An Agent-Based Model of Contagion Effects in Affected Depression and Its Recovery Process

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Abstract. Depression, as the most common mental worldwide disorder, has been the major contributor to suicide deaths. In this paper, we model how depression is contagious among the population using Agent-Based Modeling approach. A sufferer can be affected due to contagion effects of social interactions, particularly from close relationships, then undergo a depressive episode that categorized by mild, moderate, severe. Every episode can be recovered by doing therapy. Those transition processes are described based on gender in a flowchart diagram and simulations, which depend on time using software. Our simulation results represent that the greater contacts rate with someone who affected depression, the more severe of depressive episodes that will be experienced. Further, the greater probability of someone who is going to a therapy can reduce the number of depressed persons over time, especially for contagious depression. Thus, these program simulations and modeling method will be used to calculate and handle the contagion of depression, helping for sufferers’ recovery, and decreasing number of depressed people who commit suicide.

1. Introduction

More than 300 million people are estimated to suffer from depression, equivalent to 4.4% of the population of the world. Depression is a significant contributor to the global burden of disease and affects people of all ages and gender of all communities across the world in either a single or recurrent episode. At its most severe, it leads to suicide deaths, which claims close to 800,000 lives each year [1-2].

People in close relationships with depressed others are heightened risk for developing depression themselves. Coyne (1976) posited that depressed people induce negative affect in others which may impact their interpersonal functioning, one of its important forms is the contagion of depressive symptoms [3], where 40.5% of the persons living with someone currently in a depressed episode were suitable for therapeutic versus 17.4% whom not living with a depressed person [4].

This contagion effect was significantly influenced by roommates’ level of cognitive vulnerability and vice versa that could be undergone by family dyads (include parents-children), romantic pairs, or roommate friends because of their interaction, and habit of unknowing or hiding secrets from each other [5-7]. Conversely, sufferers can be entering the recovery process in the way of another contagion effect from therapist impressions by doing therapies. Certain nonpharmacological interventions, including psychotherapies, can against the effects of contagious depression [6], provide time- and cost-effective, and protect possibly recurrence [8-10].

In this research, the transition processes of contagion effects in affected depression and its recovery by therapies are depicted and simulated using an Agent-Based Model (ABM) with AnyLogic 8.3.2 software. With agent-based modeling, active entities are identified as person’ agents with their
respective gender, their behaviors are defined, connections between them are established, environmental variables are set, and simulations run. The global dynamics of these systems of depression then will emerge from the interactions of the many individual behaviors [11-13].

2. Method

2.1. Agent Based Modeling

Simulation models can be used to describe and study phenomena even when traditional mathematical approaches fail. Agent-based modeling, which is a specific class of computer models, can be very useful in modeling systems that are irreducibly heterogeneous, irreducibly random, and contain irreducible interactions. The model represents components of the real system explicitly and keeps track of the behavior of individuals over time. Altogether, ABMs are a mixed blessing. They can deal with much detail in the system, and they can represent heterogeneity, randomness, and interactions with ease [12].

ABMs are quite unlike mathematical models, which represent components by the values of variables rather than by behaviors. ABMs are best thought in terms of the three main ingredients that are the core of every such model: the agents; the environment inhabited by the agents; the rules defining how agents interact with one another and with their environment. In an ABM, the different components (the “agents”) represent entities in the real world system to be modeled. As well as the individual entities, an ABM also represents the environment inhabited by these entities. Each of these modeled entities has a state and exhibits an explicit behavior. An agent can interact with its environment and with other entities [12].

As a computational approach, ABM is an increasingly popular method for visualizing, analyzing, and informing complex dynamic systems in social epidemiology, likewise informing care coordination among patients with serious mental health problems [13]. In the special cases, an ABM has constructed to show a direct-relation between mental health and academic success [14] and also has presented a temporal dynamic model based on several personal characteristics and representation of events (i.e. life events or daily hassles) [15]. In our work, we use this method to depict the contagion effects of affecting and recovering. We set a population of 200 persons who have social interactions probability with depressed (men and women) persons in a single episode and recurrent episodes.

2.2. Parameter Values and Flowchart for Model

We use some literature review to determine the parameter values (see Table 1) for our model. Depending on the number severity of symptoms, a depressive episode can be categorized as mild, moderate, and severe [1-2]. Severity is based on the number of criterion symptoms, the severity of those symptoms, and the degree of functional disability. These following are explained by its definition in details [1]:

1. **Mild**: Few, if any, symptoms in excess of those required to make the diagnosis are present, the intensity of the symptoms is distressing but manageable, and the symptoms result in minor impairment in social or occupational functioning.
2. **Moderate**: The number of symptoms, the intensity of symptoms, and/or functional impairment are between those specified for mild and severe.
3. **Severe**: The number of symptoms is substantially in excess of that required to make the diagnosis, the intensity of the symptoms is seriously distressing and unmanageable, and the symptoms markedly interfere with social and occupational functioning.

Every parameter value in our model is differentiated by gender correspond to theories of psychology and characters in general. Women have been affected depression two to three times more than men, but men are particularly vulnerable due to suicide, i.e. 7 compared 12 per 100,000 population or within ratio 1:1.7 [1-2]. Therefore, let 0.00007 and 0.00012 as suicide rate of women and men, respectively.

Based on the explanation in Section 1, we know that cognitive vulnerability is a potent risk factor for depression. This research measured participants who were randomly assigned to a roommate with high initial levels of cognitive vulnerability would experience greater levels of depressive symptoms
over time than those assigned to a roommate with low initial levels of cognitive vulnerability experienced [5]. It was supported by another study that assessed gender differences in cognitive variables as an explanation for gender differences in depression and behavior problems. They found that the vulnerability of women obtained higher scores on depressive symptoms than men, which is 5.30% of women than 1.64% of men, in the clinical range [16].

Recovery was conceptualized as a period of full remission lasting at least a certain number of days. It also was defined that relapse as a return of symptoms to the full syndrome criteria for an episode during remission but before recovery, whereas recurrence was defined as the appearance of a new episode after a period of recovery. Also, at least 50% of those who recover from a first (single) episode of depression having one or more additional (recurrent) episodes in their lifetime [17]. From the above materials, we took 50% for the vulnerability of each gender when someone is entering recurrent episodes: 2.65% for women and 0.83% for men.

Research also suggested that the reassurance seeking served as a vulnerability factor for the contagion effect [6]. Furthermore, the ratio of the predicted value of contagion vulnerability rate between women and men are 0.1267 and 0.0712, respectively, with assuming both in a high reassurance seeking levels of their interaction state [7].

Despite consistent differences between genders in prevalence rates for depressive disorders, there appear to be no clear differences by gender in treatment response, where the risk of recurrence is higher in individuals whose ever in preceding episodes [1]. Thus, for both gender, research has the results that recovery probabilities are approximately 20% in the first week [18].

The repetitive Transcranial Magnetic Stimulation (rTMS) have the potential for preventing depressive relapse and recurrence [10]. In rTMS, electromagnetic coils are placed on a patient’s head to deliver electromagnetic pulses that stimulate areas of the brain that regulate mood. Although rTMS is not widely available, a growing body of evidence supports its use for treating depression [9]. A little different from the others, we use the successful and unsuccessful conditions of this therapy to determine the parameter values. This is necessary done to direct someone who has been undergoing therapy will recover or not.

A study (2015) investigated the predictors of achieving remission across all severity levels of depression. In the mild-to-moderate group, 60% achieved remission (at least 40% reach mild episode); in the severe group, 19% achieved remission in mild-to-moderate episode [19]. The rTMS-containing regimens significantly reduced the recurrence rate 28.5% [10], or 71.5% rTMS succeed on other words. Hence, we assume that the therapy remission rate for recurrent episodes is 71.5% of successful therapy for each depressive episode (stage).

Based on all those above literatures, the parameter values model are set and written in Table 1 below. These parameter values are flexible to be changed corresponding to recent researches over time. We use these parameter values to depict an ABM on a flowchart (see Figure 1) afterward.

| Gender                  | Men        | Women     |
|-------------------------|------------|-----------|
| Vulnerability of affected depression rate | First ($\alpha_1$) | 0.164 | 0.530 |
|                         | Recurrence ($\alpha_2$) | 0.082 | 0.265 |
| Contagion vulnerability rate ($\beta$) | | 0.0712 | 0.1267 |
| Natural recovery probability (in first week) ($\gamma_0$) | | 0.20 |
| Therapy remission rate for a single episode |
| Mild to Normal          | Success ($\gamma_{11}$) | 0.60 |
|                         | Fail ($1-\gamma_{11}$) | 0.40 |
| Moderate to Mild        | Success ($\gamma_{12}$) | 0.40 |
|                         | Fail ($1-\gamma_{12}$) | 0.60 |
| Severe to Moderate      | Success ($\gamma_{13}$) | 0.19 |
|               | Fail \((1−γ_13)\) | 0.81 |
|---------------|------------------|------|
| **Therapy remission rate for recurrent episodes** | Success \((γ_21)\) | 0.42900 |
|               | Fail \((1−γ_21)\) | 0.57100 |
| **Mild to Normal** | Success \((γ_22)\) | 0.28600 |
|               | Fail \((1−γ_22)\) | 0.71400 |
| **Moderate to Mild** | Success \((γ_23)\) | 0.13585 |
|               | Fail \((1−γ_23)\) | 0.86415 |
| **Severe to Moderate** | Success \((γ_24)\) | 0.13585 |
|               | Fail \((1−γ_24)\) | 0.86415 |

**Suicide rate** \((η)\) 0.00012 0.00007

**Figure 1.** Flowchart of Depression (for both gender).

Figure 1 illustrates the transition processes step by step from non-depressed person (normal) into depressed person who divided by depressive episodes (mild, moderate, severe), and suicide person or recovered person from each episode by therapy in a single episode and recurrent episodes, involve the parameter values for each gender (see Table 1). Because the parameter values in this flowchart differ by its gender, we make it in 2 models, each one population for women and men.

In addition to the parameter values that are specified in Table 1, there are two other parameter values that are also triggering contagion effects of this model, namely contact rate \((c)\) and the probability of going to a therapy \((T)\) (see Figure 1). The implementation and effects of both are explained in the next section.

In other words, the mathematical model had shown in Figure 1 and can be written on the following expression:

\[
\text{Rate of each depressive episode} = \text{Rate in} - \text{Rate out}.
\]

For example, the moderate episode in the second stage (at the center of the flowchart in Figure 1) comes from several probabilities. The first possibility is contagion vulnerability rate \((β)\) of mild and contact rate with the mild sufferer mild \((c)\) are subtracted by contagion vulnerability rate \((β)\) of severe and contact rate with the severe sufferer. Secondly, sufferers will still stay in the moderate episode if they are having the probability of going to the therapy and being failed after carrying out the therapy.
Another case is the rate of the therapy from severe episode in the first stage is successful rather than its contagion vulnerability ($\gamma_{13}\beta$ of Severe), then it will form a single episode. The rest apply the same idea that cannot be shown in this article due to the complexity of expression for its equations.

3. Simulations and Results

In this section, we simulate the transition processes of our model that have been depicted in Figure 1 based on parameter values from Table 1. We run this simulation that depends on day unit of time in an Agent-Based Model using AnyLogic 8.3.2 software. When time equals to 0 days ($t = 0$), 200 persons in this simulated population are normal (non-depressed), which is showed in this following Figure 2.

![Simulation](image)

**Figure 2.** Simulation results in an initial condition as $t = 0$ (0 days).

Figure 2 shows the population in an initial condition ($t = 0$) since 200 persons in this simulated population are in normal (non-depressed) state, where all people are described in green color. We can see these on the left side, which also represent a woman person in magenta outline color and a man person in blue outline color. It means that the top left one describes the population itself, includes the movements and interaction behaviors between person-to-person that are set in random in an environment, then it is equipped by the legends of the number of the persons for all gender and all depressive stage at its bottom. At the top right side shows a graph of transition processes for all stages of depressive episodes, including the therapy (for recovery process) and suicide (at its severe), that will change by time. While at the bottom right side shows a comparison graph of the number of depressed persons between men (in blue) and women (in magenta) that also depends on time.
In the previous section, we have mentioned about contacts rate and the probability of going to a therapy (see Figure 1). We are going to see the implementations and its impact of those parameter values toward the results in our simulations that depend on time.

3.1. Contacts Rate Simulations

Contacts rate denote how many contacts from either relationships or interactions that mutually giving influences among depressed persons for a day. We assume that someone whose higher severity will affect another who in a lower state than him or her. Consequently, lower severity of person will become more severe from his or her state now. Also, the persons in the same stage of depressive episodes can affect each other into becoming more severe. For example, the persons in a moderate depression can affect someone in both of mild depression to become moderate and moderate depression to become severe.

In facts, there are no contagion effects if the contacts rate equal to 0 contacts per day. Hence, we set the contacts rate which possible circumstances, i.e. start from 1 until 30 for all integers that represent persons (agents). With same the probability of going to a therapy, we set 0.5, we check the comparison of different contacts (per day) rate by time. We look the results after \( t = 31 \) days as 1 month; \( t = 365 \) days as 1 year; and \( t = 1826 \) days as 5 years, in one simulation.

a) Simulation results after \( t = 31 \) days (1 month),

b) Simulation results after \( t = 365 \) days (1 year),
c) Simulation results after $t = 1826$ days (5 year).

**Figure 3.** Comparison simulations of significant different contacts rate, which are 2 contacts per day (left side) compared with 20 contacts per day (right side).

Figure 3 obtains the results based on significant contacts rate differences, that are 2 and 20 (or 10 times of 2) contacts per day. Those are observed at certain times above (see part a), b), and c)) for each simulation.

For the first time which means after 1 month, $t = 31$ days, we find that there are no significant differences between the comparison result. However, we also find the quantity result in a general perspective. The depressed persons in severe for a simulation of 20 contacts rate are significantly more in number than a simulation of 2 contacts rate. We see from the result of 20 contacts per day that the depressed persons seem to grow faster to be more severe stage than stay in one stage for a long time. While from the result of 2 contacts per day, the number of affected depression persons are longer in a mild stage and does not tend to fast grow into more severe.

Second, after 1 year ($t = 365$ days), we find significant differences in the number of normal persons, the number of persons in mild depression, the number of persons in severe depression, the number of persons who finally commit suicide, and the recovery process. It obvious that the left side (2 contacts rate) are showing many persons in normal and mild, few in severe condition, and zero number of suicide. It also describes that therapy processes are more tend to be successful in this simulation. On the other hand, the right side (20 contacts rate), are showing few of normal persons, zero in mild stage, many persons in severe stage, and there are persons who commit suicide.

In the last observed part, after 5 years ($t = 1826$ days), we find the significant results. For simulation of 2 contacts rate seems almost people being back to normal, whereas so many depressed people (in all stages, including suicide) over time for contacts rate that its ten times (20 contacts rate).

3.2. *The Probability of Going to a Therapy Simulations*

The probability of going to a therapy is the possibility or willingness of someone to seek a therapy for getting treatment so that he or she has a chance to undergo the recovery process. This therapy can be successful or not with respective certain remission rate is $\gamma$ and $1-\gamma$ as we say in Table 1. Thus, we set a probability of going to a therapy situate on the interval $[0,1]$ for all real numbers.

With same contacts rate, we set 10 contacts per day, we check the comparison of different the probability of going to a therapy by time. We look the results after $t = 31$ days as 1 month; $t = 365$ days as 1 year; and $t = 1826$ days as 5 years, in one simulation.
Figure 4. Comparison simulations of significant different probability of going to a therapy, which are 0.10 (left side) compared with 0.70 (right side).
Figure 4 obtains the results based on significant differences for the probability of going to a therapy, 0.10 and 0.70 (or 7 times of 0.1). Those are observed at certain times above (see part a), b), and c)) for each simulation.

Similar with the results of Figure 3, after 1 month observed (or at t = 31 days), there is no significant comparison between 0.10 and 0.70 probability. But, we find that the greater probability, 0.70 in this case, implies the more in the number of depressed persons are in a therapy state rather than simulation when 0.10 probability.

After t = 365 days or in a year, we find significant comparison results. With a small probability, we say 0.10, the more in the number of depressed people are at the same depressive episode at the same time. In another sense, the contagion effects of affected depression have a large effect, since its recovery process cannot go well. It will impact the number of normal persons into very fewer rather than the depressed persons itself. Conversely, a large probability, we say 0.70, can prevent suicide persons when they are in severe conditions and also can reduce the number of depressed people via therapy. As a result, the number of therapy is entirely necessary over time.

Finally, similar to the results of Figure 3, at t = 1826 days or after 5 years, it seems significantly of a large number of severe depression and suicide deaths from a simulation of 0.10 probability. Then, on the contrary, there is significant a large number of persons who back to normal condition from simulation of 0.70 probability.

4. Conclusions
The contagion effects in affected depression may endanger, but its recovery process by doing therapies can help. Through agent-based modeling and simulations, we can reduce this contagion by regulating contacts relations with depressed persons and help them to find therapists as soon as possible, before its contagious spreads. Although more simulation gives different results (as a random set), the model still gives the same capacities and proportions.

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Acknowledgments
This research was supported by PITTA Research, Universitas Indonesia for 2018.