variable. The model regarded estradiol excluded boys.

### 2.1.3 Gaming and Surface Area of the Insula

The second regression investigated an association between gaming time and the surface area of the insula. An additional independent variable was gaming time, while the dependent variable was the mean surface area of the insula. The model was run two times; the first excluded boys and the second included BG.

#### 2.1.4 Surface Area of the Insula and DHEA Levels

The third model has surface area of the insula was an independent variable while the DHEA level was the dependent variable. Two models were run, one with boys excluded, and one with BG.

## 3 Results

The variables used in the modeling were the mean values of the gathered data. The mean value of each variable can be seen in the Appendix E, Table 9.  $\beta$  refers to the slope of the association between gaming time and hormone level. CI refers to the confidential interval of the regression. In the graphs,  $\beta$  is symbolized as a line while the shaded area represents CI.

### 3.1 Gaming's Effect on Hormone Levels

Results show, gaming time is negatively associated to the DHEA levels in girls, but not in boys. The level of testosterone and estradiol are not affected by gaming time. The results are presented in Figure 1. Further data results is presented in the Appendix B, Table 2.



Figure 1: The graph visualises a negative association between gaming time and concentration of DHEA for girls at nine to ten years old.

## 3.2 Gaming's Effect on Estradiol in Girls

There were no association between gaming time and estradiol levels. The results can be

seen in Table 1.

Table 1: The table illustrates the association between gaming time and estradiol levels. The confidence interval is 95%. The p-value were over 0.05 which makes the result not significant.

Sex	Measurement	Estradiol $(pg/ml)$
Girls (2798)	eta	-0.002
Girls $(2798)$	CI	[-0.023 0.020]

### 3.3 Gaming's Effect on the Insula

It was found, that gaming time is positively associated with the surface area of the insula for BG included in the regression. The p-value was not significant when the model were run for the sexes separated. The results are illustrated in Figure 2 while further data can be seen in Appendix B, Table 3.



Figure 2: The image shows the surface area of the insula on the y-axis and the gaming time on the x-axis.

### 3.4 Insula's Effects on DHEA Levels

The negative value of the slope indicates an increase in the surface area of the insula resulting in a decrease of DHEA levels. Figure 3 illustrates the results from the model. Detailed data can be observed in the Appendix B, Table 4.



Figure 3: The graph illustrates the negative association between the surface area of the insula and the concentration of DHEA.

## 4 Discussion

The results show, that hormone levels of DHEA for girls are negatively affected by gaming as shown in the Appendix B, Table 2.



Figure 4: The figure shows gaming time results in an increase in surface area of the insula while the insula results in a decrease of the DHEA. The association is the result from a multiple linear regression model.

Since the p-value was under 0.05 the results are statistically certain. The reason for the decrease in DHEA levels for girls could be explained by the insula. Models of gaming time's effect in insula for BG concluded gaming time induces a larger insula, as seen in Figure 8. Furthermore, the insula inhibits secretion of DHEA, see Figure 8. When the model regarding the insula was ran with boys excluded, the p-value were not significant. Meanwhile, the results from the model for BG suggests, the insula for the individual sexes increases. More studies should thereby be run to determine the hypothesis.

Neither of the modelings regarding testosterone and estradiol had significant p-values and were thereby excluded in further models. However, the results suggest the testosterone level could increase as a consequence of gaming, and the estradiol levels would decrease 2.

Puberty could explain why the DHEA levels for boys are effected by gaming time. Their DHEA levels is at average lower than girls since they later reach puberty were the secretion of DHEA rapidly increases. If the level of DHEA increases for boys, perhaps that hormone level will be affected by gaming.

This study is the first, investigating hormonal effects of gaming and the results suggest there is an effect. Further studies would thereby be of interest were data from older participants should be used, the secretion of testosterone and estradiol are higher. In further studies, the gaming time of the participants should increase since the mean value of the time was relatively low, 0.954 hours, see the Appendix, Table 9 . Further studies should include unknown confounders. For further studies, analyzed data can be used. Results regarding the association between the volume of the total brain, hippocampus, and amygdala can be seen in Appendix C. Results of the association between grey matter and DHEA levels can be seen in Appendix D.

### 4.1 Conclusion

The DHEA level is negatively affected by an increase in gaming time for girls, but not boys. Neither testosterone nor estradiol levels were affected by gaming time.

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## A MRI

Three times before MRI scans were taken, participants meet a questionnaire to assure they did not have objects which would disturb the MRI scan (e.g., piercings, braces, and other metal objects in the body).

During the process of MRI, the spin of a proton is used. Spin is determined as the rotation of a magnetic field. When an outer magnetic field is applied, a proton will align to the magnetic field. That means, the magnetic field of the proton will turn in an equilibrium way to the outer magnetic field. Radio waves are shot through the body to alter the gradient of the protons. It can be aligned  $90^{\circ}$  or  $180^{\circ}$  to the original position. When the radio wave has passed through the body the protons will realign to the original equilibrium. This process is different for protons, depending on their environment and the molecule it binds to. The different factors result in the different time it takes for the proton to realign, as well as the amount of energy it releases. The MRI can use that difference to project a picture. A software reconstructs a three-dimensional image from the data, using an algorithm. [15]

## **B** Gaming Time and Hormone Levels

Table 2: The table below illustrates the association between gaming time and hormone levels of testosterone and estradiol. The confidence interval is 95%. \* marks a p-value < 0.05 and \*\* marks a p-value < 0.1. \*\*\* marks a p-value > 0.1.

Sex	Measurement	Testosterone (pg/ml)	DHEA (pg/ml)
Girls (2884)	eta	-0.496	-2.698*
Girls (2884)	$\operatorname{CI}$	[-1.269 0.276]	[-4.903 -0.494]
Boys (3121)	eta	0.623	-0.119
Boys (3121)	CI	[-0.657 1.902]	[-1.698 1.460]
BS (6005)	eta	-0.729	0.344
BS (6005)	CI	[-1.892 0.435]	[-0.132 0.821]

Table 3: The table below illustrates the association between hormone levels and the surface area of the insula. The confidence interval is 95%. \* marks a p-value < 0.05 and \*\* marks a p-value < 0.01. \*\*\* marks a p-value < 0.001.

Sex	Measurement	Insula $(mm^3)$
Girls $(2884)$	eta	-1.551
Girls $(2884)$	CI	[-15.827 12.725]
Boys $(3121)$	eta	7.2340
Boys $(3121)$	CI	[-5.850 20.318]
BG $(6005)$	eta	9.896*
BG (6005)	CI	[-0.311 20.104]

Table 4: The table below illustrates the association between hormone levels and the volume of the total brain. The confidence interval is 95%. \*\* marks a p-value between 0.05 and 0.1. \*\*\* marks a p-value > 0.1.

Sex	Measurement	DHEA (pg/ml)
Girls (2884)	eta	0.001
Girls $(2884)$	CI	[-0.005 0.006]
Boys (3121)	eta	$-0.006^{**}$
Boys (3121)	$\operatorname{CI}$	[-0.009 -0.002]
BG (6005)	eta	-0.008***
BG (6005)	CI	[-0.010-0.005]

## C Hormones Effect on Brain Volume

It was found out, the brain volume is negatively effected by DHEA and testosterone, but not estradiol. The result can only be seen in boys and both gender. The p-value, the statistically confidence of data, was not in the accepted limit. The results is demonstrated in the tables 5 6 7.

## C.1 Total Brain Volume

Effects from the hormone levels on the volume of the brain were examined, using a multiple linear regression model. The results can be seen in table 5

Table 5: The table below illustrates the association between hormone levels of testosterone, DHEA, and estradiol and the volume of the total brain. The confidence interval is 95%. \* marks a p-value < 0.05 and \*\* marks a p-value between 0.05 and 0.1. \*\*\* marks a p-value > 0.1.

Sex	Measurement	Testosterone $(pg/ml)$	DHEA $(pg/ml)$	Estradiol (pg/ml)
Girls	eta	5.513	-11.574	4111.998
Girls	$\operatorname{CI}$	[-182.706 193.733]	[-77.479 54.331]	$[-2743.337 \ 1.1 * 10^4]$
Boys	eta	-207.514	-281.381***	-
Boys	$\operatorname{CI}$	[435.642 20.613]	[-391.039 -171.724]	-
Both	eta	-282.708**	-249.220***	-
Both	CI	[-447.091 -118.326]	[-317.247 -181.193]	-

## C.2 Hippocampus

A multiple linear regression model was done, examining the effect of hormone levels on the surface area of hippocampus. The results can be seen in table 6.

Table 6: The table below illustrates the association between hormone levels and the volume of the hippocampus. The confidence interval is 95%. \* marks a p-value < 0.05 and \*\* marks a p-value between 0.05 and 0.1. \*\*\* marks a p-value > 0.1.

Sex	Measurement	Testosterone (pg/ml)	DHEA (pg/ml)
Girls	eta	0.743	-0.090
Girls	CI	[-0.717 2.203]	[-0.601 0.421]
Boys	eta	-0.119	-1.678***
Boys	CI	[-1.698 1.460]	[-2.437 -0.918]
Both	eta	-0.638	-1.531***
Both	CI	[-1.810 0.534]	[-2.009 -1.052]

## C.3 Amygdala

To examine the effect of hormone levels on the surface area of hippocampus, a multiple linear regression model was made. The results can be seen in table 7.

Table 7: The table below illustrates the association between hormone levels and the volume of the amygdala. The confidence interval is 95%. \* marks a p-value < 0.05 and \*\* marks a p-value between 0.05 and 0.1. \*\*\* marks a p-value > 0.1.

Sex	Measurement	Testosterone $(pg/ml)$	DHEA (pg/ml)
Girls	eta	0.564	0.1245
Girls	$\operatorname{CI}$	[-0.202 1.331]	[-0.144 0.393]
Boys	eta	-0.142	-0.903***
Boys	$\operatorname{CI}$	[-0.957 0.673]	[-1.295 -0.511]
Both	eta	-0.243	-0.643***
Both	CI	[-0.837 0.351]	[-0.886 -0.400]

## D Grey Matter

Table 8 illustrates the association between hormone levels and the volume of the total brain. A decrease in brain volume in boys could be a consequence of high DHEA levels in boys. A model which was run showed grey matter decreases by DHEA. A decrease of grey matter is proportional to a decrease in brain volume.

Sex	Measurement	DHEA $(pg/ml)$
Girls $(3121)$	eta	-5.414
Girls $(3121)$	$\operatorname{CI}$	$[-16.342 \ 5.514]$
Boys (3121)	eta	-47.639***
Boys (3121)	CI	[-65.408-29.870]
BG (6005)	eta	-42.901***
BG $(6005)$	CI	[-53.954-31.848]

Table 8: The confidence interval is 95%. \* marks a p-value < 0.05 and \*\* marks a p-value between 0.05 and 0.1. \*\*\* marks a p-value > 0.1.

## E Mean value

The mean value of the independent variables is shown in the table 9. The results were calculated in python.

Table 9: The table shows the mean value of the independent variables, age, SES, gaming time, and puberty score.

Independent variables	Mean value
Age	118.582
SES	$1 \ 442 \ 670$
Puberty score	7,799
Gaming time	0.954

#### Page 1 ID: \_\_\_\_\_ Child Report

#### Interviewer ID

#### PUBERTAL DEVELOPMENT SCALE: ADOLESCENT REPORT (FEMALE VERSION)

Because some of the following questions are very personal, students often ask us why we are interested in their physical development. Our reasons are quite simple. Physical development is one of the more important, if not <u>the</u> most important change, a teenager will experience.

To answer each question, please circle the letter in front of the answer that best describes what is happening to you <u>right now</u>. Please choose only <u>one</u> answer for each question.

- 1. Would you say that your growth in height (getting taller)
  - (1) has not yet begun to spurt ("spurt" means more growth than usual)
  - (2) has barely started to spurt
  - (3) has definitely started to happen, but is not finished
  - (4) seems completed (you're about as tall as you're going to get)

 1\_a. How tall are you now?
 \_\_\_\_\_meters OR \_\_\_\_cm OR \_\_\_ft\_\_in

 1\_b. How much do you weigh now?
 kg OR \_\_\_\_lb

2. How about the growth of body hair (e.g., under your arms)? Would you say that your body hair has:

- (1). not started growing
- (2) barely started growing
- (3) definitely started growing, but is not finished
- (4) seems completed (you have as much body hair as you're going to get)
- 3. Have you noticed any skin changes, especially pimples?
  - (1) not yet started showing changes
  - (2) have barely started showing changes
  - (3) skin changes have definitely started but are not finished
  - (4) skin changes seem completed
- 4. Have your breasts begun to grow?
  - (1) not yet started growing
  - (2) have barely started growing
  - (3) breast growth has definitely started but is not finished
  - (4) breast growth seems completed
- 5. Have you begun to menstruate? ("menstruate" means to get your period)
  - (0) no
  - (1) yes

5a. If you answered "yes", how old were you when you first got your period?

years old. (data entry: please enter "99" if answer to questions #5 = no)

6. Would you say your health in general is...

#### Wave 5

Figure 5: The image is part 1 of the paper girls filled in to determine their puberty score.

Page 2 ID: \_\_\_\_\_ Child Report

Interviewer ID					
Excellent	Very good	Good	Fair	Poor	
1	2	3	4	5	

Wave 5

Figure 6: The image is part 2 the paper girls filled in to determine their puberty score.

#### Page 3 ID: \_\_\_\_\_ Child Report

#### Interviewer ID \_\_\_\_\_\_ PUBERTAL DEVELOPMENT SCALE: ADOLESCENT REPORT (MALE VERSION)

Because some of the following questions are very personal, students often ask us why we are interested in their physical development. Our reasons are quite simple. Physical development is one of the more important, if not <u>the</u> most important change, a teenager will experience.

To answer each question, please circle the letter in front of the answer that best describes what is happening to you <u>right now</u>. Please choose only <u>one</u> answer for each question.

- 1. Would you say that your growth in height (getting taller)
  - (1). has not yet begun to spurt ("spurt" means more growth than usual)
  - (2) has barely started to spurt
  - (3) has definitely started to happen but is not finished
  - (4) seems completed (you're about as tall as you're going to get)

1_a. How tall are you now?	meters OR	cm OR	ft_	in
1_b. How much do you weigh now?	kg OR	lb		

# 2. How about the growth of body hair (e.g., under your arms)? Would you say that your body hair: (1). not started growing

- not started growing
   barely started growing
- (2) outry started growing(3) definitely started growing, but is not finished
- (4) seems completed (you have as much body hair as you're going to get)
- 3. Have you noticed any skin changes, especially pimples?
  - (1) not yet started showing changes
  - (2) have barely started showing changes
  - (3) skin changes have definitely started but are not finished
  - (4) skin changes seem completed
- 4. Has your voice started to change?
  - (1) not yet started changing
  - (2) has barely started changing
  - (3) voice change is definitely happening but is not finished
  - (4) voice change seems completed
- 5. Have you started to grow facial hair (beard or mustache)?
  - (1) not yet started growing facial hair
  - (2) have barely started growing facial hair
  - (3) hair growth has definitely started (enough to shave)
  - (4) probably grows now as fast as it will ever grow

6. Would you say your health in general is...

Excellent	Very good	Good	Fair	Poor

Figure 7: The image is part 1 of the paper boys filled in to determine their puberty score.

Interviewer ID			F	Page 4	ID: Child Report
1	2	3	4	5	

Wave 5

Figure 8: The image is part 2 of the paper boys filled in to determine their puberty score.