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Research Article

THE IMPACTS OF WHO REGIONS, GENDER, AND AGE ON THE HIV INCIDENCE IN THE WORLD IN GLOBAL PUBLIC HEALTH BY LOG-LINEAR MODELS FOR THREE-WAY CONTINGENCY TABLE

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Abstract

Purpose: Human Immunodeficiency Virus (HIV) incidence is defined as the number of new HIV cases at a time period calculated divided by the number of cases at risk of HIV infection. Contingency tables display frequencies for combinations of two or more categorical variables. In this study, it is aimed to investigate the impacts of WHO regions, gender, and age on HIV incidence all over the world in global public health by log-linear models for a three-way contingency table.

Method: Log-linear models are constituted for investigating relationships between categorical variables. In this study, log-linear model for three-way contingency table is fitted to the HIV incidence data all over the world according to the World Health Organization (WHO) regions, gender, and age groups taken as the 2019 Global Burden of Disease (GBD) study data from Global Health Data Exchange website.

Results: The main effects of age, gender and WHO regions, and also two-way interaction effects between age* gender, age* WHO region and gender* WHO regions; three-way interaction effect between age*gender*WHO regions are found statistically significant at $\alpha = 0.05$ significant level.

Conclusion: As a conclusion of this study, age, gender, and WHO regions are determined as the main effects with all interaction effects of these variables on the HIV incidence.

Keywords: Contingency Table, Human Immunodeficiency Virus (HIV), Log-linear Model, World Health Organization

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Üç Yönlü Olumsallık Tablosu İçin Log-Lineer Modeller İle Dünyadaki Küresel Halk Sağlığındaki HIV Vakalarına DSÖ Bölgeleri, Cinsiyet Ve Yaşın Etkileri

Öz

Amaç: İnsan İmmün Yetmezlik Virüsü (HIV) insidansı, bir zaman dilimindeki yeni HIV vakalarının sayısının HIV enfeksiyonu riski taşıyan vaka sayısına bölünmesiyle tanımlanır. Olumsallık tabloları, iki veya daha fazla kategorik değişkenin kombinasyonları için frekansları sağlar. Bu çalışmada, küresel halk sağlığında DSÖ bölgelerinin, cinsiyetin ve yaşın tüm dünyadaki HIV insidansı üzerindeki etkilerinin üçlü olumsallık tablosu için log-lineer modeller ile araştırılması amaçlanmaktadır.

Yöntem: Kategorik değişkenler arasındaki ilişkileri incelemek için log-lineer modeller kullanılır. Bu çalışmada, 2019 yılı için Küresel Sağlık Veri Alışverişi web sitesinde yer alan Küresel Hastalık Yükü çalışma verilerinden alınan Dünya Sağlık Örgütü (WHO) bölgeleri, cinsiyet ve yaş gruplarına göre tüm dünyadaki HIV insidans verileri üç yönlü olumsallık tablosu şeklinde sunulmuş ve bu veriler üzerinde log-lineer model elde edilmiştir.

Bulgular: Çalışmada yaş, cinsiyet ve DSÖ bölgelerinin ana etkileri ile ayrıca yaş*cinsiyet, yaş*DSÖ bölgesi ve cinsiyet*DSÖ bölgeleri arasındaki çift yönlü etkileşim etkileri; yaş*cinsiyet*DSÖ bölgeleri arasındaki üç yönlü etkileşim etkisi istatistiksel olarak anlamlı bulunmuştur.

Sonuç: Bu çalışmada, yaş, cinsiyet ve DSÖ bölgeleri değişkenlerinin ana etkileri ile bu değişkenlerin tüm etkileşim etkilerinin HIV insidansının belirlenmesinde etkili olduğu sonucuna varılmıştır.

Anahtar Kelimeler: Dünya Sağlık Örgütü, İnsan İmmün Yetmezlik Virüsü (HIV), Log-lineer Model, Olumsallık Tablosu

1. INTRODUCTION

Human Immunodeficiency Virus (HIV) that causes Acquired Immune Deficiency Syndrome (AIDS) was first identified in the United States in 1983 in homosexual men and immigrants from Haiti (WHO, 2008). This virus destroys the human body's defense power, and diseases that can be easily treated under normal conditions cannot be treated because of the insufficient human body's defense power (CDC, 2001). World Health Organization (WHO) reported on 13 July 2023 that approximately 40.4 million people died from this contagious disease in the world (WHO, 2023). HIV/AIDS continues to be transmitted and spread rapidly all over the world due to sexual transmission and lack of adequate health precautions especially in the WHO African Region (Boutayeb, 2009; Hajizadeh et al., 2014; WHO, 2005). In this aspect, WHO has an important target as Sustainable Development Goal (SDG) 3.3 for preventing and ending HIV all over the world by 2030. Based on this information, in this study, globally the incidence of HIV all over the world according to the WHO regions as African Region (AFR), Eastern Mediterranean Region (EMR), European Region (EUR), Region of the Americas (AMR), South-East Asian Region (SEAR), and Western Pacific Region (WPR) are investigated in terms of age and gender. For this aim, age groups, gender groups, and WHO regions are constituted in a three-way contingency table as categorical variables to investigate HIV incidence all over the world for 179 countries by log-linear models.

In this aspect there are valuable studies in the literature on HIV/AIDS especially in terms of age and gender by log-linear models as follows; Lewden et al. (2006) studied adults infected by HIV in the aspect of age, gender and regions of France by log-linear models. Akinrefon et al. (2023) investigated HIV/AIDS prevalence in Nigeria in the aspect of age, gender, years, and marital status by log-linear models. Shoko and Chikobvu (2019) investigated the effects of age, gender, viral loads, and CD4 cell count in HIV treatment by log-linear models. Powles et al. (2009) investigated the effects of age, gender, ethnic region, CD4 cell count, and duration of HIV on Castleman's disease related with HIV by log-linear models. Colasanti et al. (2016) investigated the effects of age, race, gender, risk groups, and social indicators on the HIV care of 655 patients in a cross-sectional study by log-linear models. Ren et al. (2022) investigated the effects of age, gender, and time period from 1990 to 2019 on the HIV in elderly people in China by log-linear models. In addition, current studies using the log-linear model approach in the HIV/AIDS-related literature are done by Du et al. (2022), Gao et al. (2020), Hasankhani et al. (2021), Martial (2021), Odetunmibi et al. (2019), Segarra et al. (2021), Sia et al. (2020), Shaw et al. (2019), Tombini et al. (2019) and, Zang et al. (2019).

This study is organized as follows; Introduction part consisting of HIV knowledge and related literature is given in Section 1. Materials and method part including HIV incidence data and log-linear models are given in Section 2. Results and discussion, and also conclusion parts from investigating HIV incidence data by log-linear models are given in Section 3 and Section 4, respectively.

2. MATERIAL AND METHODS

2.1. Materials

In this study, a three-way contingency table is constituted in Appendix for the HIV incidence data of 179 countries all over the world according to the World Health Organization (WHO) regions, gender, and age groups taken as the 2019 Global Burden of Disease (GBD) study data from Global Health Data Exchange $\left(IHME \middle| GHDx\right)$ global website (https://ghdx.healthdata.org/). The cells of Table I are arranged as the number of new HIV cases in 2019 as an indicator of HIV incidence. 39 countries from African Region (AFR), 21 countries from Eastern Mediterranean Region (EMR), 52 countries from European Region (EUR), 31 countries from Region of the Americas (AMR), 11 countries from South-East Asian Region (SEAR), and 25 countries from Western Pacific Region (WPR) are included to the study.

2.2. Log-Linear Models for Three-Way Contingency Table

Log-linear model approach for the contingency tables is a special case of generalized linear models for categorical variables (Odetunmibi et al., 2019). The response variable in the log-linear model follows Poisson distribution while the response variable in the analysis of variance (ANOVA) model follows normal distribution (Altun, 2019; Lawal,2003). When there are more than two categorical variables in the contingency tables, log-linear model approach is popularly used instead of chi-square analysis to examine the relationships between pairs of variables. In this case log-linear model investigates high-order interactions between the variables and avoids loss of information caused by the third and fourth variables in the model (Çağılcı, 2020). Also, log-linear models provide a systematic approach to the analysis and modeling of observed frequencies in the contingency tables, developed solely for modeling of categorical data (Bishop, 1975). Especially in the field of health and medicine, examining the main effects and higher-order interaction effects between more than two categorical variables in the contingency tables is possible with the use of log-linear models. Log-linear models estimate the magnitude of relevant effects. Log-linear models can be defined as an additive model in which the logarithms of the expected frequencies are taken as the dependent variable (Altunay, 2021).

Suppose that we want to examine the relationships between the categorical variables X, Y, and Z with $i = 1, 2, \ldots, R;\ j = 1, 2, \ldots, C;\ k = 1, 2, \ldots, K$ levels for the contingency tables with three variables. Let the observed frequency and the expected frequency of the cell (ijk) be n_{ijk} and E_{ijk}, respectively. Saturated log-linear model for three-way contingency tables can be written as follows;

$$\log\left(E_{ijk}\right) = \lambda + \lambda_i^X + \lambda_j^Y + \lambda_k^Z + \lambda_{ij}^{XY} + \lambda_{ik}^{XZ} + \lambda_{jk}^{YZ} + \lambda_{ijk}^{XYZ} \quad (1)$$

where $i = 1, 2, \ldots, R;\ j = 1, 2, \ldots, C; k = 1, 2, \ldots, K$.

In Eq.(1), the terms in the saturated log-linear model are defined as follows;

λ: Constant term

λ_i^X : ith level main effect of the 1st variable (X)

λ_j^Y : jth level main effect of the 2nd variable (Y)

λ_k^Z : kth level main effect of the 3rd variable (Z)

λ_{ij}^{XY} : interaction effect of the ith level and jth level of the 1st variable (X) and the 2nd variable (Y)

λ_{ik}^{XZ} :interaction effect of the ith level and kth level of the 1st variable (X) and the 3rd variable (Z)

λ_{jk}^{YZ} :interaction effect of the jth level and kth level of the 2nd variable (X) and the 3rd variable (Z)

λ_{ijk}^{XYZ} : interaction effect of the ith level, jth level and kth level of the 1st variable (X), the 2nd variable (Y), and the 3rd variable (Z)

Basically, there are nine different log-linear models for three-way contingency tables (Andersen, 1990). These are the log-linear models with "complete independence", "partial independence", "conditional independence", “mutual independence” and log-linear models with all interactions as the saturated model (Altun, 2019). Log-linear model types, equations and degrees of freedom are given in Table II where R, C, and K are the number of levels of the categorical variables X, Y, and Z, respectively.

Table II: Log-Linear Model Types and Equations

Model	Log-Linear Model Equations	Degrees of Freedom
Complete Independence M_0 (X,Y,Z)	$\log(E_{ijk}) = \lambda + \lambda_i^X + \lambda_j^Y + \lambda_k^Z$	*RCK-R-C-K+2*
Partial Independence M_1(X,YZ)	$\log(E_{ijk}) = \lambda + \lambda_i^X + \lambda_j^Y + \lambda_k^Z + \lambda_{jk}^{YZ}$	*RCK-R-CK+1*
M_2(Y,XZ)	$\log(E_{ijk}) = \lambda + \lambda_i^X + \lambda_j^Y + \lambda_k^Z + \lambda_{ik}^{XZ}$	*RCK-C-RK+1*
M_3(Z,XY)	$\log(E_{ijk}) = \lambda + \lambda_i^X + \lambda_j^Y + \lambda_k^Z + \lambda_{ij}^{XY}$	*RCK-K-RC+1*
Conditional Independence M_4(XZ,YZ)	$\log(E_{ijk}) = \lambda + \lambda_i^X + \lambda_j^Y + \lambda_k^Z + \lambda_{ik}^{XZ} + \lambda_{jk}^{YZ}$	*K(R-1)(C-1)*
M_5(XY,YZ)	$\log(E_{ijk}) = \lambda + \lambda_i^X + \lambda_j^Y + \lambda_k^Z + \lambda_{ij}^{XY} + \lambda_{jk}^{YZ}$	*C(R-1)(K-1)*
M_6 (XY,XZ)	$\log(E_{ijk}) = \lambda + \lambda_i^X + \lambda_j^Y + \lambda_k^Z + \lambda_{ij}^{XY} + \lambda_{ik}^{XZ}$	*R(C-1)(K-1)*
Mutual Independence M_7 (XY,XZ,YZ)	$\log(E_{ijk}) = \lambda + \lambda_i^X + \lambda_j^Y + \lambda_k^Z + \lambda_{ij}^{XY} + \lambda_{ik}^{XZ} + \lambda_{jk}^{YZ}$	*(R-1)(C-1)(K-1)*
Saturated Model M_8 (XYZ)	$\log(E_{ijk}) = \lambda + \lambda_i^X + \lambda_j^Y + \lambda_k^Z + \lambda_{ij}^{XY} + \lambda_{ik}^{XZ} + \lambda_{jk}^{YZ} + \lambda_{ijk}^{XYZ}$	*0*

2.3. Goodness-of-fit Tests and Model Selection in Log-Linear Models

Log-linear models for three-way contingency tables are built on stepwise methods such as forward selection or backward elimination. The goodness-of-fit measures of a log-linear model are the chi-square statistics, likelihood ratio, and information criteria as AIC and BIC (Milewska, 2018).

When testing the fit of models for three-way contingency tables, chi-cquare $\left(\chi^2\right)$ and likelihood ratio $\left(G^2\right)$ goodness-of-fit test statistics are used as follows;

$$\chi^2 = \sum_{i=1}^{R}\sum_{j=1}^{C}\sum_{k=1}^{K}\frac{\left(n_{ijk}-E_{ijk}\right)^2}{E_{ijk}} \tag{2}$$

and

$$G^2 = \sum_{i=1}^{R}\sum_{j=1}^{C}\sum_{k=1}^{K} n_{ijk}\log\left(\frac{n_{ijk}}{E_{ijk}}\right) \tag{3}$$

Since the chi-square $\left(\chi^2\right)$ test approaches likelihood ratio $\left(G^2\right)$ for large samples, the two test statistics have similar values in log-linear analysis. In the evaluation of log-linear model fit, likelihood ratio statistics $\left(G^2\right)$ gives an advantage over chi-square test statistics$\left(\chi^2\right)$ because of having divisible property (Altaş, 2003).

Akaike (AIC) and Bayesian (BIC) information criteria are used to select the best model from suitable log-linear models. Akaike (AIC) and Bayesian (BIC) information criteria are given as follows;

$$AIC = G^2 - 2df \tag{4}$$

$$BIC = G^2 - df\log(n) \tag{5}$$

where df is the degrees of freedom.

The log-linear model that gives the smallest AIC or BIC value is determined as the best model. After the best model is determined, parameter estimates are calculated and interpreted according to the best model (Altunay, 2021).

3. RESULTS AND DISCUSSION

Let X, Y, and Z be the effects of age, gender, and WHO regions on the HIV incidence, respectively. Significance tests of main effects and interaction effects for age, gender, and WHO regions by the log-linear model approach are given in Table III.

Table III. Significance tests of main effects and interaction effects for age, gender, and WHO regions by the log-linear model approach

	K	df	G^2	p-value	χ^2	p-value
K-Way and Higher Order Effects	1	155	3484535,009	0,000	6508930,650	<0,0001
	2	137	360932,421	0,000	379531,597	<0,0001
	3	60	21545,260	0,000	22590,023	<0,0001
K-Way Effects	1	18	3123602,588	0,000	6129399,053	<0,0001
	2	77	339387,161	0,000	356941,574	<0,0001
	3	60	21545,260	0,000	22590,023	<0,0001

As can be seen from Table III, the main effects (K=1), the two-way interaction effects (K=2), and the three-way interaction effect (K=3) of the age, gender, and WHO region categorical variables are found statistically significant at $\alpha = 0,05$ significance level. Significance tests of the main effects and the interaction effects for age, gender, and WHO regions by the log-linear model approach are given in Table IV.

Table IV. Significance tests of the main effects and the interaction effects for age, gender, and WHO regions by the log-linear model approach

Effect	Df	χ^2	p-value
AGE*GENDER	12	74676,871	<0,0001
AGE*WHO REGION	60	132371,156	<0,0001
GENDER*WHO REGION	5	125304,144	<0,0001
AGE	12	1158446,582	<0,0001
GENDER	1	265,505	<0,0001
WHO REGION	5	1964890,501	<0,0001

According to the Table IV, the main effects of age, gender and WHO regions, and also two-way interaction effects between age* gender, age* WHO region and gender* WHO regions; three-way interaction effect between age*gender*WHO regions are found statistically significant at $\alpha = 0.05$ significant level. The saturated log-linear model for the HIV incidence data of 179 countries all over the world is constructed as follows;

$$\log\left(E_{ijk}\right) = \lambda + \lambda_i^{age} + \lambda_j^{gender} + \lambda_k^{WHOregion} + \lambda_{ij}^{age*gender} + \lambda_{ik}^{age*WHOregion} + \lambda_{jk}^{gender*WHO\,region} + \lambda_{ijk}^{age*gender*WHO\,region} \tag{6}$$

4. CONCLUSION

Saturated log-linear model for the HIV incidence data of 179 countries in the world best fits to the data with the statistically significant main effects of age, gender and WHO regions, two-way interaction effects between age* gender, age* WHO region and gender* WHO regions, and three-way interaction effect between age*gender*WHO region. In the light of this study, parameter estimations will be made for these main effects and interaction effects in a future study.

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APPENDIX

Table I. Three-way contingency table for investigating HIV incidence of 179 countries all over the world in terms of age, gender, and WHO regions

AGE	GENDER	WHO REGIONS						TOTAL
		AFR	EMR	EUR	AMR	SEAR	WPR	
0-14 years	Female	40594	2071	980	2329	4080	3593	53647
	Male	41725	2152	1208	2713	4204	4202	56204
15-19 years	Female	99079	2416	1460	5970	6586	5025	120536
	Male	16597	1618	1363	6134	4856	11738	42306
20-24 years	Female	88336	2478	5830	10165	10757	5187	122753
	Male	29981	2332	5648	23241	14122	16691	92015
25-29 years	Female	151268	3386	12988	11966	9352	4291	193251
	Male	93190	3481	23022	28734	14724	15391	178542
30-34 years	Female	82158	2285	17065	11344	7982	2847	123681
	Male	98294	3699	47479	22936	12740	11396	196544
35-39 years	Female	61993	1819	7938	8247	4516	1782	86295
	Male	75073	3025	29919	19308	8617	8384	144326
40-44 years	Female	43146	1367	4571	5168	2555	1329	58136
	Male	35166	1483	9433	11773	4024	4831	66710
45-49 years	Female	33152	896	2832	3015	1635	1014	42544
	Male	21448	874	3868	6011	1959	3133	37293
50-54 years	Female	21942	503	1851	2184	1631	911	29022
	Male	12547	551	2323	4966	2156	3378	25921
55-59 years	Female	13652	389	2661	3123	2304	901	23030
	Male	8159	595	2933	7496	2603	3517	25303
60-64 years	Female	8100	433	1613	2860	2071	1142	16219
	Male	6173	459	1785	5172	2093	3805	19487
65-69 years	Female	5367	202	423	1339	827	739	8897
	Male	4729	337	766	3447	1276	3177	13732
70+ years	Female	5104	85	59	399	172	267	6086
	Male	4180	150	171	1169	359	1485	7514
TOTAL		36414	1921	809	1160	3721	2108	1789994