ORIGINAL ARTICLE

eISSN 2005-7571

Korean J Biol Psychiatry 2022;29(1):1-8

https://doi.org/10.22857/kjbp.2022.29.1.001

Evolutionary Model of Depression as an Adaptation for Blocked Social Mobility

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Objectives In regard to the social competition hypothesis, depression is viewed as an involuntary defeat strategy. A previous study has demonstrated that adaptation in microenvironments can result in a wide range of behavioural patterns including defense activation disorders. Using a simulation model with evolutionary ecological agents, we explore how the fitness of various defence activation traits has changed over time in different environments with high and low social mobility.

Methods The Evolutionary Ecological Model of Defence Activation Disorder, which is based on the Marginal Value Theorem, was used to examine changes in relative fitness for individuals with defensive activation disorders after adjusting for social mobility.

Results Our study examined the effects of social mobility on fitness by varying the d-values, a measure of depression in the model. With a decline in social mobility, the level of fitness of individuals with high levels of defense activation decreased. We gained insight into the evolutionary influence of varying levels of social mobility on individuals' degrees of depression. In the context of a highly stratified society, the results support a mismatch hypothesis which states that high levels of defence are detrimental.

Conclusions Despite the fact that niche specialization in habitats composed of multiple microenvironments can result in diverse levels of defensive activation being evolutionary strategies for stability, decreased social mobility may lead to a decrease in fitness of individuals with highly activated defence modules. There may be a reason behind the epidemic of depression in modern society.

Keywords Evolutionary ecology; Social mobility; Defence activation disorder; Agent-based simulation.

Received: January 26, 2022 / **Revised:** February 9, 2022 / **Accepted:** February 16, 2022
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Introduction

Depressive disorders are often considered to be merely undesirable outcomes because they are closely associated with negative emotions that result from environmentally and socially unfavorable circumstances.[1)2)] In general, negative emotions are related to difficulties in life, but overactive defensive behaviors can be normal responses that are adaptive in nature.[1)3)] Evolutionarily, not the well-being of individuals governs cost and benefit, but reproductive fitness. When it can increase fitness, it can be said to be an adaptive trait, even if it causes an unpleasant emotional reaction.[4)] It's still up for debate whether depression should be considered an abnormal mood.[5)] It's clear that clinical depression lowers reproductive fitness, but it's been argued that the trait could improve fitness in certain situations.[5)]

It is also known as the social competition hypothesis or the rank theory. It is thought that, according to this theory, the optimal behavioural strategy differs according to the ranking of the individual within a group. Each individual places themselves in a specific place in the rank spectrum that ranges from dominance at one end of the spectrum to submission at the other end. The social competition hypothesis says depression is an involuntary subordinate strategy that serves three functions.[6)] Firstly, it suppresses the aggression of superior competitors and lowers the risk of being counterattacked by an attacker due to a subjective feeling of inadequacy. Secondly, the behaviors associated with depression signal non-threatening and submissive signals to competition. Thirdly, it promotes reconciliation by accepting defeat and taking action to resolve the conflict. Also referred to as an involuntary defeat strategy (IDS), depression is a yielding subroutine.[7)8)]

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An individual with depression can activate their defensive mechanisms in a variety of social or non-social threat situations to ensure that they are protected from potential or actual threats.[9] Social avoidance, arrested fight, blocked escape, or involuntary subordination is examples of defensive behavioural strategies.[1)8)] D-type disorders can be categorized into two types: distress clusters, which show predominantly depressive symptoms, and fear clusters, which display fear symptoms.[10] At the outset, social rank theory was primarily concerned with depression.[7] In Price and his colleagues' work, it was stated that anxiety promoted reconciliation, and depression culminated conflict.[7] In terms of evolutionary ecology, however, it would be better to treat them both together in order to simplify the analysis.[1)11)]

Despite this, it is difficult to prove that people with depression have greater fitness than average, so the idea that fitness will improve has serious flaws. When defense modules are overactivated (or inactivated) in the clinical and social context, dysfunctional conditions result. In 2006, major depressive disorder (MDD) ranked seventh on the list of global disability-adjusted life years. With the exception of low-income countries where infectious and malnutrition are common, MDD is ranked first or second in many industrialized countries.[12] The prevalence of depressive disorder is 10%, the median age of onset is 32 years, the mortality rate is 1.8, the total fertility rate (TFR) is only 0.9, and the heritability is 0.37.[13)14)] The idea that depression is an adaptation is somewhat doubtful based on the data.[15] It is paradoxical that mental disorders can be common, harmful and hereditary.[16]

Recent research indicates that adaptation in localized areas could evolve defense activation patterns.[1)17)18)] A localized area here does not just refer to a geographic location, but also to a position within a stratified society.[1] Balancing selection allows defence activation to be maintained at different levels in the simulation environment.[1] Futuyma and Moreno[19] proposes that niche specialization is one explanation for the phenomenon of heterogeneous behavioural patterns. As a minority strategy, the depression can also be sustained within the population, regardless of whether it increases fitness of the individual.

Humans lived in tribal societies during the Paleolithic era. In groups, there will always be both individuals with higher and lower achievement levels. Initially, it was only a very small difference. Some of these differences may be caused by genetic differences. Sloman[20] assert that the differences are amplified by the maladaptive cycle associated with IDS. Moreover, social conditions are inherited. As genetic differences become more pronounced over time, traits associated with IDS can also become more pronounced.

Even so, the difference amplification model cannot explain why depressive disorders are on the rise. The incidence of MDD has significantly increased in the late 20th century.[21] It is expected that it will quickly move up to rank No. 2 in the International Burden of Disease ranking.[22] In spite of numerous social, economic, cultural, and medical criticisms of whether clinical depression really is on the rise, it is nearly impossible to dismiss the global depression epidemic as merely an illusion.[22-25]

The movement between social strata of a group or individual over time is referred to as social mobility. It has been shown in previous studies that transitioning to a new ecological location has an important effect on fitness. Also, in an environment with a constant gradient of resources, multiple levels of defense activation are maintained as an evolutionarily stable strategy. The fitness of subgroups with high or low levels of defence activation will likely change significantly if mobility declines or increases.[1] It means the expected fitness of IDS fixed genetically to some subpopulations will vary significantly in a novel environment, and this mismatch is likely to contribute to the depression epidemic.

As far as we know, no study has assessed the fitness of defense activation disorders in environments with resource gradients over long evolutionary timespans. An evolutionary ecological agent-based simulation model of defence activation disorder[1] was used to investigate how over time the fitness of a variety of defence activation traits changes in a variety of environments with high or low social mobility.

Methods

In order to address the following four research questions, we created a spatially explicit agent-based model:

1) Does the difference in the Movement Cost (Mov.Cost) affect the d-value of the population?

2) What will be the differential fitness between the agents with an over-activated defence level and an under-activated defence level in the presence of different Mov.Cost?

3) How does the difference in the achievable movement distance translate into the difference in the d-value of the population?

4) Under a situation of differing socio-ecological fluidity, how can an agent with an overactive defense level and an underactive defense level differentiate their fitness?

Based on the the Marginal Value Theorem (MVT), an agent-based model of defence activation disorders was constructed using NetLogo (http://ccl.northwestern.edu/netlogo/). The full model description following overview, design concepts, details protocol[26] can be accessed at https://doi.org/10.30773/pi.2020.0051. As follows is an abridged version of the full model description.

Humans are represented in this model by individual agents (also called "circles") who are capable of movement and reproduction. Patches of the environment are arranged on a two-dimensional plane wrapped as a torus in order to avoid edge effects. The patches are arranged spatially gradient resource levels. From the patch, the circle can learn the current resource level (R). It can be imagined that the modelled world is an abstract landscape of uneven population and resources. According to the MVT, the circle moves to a new patch if the amount of energy acquisition on the patch is less than the amount of energy acquisition in the entire habitat, plus Mov.Cost, and if energy (E) exceeds Mov.Cost. The circle gets resources from the patch. The circle breeds new offspring when the age is between 15 and 40 years old, the E is greater than the Minimal Energy for Reproduction (M.E.R.), and there are empty patches in between neighbours. Here, Rep.Prob. follows the logistic function. The circle dies if its E drops below zero or its age reaches 41.

Initially, the model included 400 circles, but the number of circles can be varied from 1 to 1369 (Int. No.). The initial number of 400 circles was considered sufficient to withstand changes in short-term fertility and mortality.[27] One to three offspring are expected to be born during the lifespan of the model. It is equivalent to a woman having 2–6 children in her lifetime alone. Child mortality rates in hunter-gatherer communities can reach 50% to 60%.[28)29]

Adaptive behaviour of circles are judgements of movement. A given agent is classified as overactivated (OA), neutral (NA), or underactivated (UA) depending on its d-value. Anxiety and depression are represented by OA, whereas manic and hypoanxiety are represented by UA. As each agent's adaptive behaviour changes over generations, their d-value is modified as well.

We consider two key parameters in this study: Maximum Distance (Max.D.) and Mov.Cost. Circles can travel a maximum distance in a single movement, reflecting socio-ecological fluidity. The Mov.Cost value is calculated by multiplying Mov.Cost by the number of movements. The average number of movements is determined by summing the geometric sequences of R.O.P. which stands for the Ratio of Occupied Patches. Although mobility differs by micro-environment, it can be simplified to be determined by the occupancy of the entire habitat. Therefore, Mov.Cost is calculated as follows:

$$\sum_{k=0}^{\infty} \text{Mov.Cost} \times \text{R.O.P.}^{k}$$

$$= \lim_{n\to\infty} \sum_{k=0}^{n-1} \text{Mov.Cost} \times \text{R.O.P.}^{k}$$

$$= \lim_{n\to\infty} \frac{\text{Mov.Cost.}(1 - \text{R.O.P}^{n})}{1 - \text{R.O.P}}$$

$$= \frac{\text{Mov.Cost.}}{1 - \text{R.O.P.}}$$

These are the main parameters of this simulation model: 1–3 for Max.D. and 3–12 for Mov.Cost. Additional calibrated parameters, the Netlogo 6.0.3 source code, the complete schedule of the model and other details can be found in the supplemental information (online-only) at https://doi.org/10.30773/pi.2020.0051.

Results

Ecological factors (Max.D. and Mov.Cost.) affecting fitness of agents with different d-values are presented. We also discussed evolutionary phenomena that emerge over time. By increasing Mov.Cost, the global average d-value fell and the UA proportion grew. Interestingly, high Moving Costs tend to increase the UA's population and the variance of the UA's TFR. In addition, when Max.D was raised, d-value jumped up. As social mobility increased, UA became more vulnerable.

For this simulation, Mov.Cost refers to the amount of energy consumed when moving to another ecological patch. Fitness relies heavily on Mov.Cost, as E must pay for survival and reproduction. When circles consume too much Mov.Cost, it makes it difficult for them to reproduce. When Mov.Cost increased within the calibrated ranges, the total population declined (Supplementary Table 1). For Mov.Cost 3, 7, and 12 (and M.E.R. is 130), the average population was 736.3, 641.7, and 560.5, respectively. Each condition had a significant difference in the composition of the population. In Supplementary Table 1, we show the percentages of UA, NA, and OA subgroups in each environmental condition.

The low Mov.Cost led to an increase in the population of OA. They behaved optimally in resource-scarce environments. However, because there were few resources, absolute resource acquisition was limited. With the increase in Mov.Cost, the population of OA declined quickly compared to other subgroups, since the energy obtained was less likely to reach M.E.R. When Mov.Cost and M.E.R. were respectively 3, 130, and 187.2, the population of OA was 187.2. As Mov.Cost increased to 12, the population of OA dropped to 6.2.

Conversely, when Mov.Cost was high, UA proportions increased. UA behaves optimally under high resource levels. Because of this, it generally outperforms OA. The increase in Mov.Cost lowered UA's absolute fitness, but in an environment where the population of the entire habitat was maintained within constant ranges according to the logistic function, UA was able to retain a relatively higher fitness. When Mov.Cost was 3 and M.E.R. was 130, UA had a population of 149.1. At Mov.Cost 12, UA would have had a population of 345.6.

During periods of high Mov.Cost, the average d-value of the entire population tends to fall. With Mov.Cost set to 3, d = 1.017

± 0.037. The d-values were 0.954 ± 0.034 for Mov.Cost 7 and 12 (M.E.R. 130) and 0.815 ± 0.030 for Mov.Cost 12. In an environment with a high Mov.Cost, circles with relatively low d-value are advantageous (Figs. 1 and 2). Because of the same reason, the d-value did not always equal 1. Fig. 3 shows that this tendency persisted for at least five Kyr.

TFR of each subgroup differed significantly. NA has the highest TFR (1.016 ± 0.217), regardless of environmental conditions (Supplementary Table 1). If Mov.Cost is high, the reproductive fitness of OA appears to be lower (0.866 ± 0.698), and the reproductive fitness of UA appears to be higher (1.004 ± 0.211). A simulation of five kyr under three environmental conditions was repeated 16 times in order to obtain the TFR data for 240 kyr. A high Mov.Cost was associated with a high variance in the reproductive fitness of UA, and vice versa (Fig. 4).

It is believed that each subgroup receives a different amount of energy, which contributes to the decline in reproductive fitness. A high Mov.Cost environment reduced the energy gain of the circle with a high d-value, and the variance of energy acquisition increased by a high mortality rate.

A higher Mov.Cost led to a shorter lifespan. In the case of Mov.Cost 3, the lifespan was 29.62 ± 1.85. The lifespans, however, were 28.08 ± 1.69 and 26.24 ± 1.36 when Mov.Cost was 7 and 12, respectively (Supplementary Table 1). Despite statistical significance, life expectancy did not differ substantially in UA, NA, and OA under the same environmental conditions. With increasing Mov.Cost, however, OA lifespan tended to increase, while UA lifespans tended to converge. In other words, the environment that has a high Mov.Cost is less favorable to OA than to UA.

In this study, we investigated the Max.D. that the distance cir-

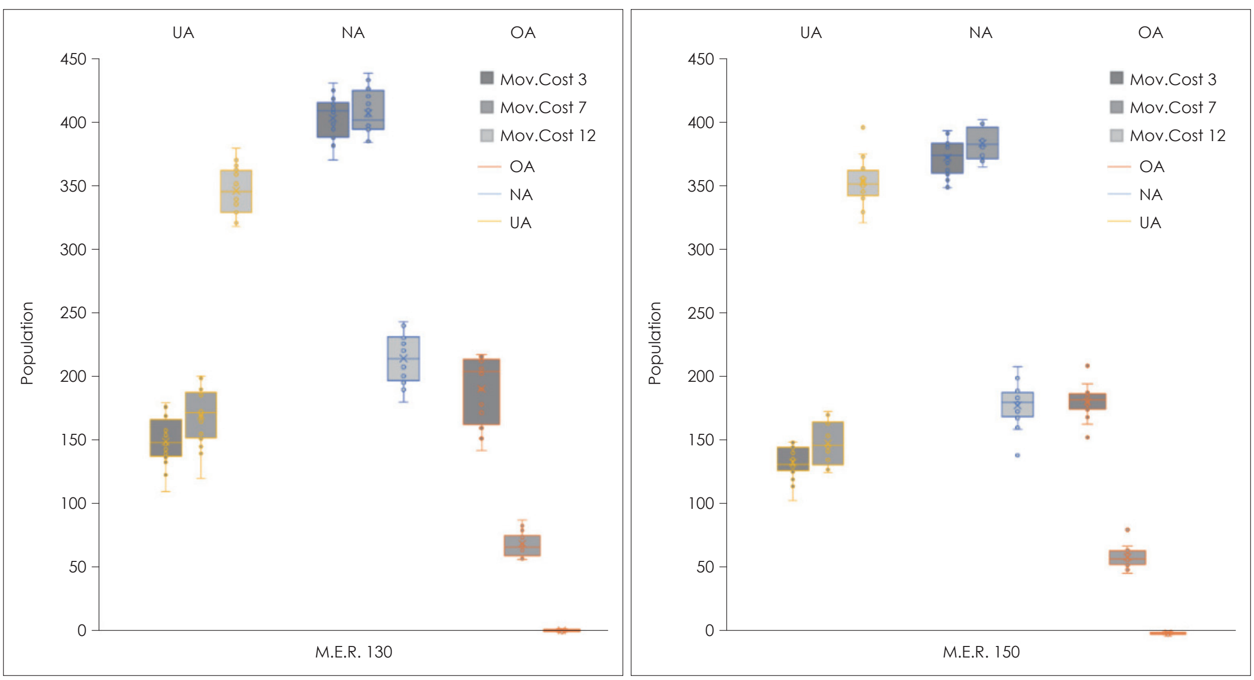

Fig. 1. Population of each subgroup according to Mov.Cost (M.E.R.130). UA, underactivated; NA, neutral; OA, overactivated; Mov.Cost, Movement Cost; M.E.R., Minimal Energy for Reproduction.

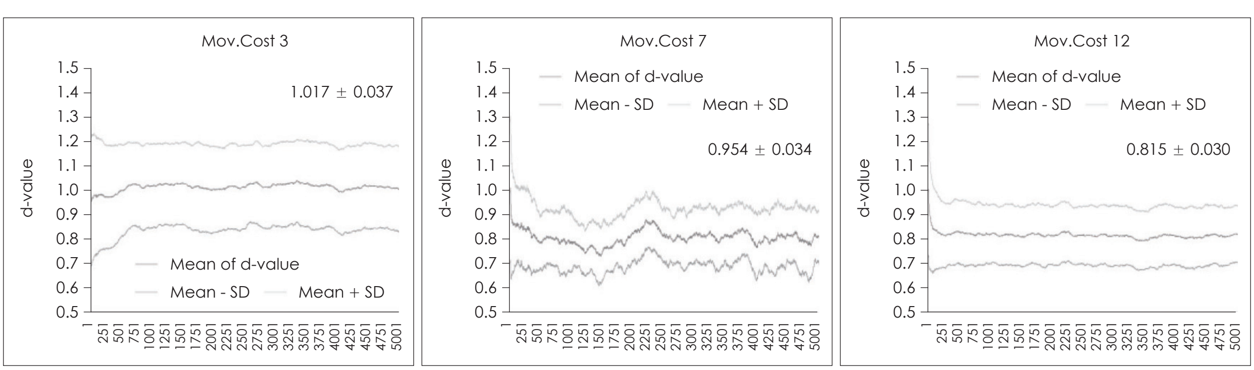

Fig. 2. Time-Series Patterns of d-value according to Mov.Cost 3, 7, and 12 (M.E.R.130). Mov.Cost, Movement Cost; M.E.R., Minimal Energy for Reproduction.

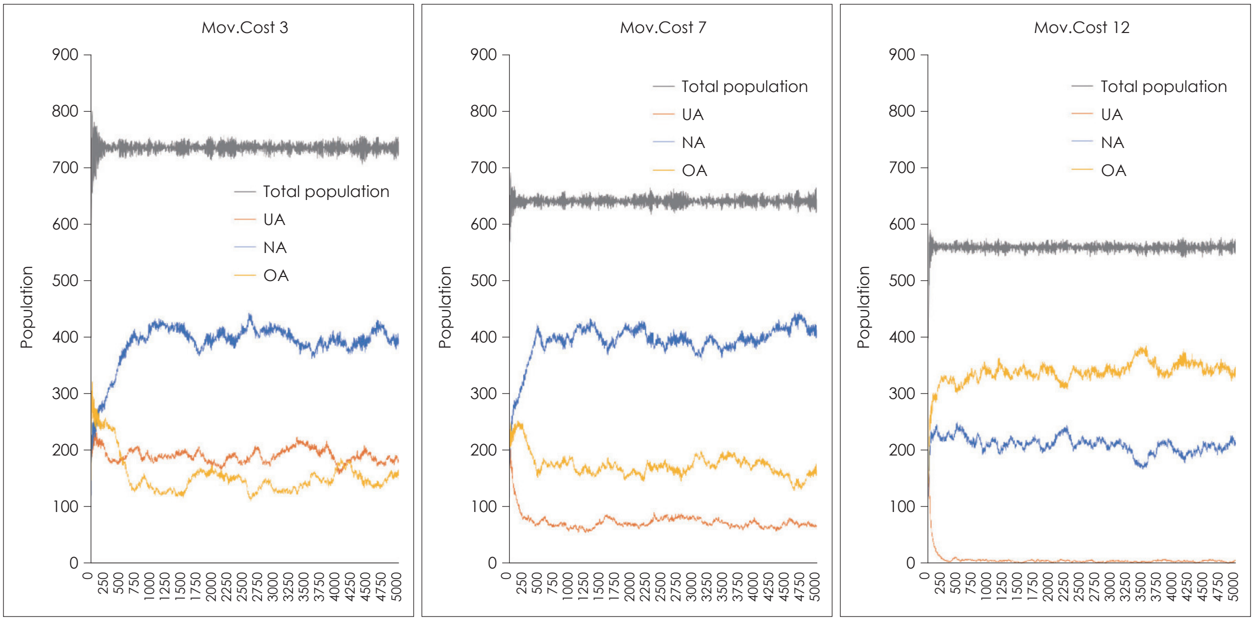

Fig. 3. Time-Series Patterns of sub-population UA, NA, and OA (M.E.R.130). UA, underactivated; NA, neutral; OA, overactivated; Mov. Cost, Movement Cost; M.E.R., Minimal Energy for Reproduction.

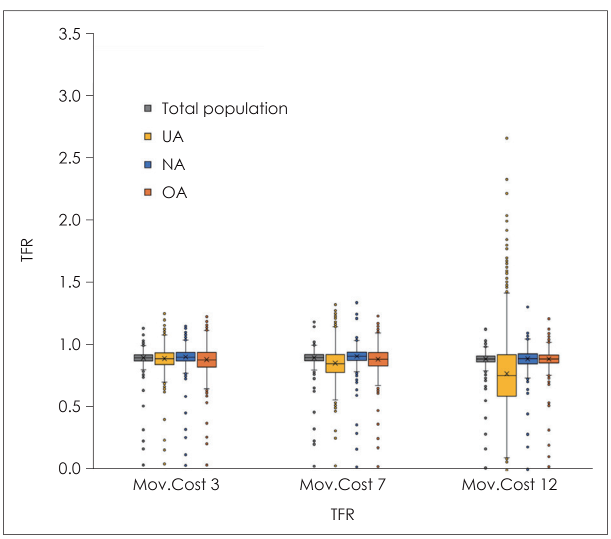

Fig. 4. Comparison of the TFR of three subgroups for a total of 240 kyr. UA, underactivated; NA, neutral; OA, overactivated; Mov. Cost, Movement Cost; TFR, total fertility rate.

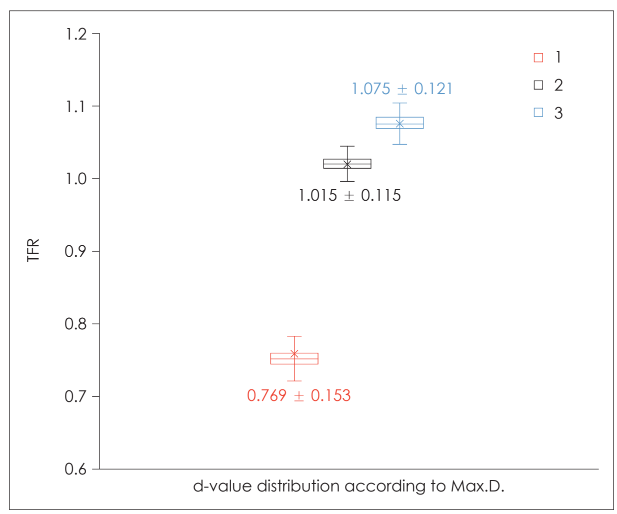

Fig. 5. Relationship between d-value and Max.D. Max.D., Maximum Distance.

cles can move at one time, i.e., Max.D., a factor that affects the proportion of UA, NA, and OA, as well as the d-value. In the default model, an agent can move to one of eight patches nearby. In order to determine the effect of Max.D., it was divided into 1, 2, and 3 based on the maximum radius from the current position. Thus, the number of patches an agent can move at a time increases to 4, 12, and 28 respectively. Fig. 5 shows the results (8 runs for each situation).

Intriguingly, the overall d-value increased with more patches available. In case Max.D is 1, d-value is 0.769 ± 0.153. On the other hand, when Max.D. rises to 2 or 3, d-values are 1.015 ± 0.115 and 1.075 ± 0.121, respectively. As a result, the proportion of UA decreased and the ratio of OA increased, probably because there was a greater likelihood of UA spreading to relatively unfavourable patches because of increased mobility. For OA, when the Max.D. is higher, the probability of moving to an unfavourable patch is reduced (Fig. 6). In summary, the increased socio-ecological fluidity of the simulated environment may benefit highly defensive people.

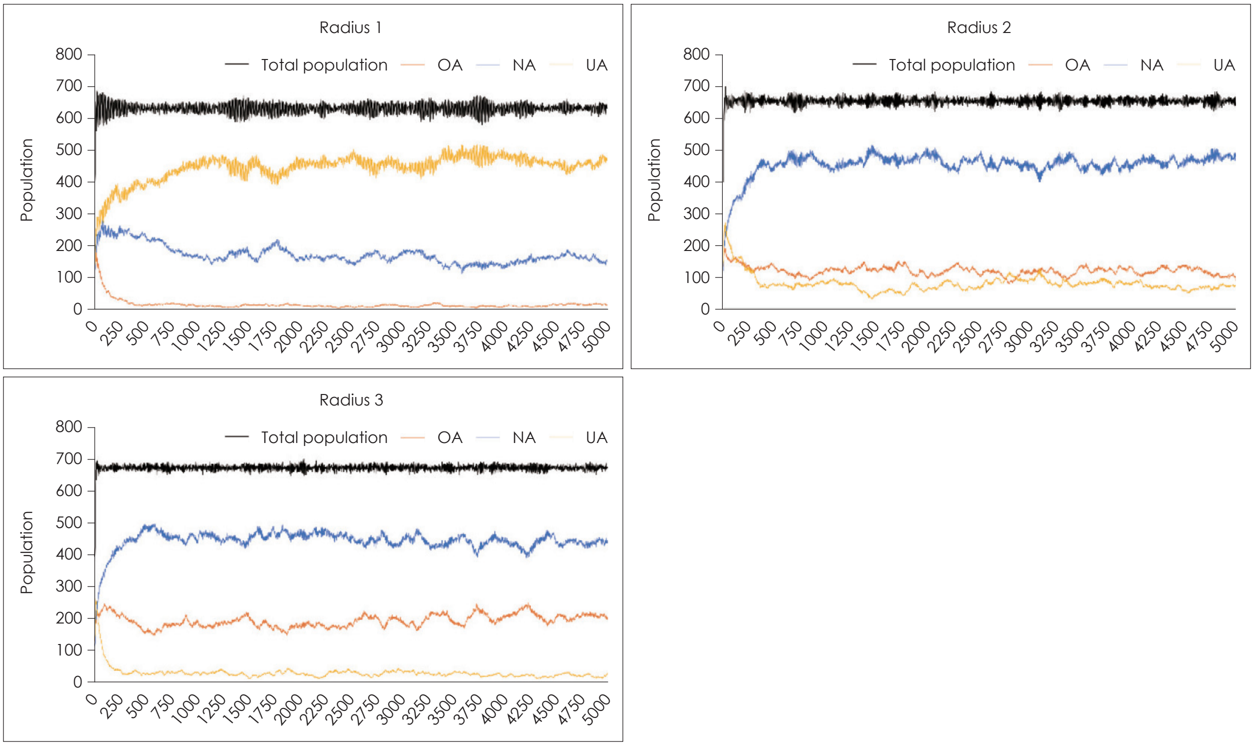

Fig. 6. Proportion of UA, NA, and OA relative to Max. D. UA, underactivated; NA, neutral; OA, overactivated; Max.D., Maximum Distance.

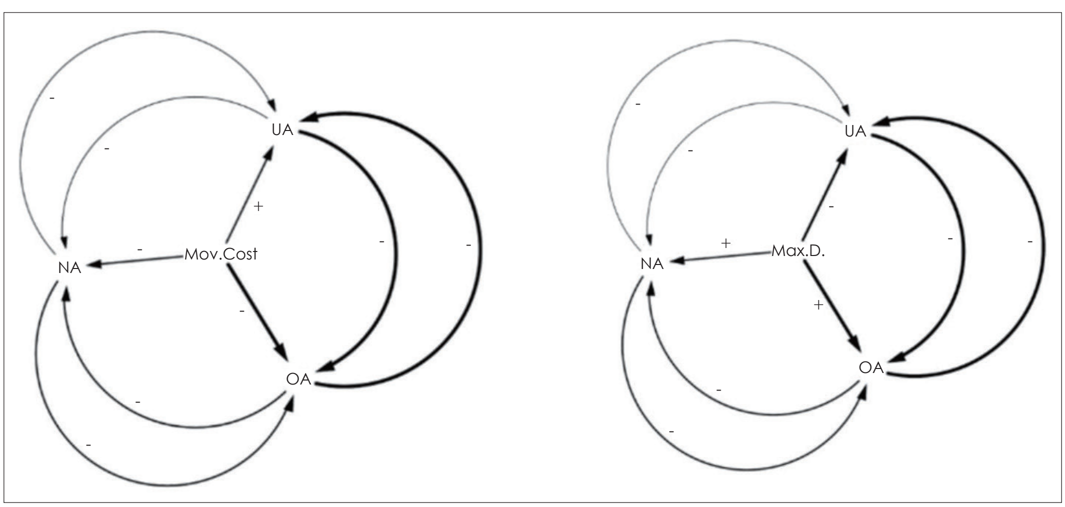

Fig. 7. Effect of mobility (Mov.Cost and Max.D.) on UA, NA, and OA. Mov.Cost, Movement Cost; Max.D., Maximum Distance; UA, underactivated; NA, neutral; OA, overactivated.

Discussion

Here we discuss two aspects of mobility. Firstly, mobility is determined by the cost of movement. According to this model, every individual can move only to nearby patches. Due to this, the Mov.Cost plays a geo-ecological limiting role. The second aspect of mobility is the Max.D. an individual can move at a single time. As such, fluidity could serve as a socio-ecological limiting factor, so-called social mobility.[30] With an increase in Mov. Cost, individuals with highly activated defences have been losing fitness. In addition, fluidity has increased the fitness of those with highly activated defences. Fig. 7 is a schematic diagram of this phenomenon.

People have been mobile since the beginning of time. Throughout history, hunter-gatherers have moved from place to place. The sedentary lifestyle is relatively new. The hunter-gatherer is sometimes described as someone who "moves around a lot."[31] Hunter-gatherer societies are characterized by their adaptability to a wide range of environmental factors.[32] Because people began to settle in the same ecological environment after the Younger Dryers, geographical and environmental heterogeneity declined. Nevertheless, social heterogeneity has become more pronounced as differences in the social-ecological ecosystem have become more complex.

According to the study, either an increase in Mov.Cost or a decrease in fluidity has the same effect. In hunter-gathering societies, there may be a selective pressure for geographical mobility that is similar to the selective pressure for social mobility found in stratified societies. In spite of humans' long-term adoption of sedentary lifestyles, environmental heterogeneity has been switched with social heterogeneity. In the socioecological niches, humans are still moving around a lot. Every day, people change their jobs, move to distant cities, migrate to other societies, make new families, or gain or lose social status.

Social mobility and depression are well known to be related. In fact, most studies have examined the relationship between downward social mobility and depression disorders.[33][34] It has been found that upward social mobility is beneficial to a person's mental health in general.[35] The minority view holds that social mobility has nothing to do with depressive disorders.[36] In fact, most of these studies investigate how individuals feel when they experience social mobility. According to evolutionary theory, social mobility leads to large-scale changes in ecological conditions. There may be lower fitness in individuals with high levels of activated defence modules, if their mobility has been reduced. Locally, this may have been optimal for resource-poor niches before. The mismatch hypothesis holds that some neutral traits can be changed into negative traits when environmental factors are drastically altered (cryptic genetic variation).[37] In this sense, it is likely that the results of this study may shed some light on the central paradox of defence activation disorder, at least in a simulated environment.

The study has some limitations. In general, the socioeconomic gradient of health is strongly related to depressive disorders or anxiety disorders. It is partly a direct reaction to deprivation or suffering.[38] Nevertheless, the results from this study suggest that it might be an evolutionary outcome in the long run. Those with optimal d-values in deprived areas will have suboptimal reactions to average environments, so moving to more resource-rich areas will lead to better fitness. Despite this, a suboptimal d-value in relation to others does not necessarily mean it is not evolutionarily unstable since it may be optimal for deprived niches under circumstances of limited social mobility.

It is not included in the simplified model, but it is likely that the d-value as a supraordinate appraisal guideline will be adjusted during the process of development. There was no consideration of environmental plasticity, developmental plasticity, learning, communication, and cooperative behavior in this model. Even though simplified approaches are favored in evolutionary simulation, the results of the study should not be directly applied to reality without proper consideration.

This deserves further consideration. As long as there is not a globally optimal d-value regarding defence activation, this is not just a matter of personal mental health, but of public health.[39] Cognitive-behavioral therapy targets the distorted schema about the self, the world, and the future.[40] It may be possible to combine evolutionary approaches to dysfunctional behavior patterns with cognitive behavioral therapy,[41][42] as appropriate schema about them may be different depending on the social situation and individual conditions in a socio-ecological context. Evolutionary approaches to mental disorders, such as defence activation disorders, go beyond the academic, and can also be applied to rationalize therapeutic interventions.

Supplementary Materials

The online-only Data Supplement is available with this article at https://doi.org/10.22857/kjbp.2022.29.1.001.

Acknowledgments

None

Conflicts of interest

The authors have no financial conflicts of interest.

Author Contributions

Conceptualization: Sunyoung Pak. Data curation: Hanson Park. Formal analysis: Hanson Park. Funding acquisition: Hanson Park. Investigation: Hanson Park. Methodology: Hanson Park. Project administration: Sunyoung Pak. Resources: Hanson Park. Supervision: Sunyoung Pak. Writing—original draft: Hanson Park. Writing—review & editing: Sunyoung Pak.

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