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Review Article

Evolutionary and genetic origin of suicide

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Abstract

Introduction: Every year, around one million people die by suicide throughout the world. So, understanding the biological origins of suicide can provide etiological and preventive advantages to our understanding of this complicated phenomenon.

Materials and Methods: The current study is a review study aimed at assessing the validity of evolutionary hypotheses based on the newest findings of this domain. For this reason, relevant articles from the reliable scientific database until August 2018 were selected.

Results: According to the literature, various models such as altruistic suicide, eusociality, the bargaining hypothesis, the parasite manipulation hypothesis etc., to some extent, can explain suicide behavior. However, no precise evolutionary mechanism yet identified. In addition, almost all of the new suicide models, particularly the crying for help model and interpersonal psychological model of suicide, are formed based on these evolutionary hypotheses. These models, along with other genetical studies, showed that suicide is not just a socio-cultural phenomenon; genes have an important role in suicide incidence.

Conclusion: In sum, the evidences suggest that suicide is probably the by-product of pain rather than the direct product of natural selection.

Keywords: Behavioral genetics, Evolution, Evolutionary psychology, Suicide

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Introduction

Suicide is a widespread phenomenon in the world as well as in Iran. It was estimated that 800,000 people die of suicide each year worldwide (1). Studies show that since 2000, the suicide rate in Iran has increased by at least 1.3 per 100,000 people (1,2). According to more recent studies, the suicide rate in Iran in 2017 was 9.9 per 100,000 people (1). Furthermore, global studies show that for every successful suicide, there are 20-25 unsuccessful suicides (3). With this in mind, a conservative estimate suggests that at least 15,840 suicide attempts were made in Iran in 2017. Therefore, understanding all the theoretical and scientific aspects of suicide is essential in creating a coherent and

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comprehensive model for better understanding, treatment, and prevention of suicide.

Many theorists have sought to explain suicide in various forms: Klonsky and May's three-stage model of suicide theory (4) offers different explanations for a) the growth of suicide ideation and b) the progression from ideation into suicide. This theory is somewhat simplistic because the idea and attempt of suicide can be explained based on only four factors: pain, hopelessness, connectedness, and capability of committing suicide. This theory is explained in Figure one. Joiner T. (5) proposed the interpersonal theory of suicide. This model suggests that the interaction of three elements creates the extreme risk of suicide: 1. The experience of loneliness and isolation (thwarted belongingness), 2. The perception of being a burden on others (perceived burdensomeness), and 3. Habit of self-harm with the priority of non-suicidal self-harm, suicidal behavior, or other dangerous behaviors (acquired capability) (6). Another model of suicide was proposed by O'Connor (7) and was called the Integrated Motivational-Voluntary model of suicide. O'Connor suggests that failure and entrapment are the first motivators for suicidal ideation and that acquired capability, along with other factors (such as access to killing tools, planning, and impulsivity), explains the tendency to commit suicide. According to this model, underlying and motivating factors (such as environmental factors and life events) activate the feeling of failure and humiliation, and then the threat to their modulators causes people to feel trapped. This feeling can lead to suicidal ideation if motivational modulators (such as perceived burdensomeness and thwarted belongingness) (8). Finally, suicidal ideation is transformed into a suicidal commitment with the help of voluntary motivational modulators (7). The development of the theory and Evolutionary Perspective on suicide has been linked to the extensive studies of de Catanzaro (1980), which continue to this day. In general, the primitive evolutionary theory emphasizes two proven phenomena of Natural Selection and Sexual Selection: the goal of natural selection and sexual selection is to increase the probability of survival and increase the reproduction of organisms; therefore, it seems that suicide attempts cannot be explained from an evolutionary point of view, because an individual needs to survive in order to increase his share in the next-generation gene pool (9,10).

A more accurate understanding of suicide requires understanding another set of evolutionary laws, including the theory of inclusive adaptation and kinship selection. Inclusive adaptation and kinship selection provide strong evidence that in some cases, the set of behaviors of organisms may not be directly in their favor, but indirectly increase the likelihood that their genes will be passed on to the next generation through the relatives; as a result, although behavior may lead to the death of an organism, it is a consistent and beneficial behavior if that behavior causes most of that person's genes to be passed on to the next generation (11). Another matter is understanding the process and mechanisms and explaining how suicide is preserved in evolutionary history and why it occurs; explaining how it is called Proximate explanation and why it is called Ultimate explanation (9). Another issue is classifying a behavior such as suicide in terms of "how it occurs". This classification includes the following three subgroups. 1. Compatible (direct) product: inheritable traits that increase the likelihood of survival and reproduction, 2. Accompanied product: traits that are not compatible but are transmitted from one generation to the next due to conjugation and association with compatible traits, and 3. Noise: changes caused by accidental environmental events or gene mutations (11). Also, some researchers use the mismatch explanation. In this case, the set of systems that may have been compatible in our hunter-gatherer ancestors would be ineffective or even harmful in modern life, such as the energy storage system that was so effective in the human's evolution in the past, but it can cause obesity and related diseases in modern life (9-11).

Materials and Methods

This study aimed to summarize other studies in the evolutionary psychology of suicide. For this purpose, the keywords, Evolutionary Psychological Disorder, Evolution, Behavioral genetics, Suicide, Suicide models, Suicidal behavior, Suicidal ideation were searched in the databases of ScienceDirect, NCBI (The National Center for Biotechnology Information), Springer,

etc., and a collection of related review articles were collected by August 2018. Since not many studies have been conducted in the field of evolutionary suicide, and most theories have been developed based on mathematical models or hypotheses, our focus has been on summarizing general views in this area and providing results that partly address some of these hypotheses (Figure 1).

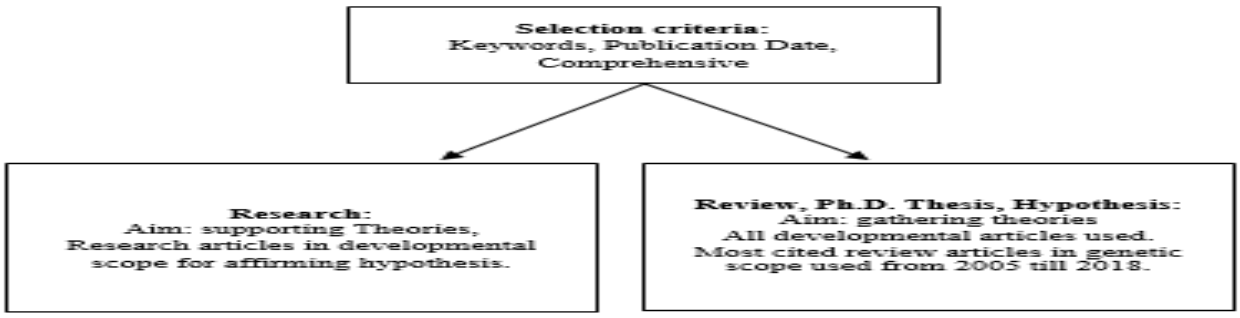

Figure 1. Selection criteria

Table 1. Summary of important articles

No.	Author	Year	Title	Method	Results
1	Aubin, Berlin and Kornreich	2013	The Evolutionary Puzzle of Suicide	Review	The hypotheses accept self-destructive behavior within the framework of evolutionary theory
2	Soper CA.	2017	Towards solving the evolutionary puzzle of suicide.	A thesis	Synthesize the principles of evolutionary theory with the epidemiology of suicide and other empirical inputs drawn from psychology, psychiatry and related domains
3	John Orbell	2011	An Evolutionary Account of Suicide Attacks: The Kamikaze Case	Content analysis	The evolutionary perspective is a paradigm around which diverse proximate explanations can be organized
4	David A. Brent and J. John Mann	2005	Family Genetic Studies, Suicide, and Suicidal Behavior	Case study	Suicide and suicidal behavior are familial, and appear to be heritable, through at least two components-liability to psychiatric disorder, and liability to impulsive aggression.
5	Midori Tanaka and Dennis K. Kinney	2011	An Evolutionary Hypothesis of Suicide: Why It Could Be Biologically Adaptive and Is So Prevalent in Certain Occupations	Review	In several other highly social species, suicide-like behaviors have evolved to reduce transmission of infections.
6	Gunn J.	2017	The Social Pain Model: Understanding Suicide Through Evolutionary Psychology	Review	Overview of suicide evolutionary models
7	Mirkovic B, Laurent C, Podlipski M-A, Frebourg T, Cohen D, Gerardin P.	2016	Genetic association studies of suicidal behavior: a review of the past 10 years, progress, limitations, and future directions. Frontiers in psychiatry	Review	Different studies have proven that genes play an important role in the development of the suicide
8	Brent DA, Mann JJ	2005	Family genetic studies, suicide, and suicidal behavior.	Review	Suicide behavior variability can be explained to some extent by genetic factors

Results

This section includes all the recent models presented in the evolutionary origin of suicide. Due to the lack of empirical research and the reliance of all models on mathematical, statistical, and evolutionary hypotheses, we used only review

articles and journals that grouped all models in a regular frame. The few existing research findings can only explain small parts of the models, and there is still no superiority or extensive empirical findings to support any of the theories.

1. Altruistic Suicide: de Catanzaro (1980) developed a formula based on the inclusive fitness theory, which uses an individual's survival ability, in addition to the effect he has on the reproductive ability of his kin, to play a reproductive role during the life expectancy predicted by him, which each weighted by the coefficient of relationship. More simply, being overburdened with relatives and low reproductive ability may increase a person's tendency to suicide. In fact, in this case, the person performs an altruistic behavior, especially for his close relatives, during which he increases the probability of the survival of the gene pool and the survival of his relatives by reducing the burden that he imposes on them. As a result, although suicide eliminates a person's chances of reproduction, it can transmit its genetic traits from one generation to another by increasing the chances of survival and reproduction of other relatives. However, such an explanation can only be generalized to the small number of suicides in modern society. Previous studies, however, have shown that some species of animals have altruistic suicides (9), or even some people who have had unsuccessful suicides claimed that they have committed suicide for the sake of their relatives and to reduce the harm done to them (10). Many studies also support a strong association between perceived burden and suicide attempts.

2. Low Fitness of the Organism Model: This model was also presented by de Catanzaro (1980), who use the mismatch rule, tries to explain that it is possible that the genotype of suicide that originated in the original environment was effective and compatible at that time, but not effective and compatible in the current environment and time. This may be because, unlike in the past, individuals activate in a larger human community and have less contact with their relatives than in the past, so that the individual will bear less of a burden on his or her relatives' genes than in the past (9).

3. Suicide as a By-product of Learning: de Catanzaro (1980) states that suicide could be the result of a person's unique ability to learn; therefore, despite the negative impact of this behavior on the fitness of species, it can be maintained and expanded through the process of learning and culture. The idea that some behavioral, cognitive, and emotional units can spread across a wide range of societies, especially through imitation, and can self-replicate like genes, has been accepted by some scientists (10). A clear example of such behaviors can be seen in accepting adoption, remaining a virgin, or even using different methods to prevent fertility, in which genes have no effect but are a direct result of cultural and social factors (10). It has also been suggested that suicide may be the product of cultural systems to reinforce or punish a series of behaviors without the need for genetic origin (12). Consequently, suicide can play a similar role; however, the results of behavioral genetics provide very strong evidence for the existence of gene bases in the development of suicidal behavior or at least the characteristics that cause suicidal behavior (12-14). However, some suicides, especially imitative suicides, can be justified by this view (15).

4. Suicide Tolerance Hypothesis: According to de Catanzaro (1980), suicide is likely to occur in people who are unable to reproduce; in other words, the conditions and circumstances are such that they prevent them from reproducing, and therefore, their survival or non-survival will not affect their reproduction (9, 10). As a result, evolution can tolerate the suicide of those who cannot reproduce since they cannot change their gene pool. An example of such behavior in animals is found in Pacific salmon, which can reproduce only once in their lifetime, and after their reproductive mission has ended by spawning in upstream waters, they die there, since, without a future reproduction, there is no reason for them to survive; therefore, there is no reason to choose features that can increase the likelihood of their survival, because, in order to transmit such traits to the next generation, it is necessary to transfer the gene pool of individuals to the next generation. In contrast, these animals will never have the opportunity to reproduce again (10). Thus, de Catanzaro (1981) also claims that traits such as despair, a sense of burdensomeness, and a sense of thwarted belonging are internal emotional traits that signal a person that he or she

cannot reproduce. Furthermore, if people predict low reproductive capacity, they are more likely to commit suicide because there is no genetic reason for their survival (10).These findings align with the research results that show that the suicide rate among the elderly, homosexuals and critically ill patients are very high (9). De Catanzaro (1981) also claims that traits such as despair, a sense of burdensomeness, and a sense of thwarted belonging are internal emotional traits that signal a person that he or she cannot reproduce. He also believes that suicide leads to more deaths among men because, unlike women, they have much less parental investment in their children (10).

5. Bargaining Hypothesis: According to this hypothesis, suicide is gambling. When a person is in trouble, he may show to those in access and his area of support that he desperately needs their support and help (9,10,14). According to this suicidal hypothesis, this Machiavellian gambling takes place consciously or unconsciously in some cases, especially among uneducated young women. Bargaining theory is close to the "cry for help" model (10). Recent intercultural research on this model shows that at least some suicide attempts benefit from being saved by others (17). Thus, if the average evolutionary benefits to genes through suicide attempts are more significant than the average loss, it may indicate that this behavior results from natural selection.

6. The Parasite Manipulation Hypothesis: The parasite manipulation hypothesis in the host body to change their behavior is relatively well-known. A clear example of such a parasite, which can manipulate all mammals, is called Tagazoplasma gondii (9, 10). Tagazoplasma gondii is a single-cell that is the ultimate host to complete the reproductive cycle of the feline family. Felidae (i.e., cats) can spread the product of the parasites through their feces. These parasites grow in the secondary host (mice) brain and, after completing their required cycle, manipulate the brains of these organisms to eliminate their fear of predators (cats); for example, mice infected with the parasite deliberately approach cats instead of being afraid of them and running away from them (9). Areas that the parasite manipulates include the amygdala, the center of fear, fear control, defense behaviors, and the peripheral lobe areas (9). It is estimated that 23% of Americans are infected with this parasite (10). In human specimens, this parasite typically causes a change in reaction time, increased activity, and even a change in personality profile (10). Interestingly, more than 2% of fatal road accidents are suicidal ideation, and Tagasoplasma disease is strongly associated with traffic accidents (9). In addition, researchers point out that until the 20th century, cats such as tigers, lions, and leopards were predators of humans, and they have existed throughout human evolution. Therefore, it is possible that this parasite, by manipulating humans' brains and eliminating fear in them, has increased the probability of being hunted by these predators and, as a result, has increased the probability of completing their life cycle (10).

Table 2. Whose gene may benefit from suicide?

Type of suicidal behavior	Ancestor ecosystem	Western modern ecosystem
Physical disorders	Relatives' genes can benefit from the suicide of someone who imposes a heavy burden on other people and has low reproductive ability.	As burdensomeness is shared by social welfare, virtually no genes benefit from the suicidal behavior
Depression	No gene directly benefits from suicidal behavior: suicide is a by-product of negative cognitive biases (overestimation of burdensomeness).	No gene directly benefits from suicidal behavior: No significant changes occur in the current environment.
Suicide Martyrdom	Ethnic group genes can benefit from some altruistic suicidal behaviors.	Ethnic group genes: There are no significant changes in the current environment.
Bargaining suicidal behavior	The gene of a person who has attempted suicide will benefit if the suicide is unsuccessful and subsequently the help he needs is provided.	Genes of the person who attempted suicide: There are no significant changes in the current environment.
Male Impulsive suicidal behavior	No gene directly benefits from suicide attempts. Suicide is a by-product of risk-taking.	No gene directly benefits from suicide attempts: Although risk-taking in today's Western society will be less profitable for genes than ancestral society.
Parasitic manipulation of Tagasoplasma gondii	Tagasoplasma genes will benefit.	No other genes benefit from human suicidal behavior (some exceptions may occur in Africa and India; humans are hunted by large cats).

Adapted from Aubin et al. (2013)

7. Suicide as a Result of Eusociality: Eusocial creatures are known to have the following four characteristics: 1- Multi-generational care of children, 2- Shared care of infants, 3- Division of labor, and 4- Collective defense. There is much debate about whether humans are eusocial or not (18). Joiner et al. (19) have argued that suicide is a deviant result of the very eusocial nature of humans because self-sacrificing behavior is common among eusocial creatures to defend or increase the likelihood of survival of others in the group (18). For example, suicide among people with a dangerous infectious disease occurs among eusocial creatures to prevent others from becoming ill (19). This self-destruction is a kind of self-sacrificing behavior that is done to improve the adjustment of other members of the group.

8. Anti-predator Response: Joiner and Stanley (20) have suggested that the suicide pattern in humans may follow the anti-predator response among mammals. This view states that when mammals encounter predators, they simultaneously activate two inhibitory systems (silence, withdrawal, etc.) and an excitatory system (agitation, sleeplessness, etc.), similar to the situations that occur before people who attempt suicide commit suicide. In fact, in this case, suicide is a by-product of a person's high concentration on death. Joiner and Stanley (20) state that those who commit suicide are their killers (bodyguards).

Predator-prey systems are activated in these individuals simultaneously, and the result is that the complex interactions of the two systems and the inability of the organism to protect itself in threatening conditions force it to kill itself. However, no specific research has been done on this theory so far.

9. Cry for Help Model: This model is for help due to failure, experiencing failure in a social situation or area, including disability, loss of valuable social resources, or severe interpersonal conflicts, and can lead to a sense of inability to escape from this unfavorable situation in the person (21). Eventually, the inability to escape from an unfavorable situation due to the closure of escape routes, or the person's perception of the closure of these routes, leads to confinement, which causes a sense of inability to escape from an unfavorable situation when escaping is felt desirable (21). This confinement creates an unpleasant state for the person who tries to escape through suicide. Combining these characteristics causes the person to behave obediently in the target group; in fact, expressing failure can prevent other people with higher social status from attacking the failed person (9,22). The symptoms of this condition in animals are very similar to major depressive disorder in humans (22). As a result, these situations can both reduce the damage to the broken person by others and increase the likelihood of suicide; hence, if in the evolutionary process, the rate of the benefits of this state is greater than its losses, it can be chosen through natural selection (10).

10. Interpersonal Theory of Suicide: The interpersonal theory of suicide, which is the first theoretical model that separates the etiology of suicidal ideation from a suicide attempt, claims the thwarted belonging (a person's perception that he or she is not related to relatives, friends, and society in general) and the perceived burdensomeness (the feeling that a person is an extra burden to relatives and society) models and causes the person to conclude that his/her absence improves the others' situation (23).

This model borrows the perceived burdensomeness from de Catanzaro's (1980) theory, and two recent models, the Integrated Voluntary Motivation Model (21) and the Three-Step Suicide Model (4), have adapted these two models from the interpersonal theory of suicide.

11. Social Pain Theory: This model explicitly states that suicide is a by-product of Pain Adaptation Mode development (24); in fact, suicide results from our need to escape from this pain. This model notes that physical pain and pain from rejection or lack of social involvement are perceived and processed by precisely the same areas of the brain in the frontal lobe; as a result, this model claims that the rejection or lack of social involvement process is precisely selected by the areas in which physical pain is processed in an evolutionary and coherent process to inform the individual of the possible consequences of severe social rejection or lack of involvement.

A set of rejection and lack of involvement of a person over time and in the event of recurrence can lead to conditions of frustration and depression: a set of negative social cognitions (such as rejection) and suicidal cognitions such as

frustration, perceived burdensomeness, thwarted belonging, failure, and confinement can lead to social pain, which in turn intensifies negative cognitions and suicidal ideation. The result of social pain is a suicide attempt if the person has acquired the ability to commit suicide. This model states that as long as the pain is within the tolerable threshold, the person tries to escape from it, but when the pain reaches an unbearable threshold, the only way to escape from this condition is to attempt suicide (24). In general, this model states that suicide is a by-product of pain development rooted in areas of the brain that process the perception of physical pain (24).

12. Exposed to the Suicide of Family and Friends: About 21% of people witness the suicide of relatives, friends, or acquaintances during their lifetime (25). Suicide exposure increases the risk of physical illness and adverse mental health problems such as depression, anxiety disorder, and post-traumatic stress disorder (26). In addition, the destructive effects of exposure to suicidal behavior can expose some individuals, especially young people and adolescents, to suicide ideation and suicide attempts (27). A meta-analysis by Gilayev et al. (28) showed that exposure to parental suicide and suicide attempts were associated with an increased risk of suicide and suicide attempt in children. Another systematic review (29) reported that both coping with suicide and coping with suicide attempts depended on subsequent action-taking behaviors among friends and acquaintances.

13. Family Transmission of Suicidal Behavior: Suicidal behavior occurs in families. Some collaborative research suggests a family concentration of suicidal ideation and behavior. Longitudinal surveys on communities have shown that the history of suicidal behavior in the family is one of several occurrences of suicidal behavior in adolescents. Family studies cannot distinguish between genetics and environmental factors of this transmission. Suicidal behavior transmission can occur through pure genetic transmission (specific genes) and pure environmental transmission (patterning and abusing) or the interaction of these two factors (gene-environment interaction [GxE]). Adults who commit suicide have higher levels of suicidal ideation in their families. The suicide rate is higher in oocytes compared to dizygotic (30).

Genetic structure of suicide: Research on twins has shown that the heritability of suicide is about 45% (12,13); however, the severity of heredity varies with the type of mental disorder in people who attempt suicide, as 90% of those who attempt suicide suffer from some types of mental disorder (23). Studies of adopted children also show that they are as likely to commit suicide as their biological and physical parents, rather than the parents who raised them (13). Such evidence suggests that there are genetic mechanisms, in such a way that the blood relatives of adoptees who had a history of suicide were six times more likely than the control group (31) whether or not the adopted child had a mental disorder did not change this proportion. Family studies also support the idea that suicide is a gene-dependent phenomenon: the probability of suicide among the relatives of people with a history of suicide is five times higher than those who do not have a history of suicide (14).

Discussion

Evidence suggests that suicide may not have occurred in the evolutionary cycle of a random gene mutation or environmental factors. There are three reasons for claiming that suicide is not a Noise: 1. Suicide, unlike behaviors that result from an accident, does not exist in a limited geographical area but occurs in all parts of the world; 2. Suicide, in contrast to the specific characteristics that occur randomly and have no effect on the success of reproduction, reduces the likelihood of reproduction in individuals; 3. One of the characteristics that arise as a result of an accident is that most of them are accidental and transient, while credible evidence indicates the recurrence of suicide in humans' evolutionary history (10). On the other hand, some researchers consider suicide to be a direct product of evolution; according to this group of researchers, suicide due to altruism and reduction of individual burden on relatives and society has its roots in our evolutionary history so that it could have played an adaptive role and been passed on to the next generation of the gene pool through natural selection (32). However, there are four types of criticisms of this view: 1. Confrontation with scientific findings, 2. Lack of causal relationship between overburdening and suicide attempt, 3. Confrontation of the risk of

proportionality and the resulting cost of being more rational to kill (murder) as a more appropriate way to reduce burdensomeness, and 4. Lack of an evolved mechanism or system that demonstrates the ability of relatives to determine the fertility of relatives, the extent to which relatives participate in activities, or even environmental capacities (9,10). Therefore, in order for a person to increase suicidal ideation and gene transfer by relatives through committing suicide, s/he must first be able to monitor and measure the condition (33). On the other hand, most researchers have accepted that suicide is an unfortunate by-product of a separate adaptation (9,12,21,24). However, this compatibility itself is not precisely defined; for example, suicide as a by-product of the social function of mental or emotional pain (24), behavioral learning and flexibility (34), the ability to think (35), and predicting the future and even consciousness (36) are some suggested cases. However, the evidence generally supports that suicide is an evolutionary by-product of pain. However, it is essential to note that pain alone cannot explain the whole suicidal behavior and that suicide may result from the complex co-evolution of humans' many cognitive and biological mechanisms. In general, pain motivates action because pain is inherently an unfavorable and adverse phenomenon; therefore, the appropriate action to manage it escapes (37). Research has shown that severe pain can restrict higher cognitive activities such as thinking because the only motivation is to stop the pain (37). The nature of pain makes it so crucial for survival, as it triggers immediate action with a long-lasting effect that warns living things from re-encountering that stimulus and source of pain. As a result, suicide can be a detrimental product of this evolved system; in fact, perceived pain warns that the source of pain must be confronted, but sometimes the urgent need to get rid of the source of pain outweighs it and leads to suicide (38). The model of social pain presupposes that suicide is the product of evolutionary adaptation to escape the pain. Social pain is an annoying condition that a person tries to escape by committing suicide.

For those who have suicidal cognitive schemas and have reached a suicidal crisis, this pain may reach a vulnerable point where they commit suicide as a means to escape that pain. Under such circumstances, a person may attempt suicide to escape the pain of rejection and isolation from society (20).

The advantage of this theory is that if we say that social pain is a motivator of suicidal behavior, then trying to reduce the experience of social pain can be a powerful deterrent to suicidal behavior (20). Individual psychotherapies may seek to strengthen and empower social bonds, which can have a supportive effect. Cognitive-behavioral techniques may also be used to emphasize suicide-related cognitive distortions and negative social assessments (39).

Conclusion

In general, the evidence suggests that suicide is probably not the product of a random gene mutation or a direct product of the natural selection process but is likely to be a harmful by-product of a highly evolved and efficient pain mechanism, which due to its dependence on this efficient mechanism of pain, despite the evolutionary pressure, it remains.

However, studies show that different models can diagnose the etiology of different types of suicide attempts.

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