A MATHEMATICAL MODEL OF POPULATION DYNAMICS ABOUT THE INTERNET GAMING ADDICTION ¶

Hiromi Seno

Graduate School of Information Sciences, Tohoku University, Sendai, Japan

seno@math.is.tohoku.ac.jp

WHO [3] acknowledged addiction to internet gaming as a real disorder, named Internet Gaming Disorder (IGD), which is generally defined as "Persistent and recurresnt use of the internet to engage in games, often with other players, leading to clinically significant impairment or distress" [1]. As the number of internet users appears to steadily increase each year, IGD is bound to increase as well [1].

We consider a system of ordinary differential equations as a simple mathematical model of the population dynamics about the internet gaming. We assume three stages about the internet gamer's state: moderate, addictive, and under treatment. The moderate state means the stage in which the gamer can control him/herself about playing the internet game. The addictive state means the stage in which the gamer plays the internet game pathologically (i.e., without properly controlling him/herself). We suppose that there are some chances for the addictive gamer to have a medical or/and therapeutic treatment after being identified his/her addictive gaming by him/herself or by some others near him/her. It is assumed that under the treatment the gamer has no effective contact to the other gamers on web, so that such a gamer has no significant contribution to the population dynamics, like an isolated infective individual in the epidemic dynamics. The transition of the gamer's state between the moderate and the addictive stages is significantly affected by the social nature of internet gaming [2]. As the activity of social interaction gets higher, the gamer would be more likely to become addictive. With the inherent social reinforcement of internet game, the addictive gamer would hardly re-control his/herself to recover to the moderate gamer. Our result on the model demonstrates the importance of earlier initiation of a system to check the IGD and lead to some medical/therapeutic treatment. Otherwise the number of addictive gamers would become larger beyond the socially controllable level.

¶Poster available on page 268

References

[1] Feng, W., Ramo, D.E., Chan, S.R. & Bourgeois, J.A. (2004). *Internet gaming disorder: Trends in prevalence 1998–2016*. Addictive Behaviors, 75, 17–24. http://doi.org/10.1016/j.addbeh.2017.06.010

[2] Paulus, F.W., Ohmann, S., von Gontard, A. & Popow, C. (2018). *Internet gaming disorder in children and adolescents: a systematic review*. Developmental Medicine & Child Neurology, 60, 645–659. http://doi.org/10.1111/dmcn.13754

[3] World Health Organization (2018). *International Classification of Diseases 11th Revision (ICD-11): The global standard for diagnostic health information*. https://icd.who.int/, date of retrieval: 2020-12-01

A Mathematical Model of Population Dynamics About The Internet Gaming Addiction

Hiromi SENO

Graduate School of Information Sciences, Tohoku University, Sendai, Japan

TOHOKU UNIVERSITY

Introduction

World Health Organization [3] acknowledged addiction to internet gaming as a real disorder, called by "*Gaming disorder, predominantly online*", frequently mentioned now as Internet Gaming Disorder (IGD), which is generally defined as "Persistent and recurresnt use of the internet to engage in games, often with other players, leading to clinically significant impairment or distress" [1].

We consider a system of ordinary differential equations as a simple mathematical model of the population dynamics about the internet gaming. We suppose that there are some chances for the addictive gamer to have a medical or/and therapeutic treatment after being identified his/her addictive gaming by him/herself or by some others near him/her. It is assumed that under the treatment the gamer has no effective contact to the other gamers on web, so that such a gamer has no significant contribution to the population dynamics, like an isolated infective individual in the epidemic dynamics. The transition of the gamer's state between the moderate and the addictive stages is significantly affected by the social nature of internet gaming [2]. As the activity of social interaction gets higher, the gamer would be more likely to become addictive. With the inherent social reinforcement of internet game, the addictive gamer would hardly re-control his/herself to recover to the moderate gamer.

Our result on the model demonstrates the importance of earlier initiation of a system to check the IGD and lead to some medical/therapeutic treatment. Otherwise the number of addictive gamers would become larger beyond the socially controllable level.
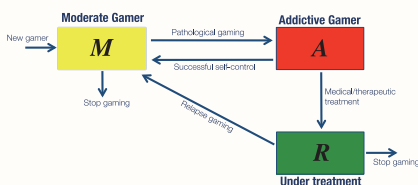
Assumptions

Figure 1: General scheme of the state transition of internet gamer in our modeling.

Gamer's states and their transition

Moderate state: the stage in which the gamer can control him/herself about playing the internet game.

Addictive state: the stage in which the gamer plays the internet game pathologically (i.e., without properly controlling him/herself).

State under treatment: the state such that the addictive gamer has a medical or/and therapeutic treatment. It is assumed that under the treatment the gamer has no effective contact to the other gamers on web.

The state transition depends on the activity of social interaction between gamers on web. As the activity of social interaction gets higher, the gamer would be more likely to become addictive.

We assume the possibility that the gamer under treatment relapses into gaming. This means stopping the treatment and re-starting gaming.

Mathematical Model

$$\frac{dM}{dt} = \lambda - f(M,A)M + g(M,A)A - \mu_M M + \rho R$$
$$\frac{dA}{dt} = f(M,A)M - g(M,A)A - \sigma A$$
$$\frac{dR}{dt} = \sigma A - \rho R - \mu_R R$$

$M = M(t)$: the population size of moderate gamerat time t.

$A = A(t)$: the population size of addictive gamerat time t.

$R = R(t)$: the population size of gamer under treatment at time t.

λ: the recruitment flux of new internet gamers.

μ_M: the rate of stopping gaming for moderate gamer.

μ_R: the rate of stopping gaming for the gamer under treatment about the addiction.

ρ: the rate of relapsing into gaming after the treatment.

σ: the rate of identifying the addiction and beginning the treatment.

$f(M,A) = \beta(M+A)$: the transition rate from the moderate to the addictive gamer.

$g(M,A) = g_0 e^{-\gamma(M+A)}$: the transition rate from the addictive to the moderate gamer. parameters

β and γ: the strength of the effect from the social interaction with the other gamers on web about the transition between the moderate and the addictive states: As each value gets larger, the effect becomes stronger.

VARIABLE AND PARAMETER TRANSFORMATIONS:

$$\tau = \mu_M t; \ \widetilde{M} = \frac{M}{\lambda/\mu_M}; \ \widetilde{A} = \frac{A}{\lambda/\mu_M}; \ \widetilde{R} = \frac{R}{\lambda/\mu_M};$$
$$\widetilde{\beta} = \frac{\lambda}{\mu_M^2}\beta; \ \widetilde{g}_0 = \frac{g_0}{\mu_M}; \ \widetilde{\gamma} = \frac{\lambda}{\mu_M}\gamma; \ \widetilde{\rho} = \frac{\rho}{\mu_M}; \ \widetilde{\sigma} = \frac{\sigma}{\mu_M}; \ \widetilde{\mu} = \frac{\mu_R}{\mu_M}.$$

NON-DIMENSIONALIZED SYSTEM:

$$\frac{d\widetilde{M}}{d\tau} = 1 - \widetilde{\beta}(\widetilde{M}+\widetilde{A})\widetilde{M} + \widetilde{g}_0 e^{-\widetilde{\gamma}(\widetilde{M}+\widetilde{A})}\widetilde{A} - \widetilde{M} + \widetilde{\rho}\widetilde{R}$$
$$\frac{d\widetilde{A}}{d\tau} = \widetilde{\beta}(\widetilde{M}+\widetilde{A})\widetilde{M} - \widetilde{g}_0 e^{-\widetilde{\gamma}(\widetilde{M}+\widetilde{A})}\widetilde{A} - \widetilde{\sigma}\widetilde{A}$$
$$\frac{d\widetilde{R}}{d\tau} = \widetilde{\sigma}\widetilde{A} - \widetilde{\rho}\widetilde{R} - \widetilde{\mu}\widetilde{R}.$$

Mathematical Results
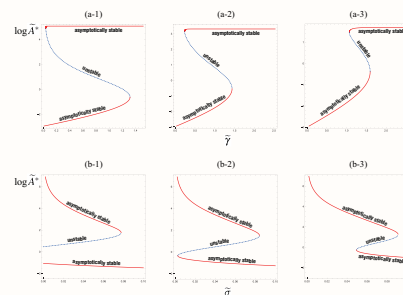
Figure 2: Numerically drawn bifurcation diagram of $\log\widetilde{A}^*$ in terms of $\widetilde{\gamma}$ and $\widetilde{\sigma}$. (a-1) $\widetilde{\sigma} = 0.01$; (a-2) $\widetilde{\sigma} = 0.03$; (a-3) $\widetilde{\sigma} = 0.05$ with $\widetilde{\beta} = 0.05$, $\alpha_c = 0.519996$ and $\widetilde{\gamma}_c = 1.26519$. (b-1) $\widetilde{\gamma} = 0.7 < \widetilde{\gamma}_c$; (b-2) $\widetilde{\gamma} = 0.84$; (b-3) $\widetilde{\gamma} = 1.0 > \widetilde{\gamma}_c$ with $\widetilde{\beta} = 0.1$, $\alpha_c = 0.704641$ and $\widetilde{\gamma}_c = 0.832529$. Commonly, $\widetilde{g}_0 = 1.0$ and $\widetilde{\rho}/\widetilde{\mu} = 1.0$.

Lemma

For a certain parameter region, the system has three equilibrium states of which one is unstable and the other two are locally asymptotically stable. For the other parameter region, the system has only one positive equilibrium which is globally asymptotically stable.

Theorem 1

The effect of the treatment operation results in the necessary existence of an asymptotically stable equilibrium state to which the system eventually approaches.

Theorem 2

For the model with sufficiently large value of $\widetilde{\sigma}$, the equilibrium value of the population size of addictive gamer depends continuously on the parameters $\widetilde{g}_0/\widetilde{\beta}$ and $\widetilde{\gamma}$.
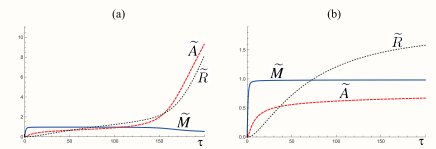
Concluding Remarks

Figure 3: Numerically obtained temporal variations of $(\widetilde{M},\widetilde{A},\widetilde{R})$: (a) $\widetilde{\sigma} = 0.04$; (b) $\widetilde{\sigma} = 0.05$. Commonly, $(\widetilde{M}(0),\widetilde{A}(0),\widetilde{R}(0)) = (0.0,0.0,0.0)$; $\widetilde{\beta} = 0.1$; $\widetilde{g}_0 = 1.0$; $\widetilde{\gamma} = 1.0$; $\widetilde{\rho} = 0.01$; $\widetilde{\mu} = 0.01$.

Only when the treatment operation has a sufficiently high efficiency, it would be successful to suppress the population size of addictive gamer at a certain level. Especially in the former case of the failure to suppress the increase of the addictive gamers, the addictive gamers under treatment are increasing in time as well.
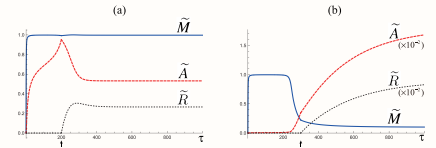

Figure 4: Numerically obtained temporal variations of $(\widetilde{M},\widetilde{A},\widetilde{R})$ with a moment $\tau = \tau_1$ before which there is no treatment ($\widetilde{\sigma} = 0$) and at which the treatment starts with $\widetilde{\sigma} = 0.01$: (a) $\tau_1 = 200$; (b) $\tau_1 = 300$. Commonly, $(\widetilde{M}(0),\widetilde{A}(0),\widetilde{R}(0)) = (0.0,0.0,0.0)$; $\widetilde{\beta} = 0.1$; $\widetilde{g}_0 = 1.0$; $\widetilde{\gamma} = 0.84$; $\widetilde{\rho} = 0.01$; $\widetilde{\mu} = 0.01$; ; $\alpha_c = 0.704641$; $\widetilde{\gamma}_c = 0.832529$.

The population size of addictive gamer alternatively approaches a certain saturating level or unboundedly grows when no treatment operation is conducted. The latter is the serious case to be resolved, so that a treatment operation has to be conducted. In such a case, if the treatment operation starts too late, the population size of addictive gamer may have been beyond a critical level so that it continues to increase and approaches a certain high saturating level. In contrast, if the treatment operation starts sufficiently early, the population size of addictive gamer may be successfully let to a certain low level.

Consequently, in order to suppress an explosive increase of addictive gamers, it is necessary to conduct a treatment operation not only high efficient but also executed at sufficiently early stage of its increase. Otherwise, the population size of addictive gamer would show an explosive increase to reach a level beyond the capacity of such a treatment.

References

[1] Feng W, et al. (2004) Addictive Behaviors 75: 17–24

[2] Paulus FW, et al. (2018) Developmental Medicine & Child Neurology 60: 645–659

[3] World Health Organization (2018) International Classification of Diseases 11th Revision (ICD-11): The global standard for diagnostic health information. link: https://icd.who.int/