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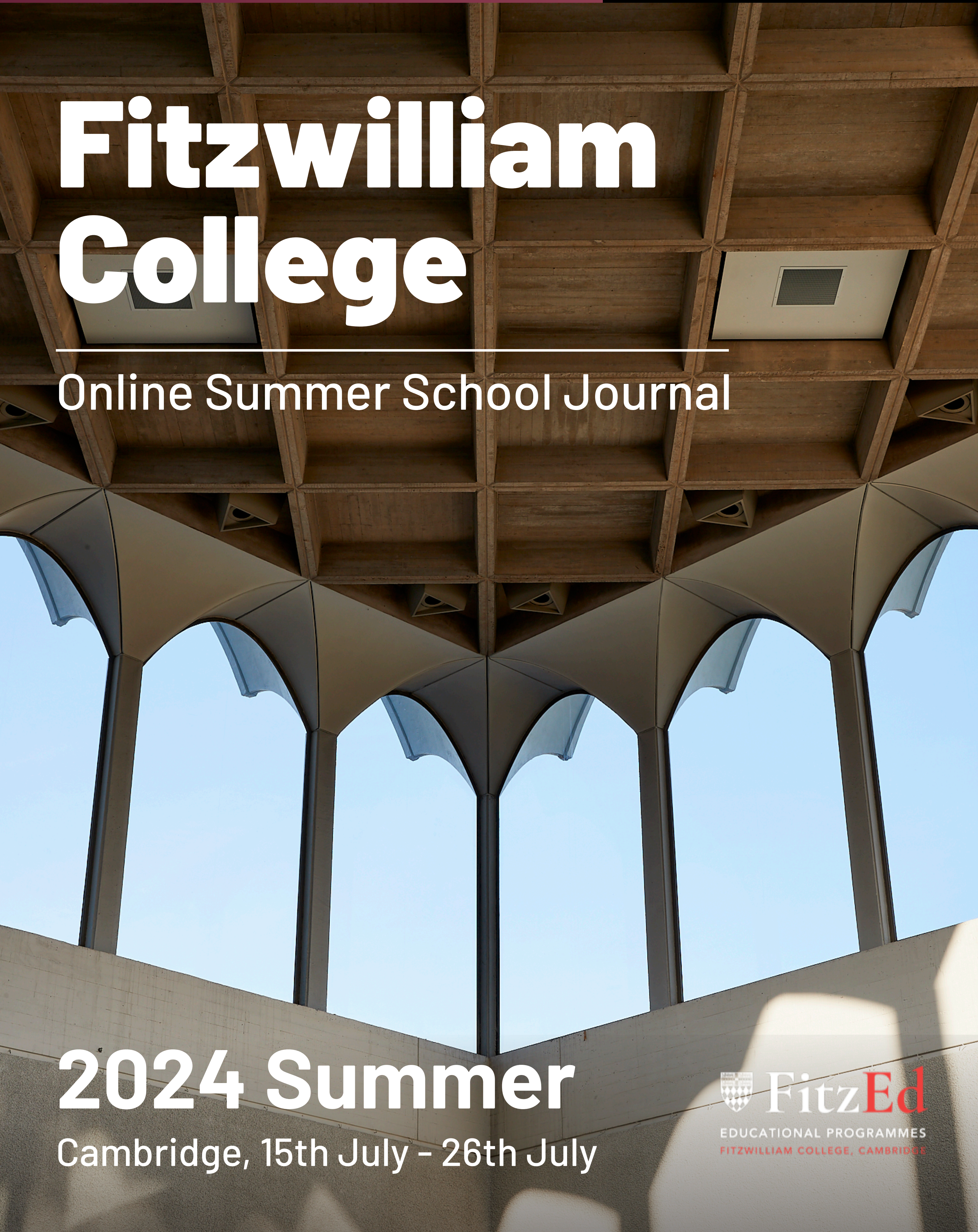

Fitzwilliam College

Online Summer School Journal

2024 Summer

Cambridge, 15th July - 26th July

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Biology

Fitzwilliam College Online Summer School Journal · 2024 Summer

Fixation in Non Legume Crops: Techniques and Innovations

DAKAI ZHANG(DK)

Abstract

Legume plants and the nitrogen fixation bacteria in root nodules are widely known as an important participant in the nitrogen cycle. However, legumes may not always be the most efficient or the most economically profitable crop to plant, so a substitution will be required. As most plant species do not possess the ability to develop nodules for symbiosis, bioengineering them could create an alternative to legumes. These engineered plants could enable agriculture production to have for flexible crop plannings, and provide an organic solution to the increasing price of nitrogen ferterlizers. This essay focus on the natural symbiosis in legumes ,the current progress of bioengineering and its possibility of creating symbiosis in non-legume plants.

1. Nitrogen fixation and the role of bacteria

Being one of the crucial nutrients limiting plant growth, nitrogen is typically provided by synthetic fertilizers or biological nitrogen fixation(BNF),particularly by legumes.[Nag *et al*.,2020] The process of nitrogen fixation will convert gaseous nitrate compounds into solid nitrate ions, which can be supplied to plants as a source of nutrient.[Masclaux-Daubresse *et al*.,2010]

The fixation is not finished by plants alone: symbiotic bacteria in a structure called nodule actually converts nitrogen gases into compounds., making then the facilitators of the process. There are genes functioning for the formation of nodules[Huisman&Geurts 2019]. Understanding the position and structure of such genes will be essential for our goal, as they are exactly the genes we plan to transfer. By bioengineering bacteria and plants, an artificial symbiotic system aimilar to a natural one will grow fully in the root on non-legume crops, which enhances the nitrogen fixation in them.

2. Current progress of bioengineering bacteria

The engineering will involve both plants and bacteria for the project, but altering the genes of bacteria is especially efficient due to the use of plasmids, as the plasmids enable avoiding the complex process involving the loops of DNA that act as'nucleus' and simplify the genetic alteration process by bypassing the complexities of the bacterial chromosome. Therefore, the usage of engineered bacteria can be found in various fields: they have been used for cancer treatment [Nguyen *et al*., 2023],bio production[Jiang &Chen 2016],and DNA detection[Kalus O 2022]. There are also cases of engineered bacteria usage in sustainable agriculture, in which methylotrophic bacteria is applied to fortify plants[M.Kumar *et al*.,2016]. It will be easier to adjust genes in bacteria that are already used in agriculture, especially for soybean root associated microbes that are already used to restore soil nutrients.[Ayilara *et al*.,2023] Usage of these bacteria will avoid the risk of putting new untested species into use, and save the effort for finding close relatives in taxonomy. With the bacteria engineered and prepared to breed , the main effort will focus on the plants and the formation of artificial nodules.

3. Current progress of bioengineering plants

The process of altering genes manually in plants is named as genetic transformation. The two main approaches of genetic transformation is Agrobacterium mediated gene delivery(direct) method, as well as external force mediated ways(indirect) method. [Su *et al*,.2023]. Both methods will prove useful to this project. In the direct method, Agrobacterium tumefaciens is applied as a powerful tool to deliver genes of interest into a host plant. [Azizi-Dargahlou *et al*,.2023] Inside the plant nucleus, the transferred DNA is capable of integrating into the plant genome for inheritance to the next generation and therefore forms stable transformation. For the indirect method, molecules can be bombarded through cell wall or be transmitted through pollen tubes. In either way, biomolecules containing genetic information will be sent into the cells and alter the previously existing genetic materials. With this technology, the specialized genes for nodule formation can be sent into non legume plants and artificially form an environment for root bacteria to grow in.

4. More practical information about genetic engineering

Genetic engineering is the use of molecular biology technology to modify DNA sequence(s) in genomes, using a variety of approaches [T. Lanigan,2020]. This is what we will really use to recreate symbiosis artificially. The most elegant and effective method is technology of genetic engineering currently is based on guided endonucleases, because these can target specific DNA sequences. The engineering processes also rely heavily on the technologies of restriction enzymes, DNA sequencing, and DNA cloning to cut off and insert certain lengths of DNA. All these techniques mentioned will be used to engineer our crops with nodules. Another useful technology ,knockins ,can be used to block gene function by inserting fluorescent reporter genes such as eGFP or mCherry, in such a way as to knock out the gene at the insertion point. This will be used to prevent the growth of unwanted structures in the roots. It is also believed that nanotechnology-based gene-delivery methods can be applied for plant genetic transformation [Yan *et al*,.2022] If this theory comes to reality, it will be a method with excellent transformation efficiency, good biocompatibility, adequate protection of exogenous nucleic acids, and the potential for plant regeneration.

5. The impact to real life agriculture production

The artificial structure of nitrogen fixation symbiosis in non-legume plants will benefit both economically and environmentally. They will enable farmers to arrange their crop cycles much more freely since they no longer need to arrange beans every cycle. They will also allow Maintaining economic production and nitrogen fixation at the same time, since the most economically profitable crops can fix nitrogen and fertile the soil by themselves. These crops will also be able to react to market pull arising from increasing awareness of health and global sustainability issues with their ability to organically provide nutrients for themselves. If we look at the bigger picture, the progress we have in bioengineering may also be applied to other related subjects. For instance, after succeeding in engineering wheat , it will be possible to use the same or similar process to engineer peach trees or peanut plants to further apply the technique in the agriculture industry. It might also be possible to adjust plant roots to gain a higher surface area for absorption.

6. Summary

With the increasing price of nitrogen fertilizer and increasing awareness of sustainable agriculture, letting the symbiosis with nitrogen fixation bacteria occur on non-legume plants will numerous benefits to agriculture production. There are a variety of methods to engineer the genes of plants and bacteria. With the correct choice, we will be able to maintain economic profits, fertilize soil organically and preserve the quality of soil at the same tine.

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Microbial Modulation of Host Immune Responses and Its Effects on Pathogens: the Case of *Lactiplantibacillus Plantarum*

SU BU (Tanya)

1. Introduction

Lactiplantibacillus plantarum (Lpb. plantarum) is a Gram-positive, non-spore-forming (Actor *et al.*,2012), and facultatively heterofermentative rod-shaped probiotic (Ibrahim *et al*., 2016). As one of the most versatile species among the lactic acid bacteria (LAB), it can thrive in ecological niches with different pH levels and oxygen conditions, such as the gastrointestinal tracts, dairy products, plants, and fermented foods (Garcia-Gonzalez *et al.*, 2021). Moreover, *Lpb. plantarum* has been frequently researched for its immunomodulatory abilities on hosts. Immunomodulation refers to the alteration and balance of enhancing and suppressing immune function. Its pro-inflammatory effects can potentially tackle immunosuppressive diseases (Wang *et al*., 2022). Whereas, the anti-inflammatory effects of *Lpb. plantarum* aim to reduce inflammation and prevent infections (Tian *et al*., 2023).

Understanding the immunomodulatory function of *Lpb. plantarum* is essential when discussing immunosuppressive diseases, which refer to the reduction of the activation or the efficacy of the immune system, resulting in immunodeficiency (Anon., 2023). According to recent statistics, 6.6% of American adults are estimated to have immunosuppression, which is twice as high as the prevalence in 2013 (Martinson, 2024). Additionally, the proportion of adults with systemic inflammation is 34.63% (G.Mainous III *et al*., 2024) and 3 out of 5 people die due to chronic inflammatory diseases (Pahwa *et al*., 2023). Therefore, investigating the immunomodulatory effects of *Lpb. plantarum* is of significant importance for developing potential treatments for these conditions.

2. Immunomodulatory abilities of *Lactiplantibacillus plantarum* : the mechanism and results

The underlying mechanism and effects induced by *Lpb. plantarum* is essential to understand when evaluating the immune-modulatory responses of *Lpb. plantarum*. The anti-inflammatory and pro-inflammatory effects (Hao *et al*., 2023) of *Lactiplantibacillus plantarum* are induced via the interaction of bacterial surfaces such as lipoproteins and lipoteichoic acid (Kim *et al*., 2021) with pattern recognition receptors – the toll-like receptors (TLRs) on immune cells such as macrophages. A high-level expression of TLRs can be found during the activation and bridging of adaptive and innate immunity (Carturan *et al*., 2014) – two stages of the immune system.

The key TLR -- TLR2 triggers a signalling pathway that is one of the main pathways to maintain immune homeostasis and it can only be activated with the presence of TLR1 or TLR6 (Fidanza *et al*., 2021). N-terminal domain makes up an ectodomain that serves as a recognition site (Syed Sameer *et al*., 2021), to enable ligand recognition and binding -- the first stage of TLR2 signalling pathway. As suggested in Figure 1 (Syed Sameer *et al*., 2021), when TLR-2 forms heterodimers with TLR-6, they can bind to diacyl lipopeptides, lipoteichoic acid, lipoproteins, zymosan, porin, atypical LPS, and peptidoglycan. The TLR-2/TLR-1 heterodimers can bind to triacyl lipopeptides (Colleselli *et al*., 2023). The toll-interleukin-1 receptor-domain-containing adaptor protein (TIRAP) is needed for TLR2/TLR1 and TLR2/TLR6 heterodimers to trigger downstream MyD88 signalling (de Bono, 2005). MyD88 is an essential adapter protein that links TLRs to the IL-1R-associated kinase (IRAK) family via homotypic interaction (Deguine *et al*., 2014). Once IRAK4 is successfully recruited and complexed with MyD88, it undergoes phosphorylation to trigger the autophosphorylation of IRAK1. MyD88 also facilitates the recruitment of IRAK2 to the TIR domain. IRAK1 is now able to recruit the ubiquitin ligase tumour necrosis factor receptor-associated factor 6 (TRAF6), which leads to the entrance of the nuclear factor kappa-light-chain-enhancer of activated B cells (NF-κB) pathway (Pennini *et al*., 2013). Pro-inflammatory cytokines are produced at the end of the NF-κB pathway after the degradation and phosphorylation of inhibitory kappa kinase (IKK)α, IKKβ, and IKKγ as illustrated in Figure 2 (Fidanza *et al*., 2021). Anti-inflammatory cytokines can also be produced via the phosphoinositide 3-kinase (PI3K)/protein kinase B (Akt) pathway, which is shown in greater detail in Figure 3 (Shi *et al*., 2019).

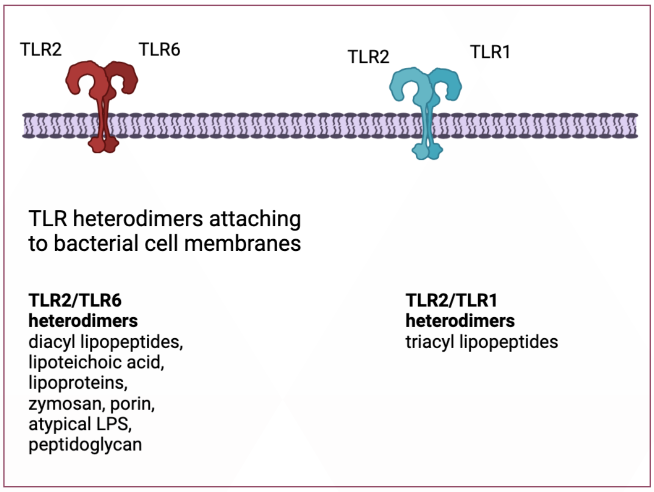

Figure 1: Recognition and binding of pathogen-associated molecular patterns (PAMPs) by various TLR heterodimers. TLR2/TLR6 heterodimers can bind to diacyl lipopeptides, lipoteichoic acid, lipoproteins, zymosan, porin, atypical LPS, and peptidoglycan. TLR2/TLR1 heterodimers can bind to triacyl lipopeptide. Figure was created with BioRender.com on data adapted from Syed Sameer *et al*., (2021).

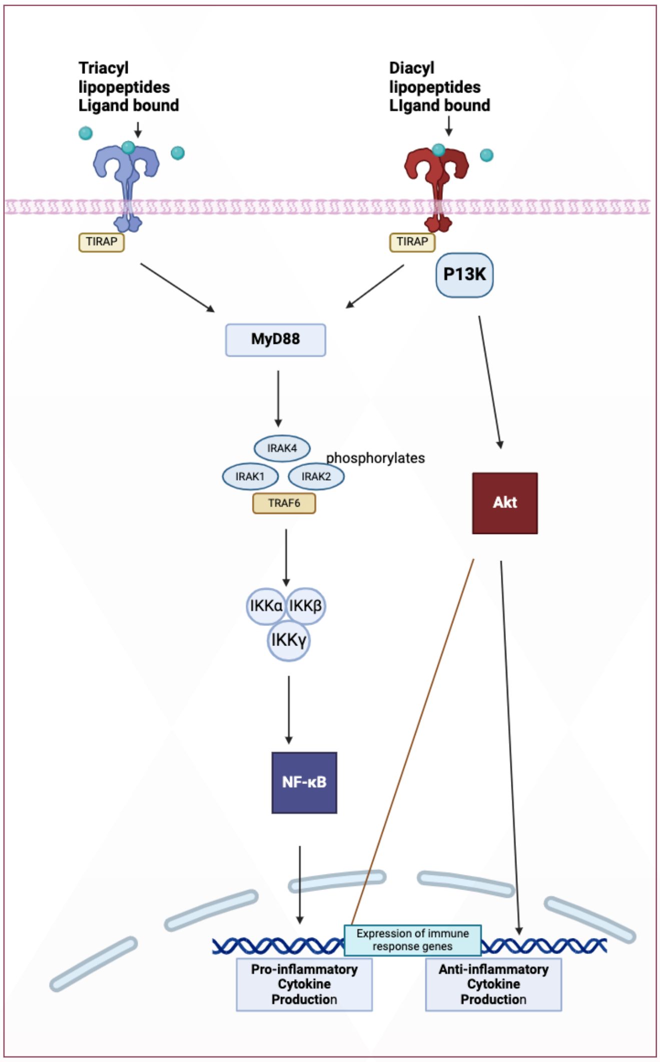

Figure 2: Schematic diagram of TLR2 signalling pathway. Figure was created with BioRender.com on data adapted from Fidanza *et al*., (2021). It presents a visual overview of the steps in TLR2 signalling pathway.

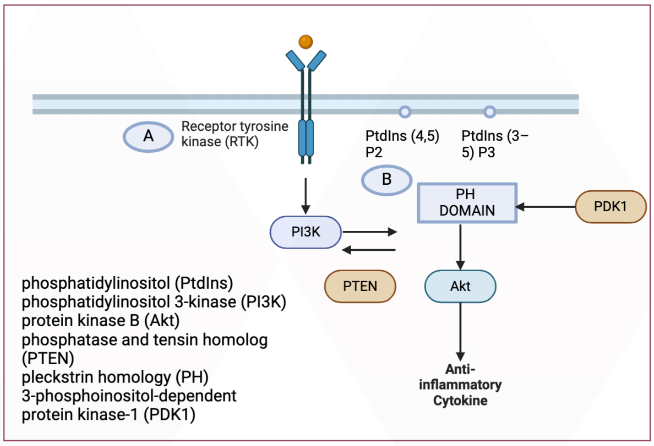

Figure 3: Schematic diagram of the PI3K/Akt signalling pathway. (A) RTK recruits PI3K after activation and phosphorylation; (B) PtdIns (4,5) P2 to PtdIns (3–5) P3 activates Akt by recruiting PDK1 to the PH domain of Akt. Figure was created with BioRender.com on data adapted from Shi *et al*., (2019).

The main pro-inflammatory cytokines produced by the TLR2 signalling pathway are interleukin (IL)-1, IL-6, IL-8, and tumour necrosis factor-alpha (TNF-α) (Czaja, 2017). Whereas, the main anti-inflammatory cytokines produced are IL-10 and transforming growth factor-beta (TGF-β) (Czaja, 2017). Ren and colleagues have collected data on the production of IL-6 and IL-10 to investigate the immune-modulatory capacities of various bacterial strains (Ren *et al*., 2016). As shown in Figure 4, *Lpb. plantarum* has resulted in the highest production for both IL-6 and IL-10, which has proven its strong immune-modulatory capacity and ability. Moreover, the strain *Lpb. plantarum* CIRM653 has significantly increased the production of IL-10 on *Klebsiella. pneumoniae*-infected dendritic cells according to research conducted by Vareille-Delarbre and colleagues, shown in Figure 5 (Vareille-Delarbre *et al*., 2019).

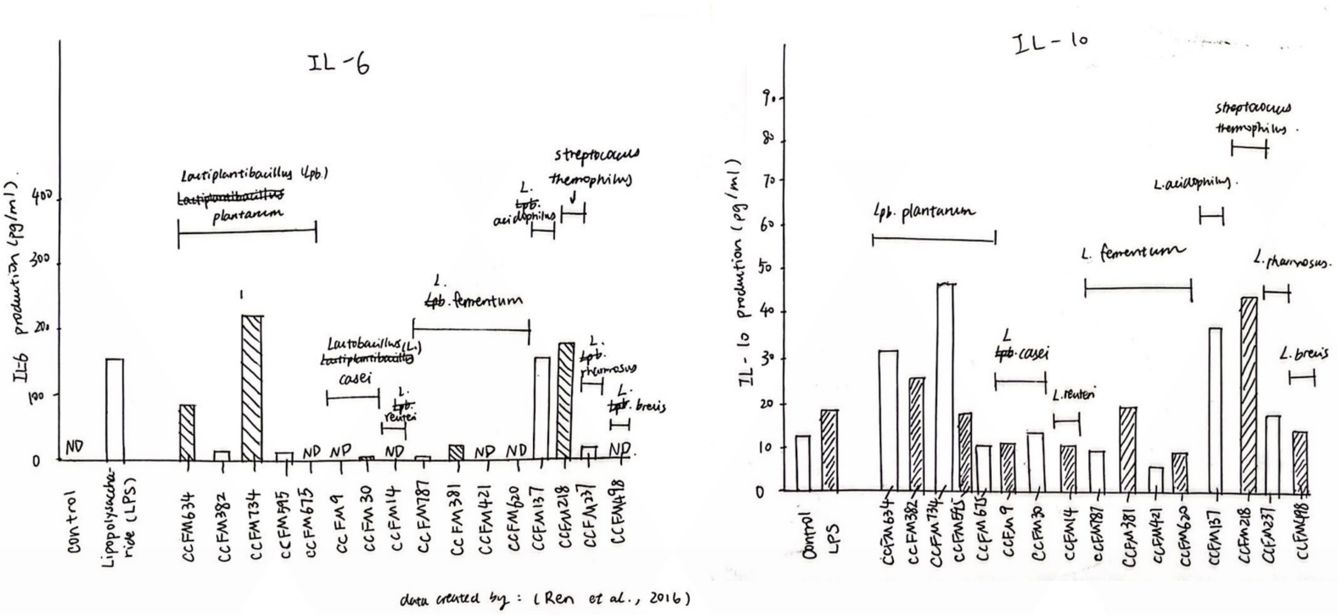

Figure 4: Cytokine production in phorbol 12-myristate 13-acetate (PMA)-stimulated tohoku hospital pediatrics-1 (THP1) macrophages of various LAB species, including *Lpb. plantarum*.

PMA-stimulated THP1 macrophages were treated with different bacteria (bacteria to cells ratios of 40:1) or 1 µg/ml LPS (positive control) for 24 h. Untreated THP1 macrophages served as negative control. ND refers to not detectable (Ren *et al*., 2016). Strain *Lpb. plantarum* CCFM734 resulted in the highest production of IL-6 and IL-10 compared to other strains of LAB species: *Lactobacillus casei, Lactobacillus reuteri, Lactobacillys fermentum, Lactobacillus acidophilus, Streptococcus thermophilus, Lactobacillus rhamnosus, and Lactobacillus brevis*. Figure was handwritten on data adapted from Ren *et al*., (2016).

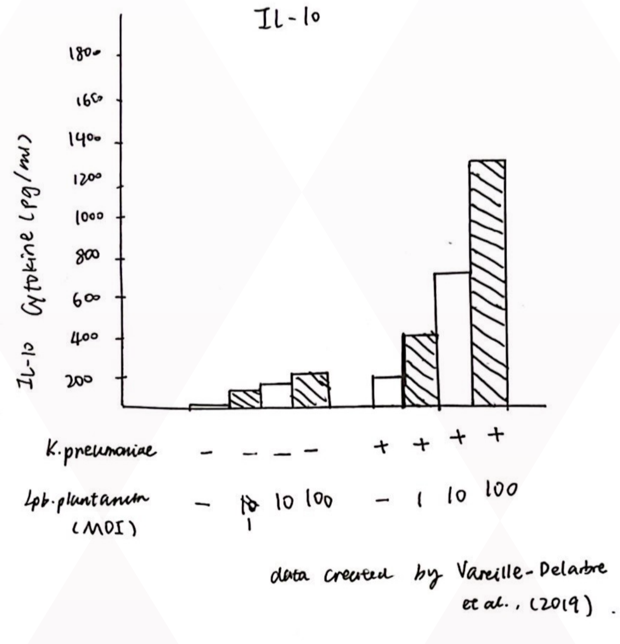

Figure 5: Effect of *Lpb. plantarum* CIRM653 on response of *Klebsiella. pneumoniae*-infected dendritic cells. MOI refers to multiplicity of infection. Human monocyte-derived dendritic cells were exposed to UV-inactivated *K. pneumoniae* (MOI of 10) and UV-inactivated *Lpb. plantarum* CIRM653 (MOI of 1 to 100) for 48 h. Results showed that coinfection of *Klebsiella. pneumoniae* with *Lpb. plantarum* CIRM653 has an increased IL-10 production in a dose-dependent manner compared to normal dendritic cells (Vareille-Delarbre *et al*., 2019). Figure was handwritten on data adapted from Vareille-Delarbre *et al*., (2016).

3. Ability to inhibit the growth of pathogens: food-borne pathogens including *Escherichia coli* (*E. coli*)

Lpb. plantarum's ability to inhibit the growth of various pathogens has been under-researched for decades, as it could develop possible vaccines and treatments against assorted diseases. As mentioned previously, *Lpb. plantarum* CIRM653 produces anti-inflammatory cytokines when co-infected with *Klebsiella. pneumoniae*, which has suggested its potential ability to reduce respiratory tract infections. This section assesses its ability to inhibit food-borne pathogens.

Carvalho and colleagues (Carvalho *et al*. 2021) discussed the effect of pre-established *Lpb. plantarum* biofilms on the adhesion of *E. coli* to urinary tract devices (UTDs). Confocal laser scanning microscopy (CLSM) and determination of culturable cells have taken place to observe *Lpb. plantarum*'s influence on *E. coli*. Results showed that *Lpb. plantarum* biofilms have strikingly reduced the culturability of *E. coli* by 76%, 77%, and 99% after 3,6, and 12 hours, respectively (Carvalho *et al*., 2021). The bactericidal effect of *Lpb. plantarum* is largely due to its ability to produce hydrogen peroxide (Wasfi *et al*., 2018). Albeit *E. coli*'s tolerance to a low concentration of intracellular hydrogen peroxide, it will cease its functionality due to the denaturation of enzymes once the concentration hits 50 nM (Ravindra Kumar *et al*., 2013).

Moreover, the probiotic strain *Lpb. plantarum* LZ206 presents to have antimicrobial activity, as a gene cluster that is responsible for bacteriocins biosynthesis – the plantaricin gene cluster is identified after complete genome sequencing conducted by Li and colleagues. This strain can be potentially used to inhibit the growth of assorted food-borne pathogens, such as Gram-positive bacteria (*Staphylococcus aureus* and *Listeria monocytogenes*), Gram-negative bacteria (*Salmonella enterica*), and fungus *Candida albicans* (Li *et al*., 2016). The strain *Lpb. plantarum* KJB23 has presented similar antimicrobial activity towards various species of gastrointestinal tract pathogens. The antimicrobial metabolites produced create an acidic environment, which interrupts the conservation of pathogens' membranes (Kavitha *et al*., 2020).

Thus, the ability of *Lpb. plantarum* to inhibit the growth of pathogenic bacteria has led to a promising use of it being a food preservative, to increase the safety and shelf-life of fermented foods and dairy products (S. Behera *et al*., 2018).

4. Conclusion and Future Prospects

This review essay discussed the mechanism of TLR2 signalling pathway to assess the anti-inflammatory and pro-inflammatory cytokines production by *Lactiplantibacillus plantarum*. The immunomodulatory ability and capacity of *Lpb. plantarum* stood out among other LAB species, which can be potentially utilised for the development of recombinant vaccines. Following the outbreak of SARS-CoV-2, Villena and colleagues have attempted to use *Lpb. plantarum* as a potential adjuvant and delivery system for the development of SARS-CoV-2 oral vaccines (Villena *et al*., 2021). This essay has also reviewed *Lpb. plantarum*'s ability to inhibit the growth of food-borne pathogenic microorganisms and its bio-preservative properties are commonly applied in food industries. There is more research evaluating the various strains of *Lpb. plantarum* on its antifungal, antiviral, and anti-allergic activity (Abdelazez *et al*., 2018). In conclusion, *Lactiplantibacillus plantarum* plays an important role in modulating human immune functions and presenting bactericidal effects against pathogens.

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02

Mathematical Economics

Fitzwilliam College Online Summer School Journal · 2024 Summer

Economics and the Environment

RUHAN ZHAO (Jake)

1. Introduction

With the rapid development of technology, the environment has been badly damaged by economic activity. Activities such as power generation, chemical processing and construction lead to high amounts of pollution, contributing to global warming and ultimately leading to climate change. Environmentalists are concerned about existential risk – the threat of human extinction. This article discusses relationship between climate change and existential risk, the relationship between economic activity and environmental damage, policies used to reduce pollution.

2. What are existential risks

Existential risks are the threats of human extinction (Conn, 2015). There are mainly two types of existential risks: natural risks, including extreme weathers and natural disasters, and anthropogenic risks, which are the threats posed by human activities. Such threats include epidemics, wars and climate change (Huggle, *et al*., 2022). We shall focus on the impact of climate change. Climate change is due to rising global temperatures, which arises from business activities such as power generation. The consequences of climate change include rising sea-levels, extreme weathers and disruptions in natural ecosystems due to the extinction of species. Natural ecosystems play a crucial role in the economy. They act as resources for genes, food, medicine and fuel (Phil, n.d.). When such resources are used up, economies might be disrupted. Species will find it harder to adapt to the rising temperatures and go extinct. Moreover, climate change could lead to a cycle. As temperatures rise, humans will use technologies such as air conditioning to lower the temperature indoors, but the overall temperature would rise even more.

3. The relationship between economic activity and environmental damage

Since the industrial revolution, global incomes have drastically increased, which indicates increased economic activity and more advanced technologies. Comparing the graphs of global temperatures (Figure 1) with world incomes (Figure 2), it is suggested that global temperatures rise as economic activities increase.

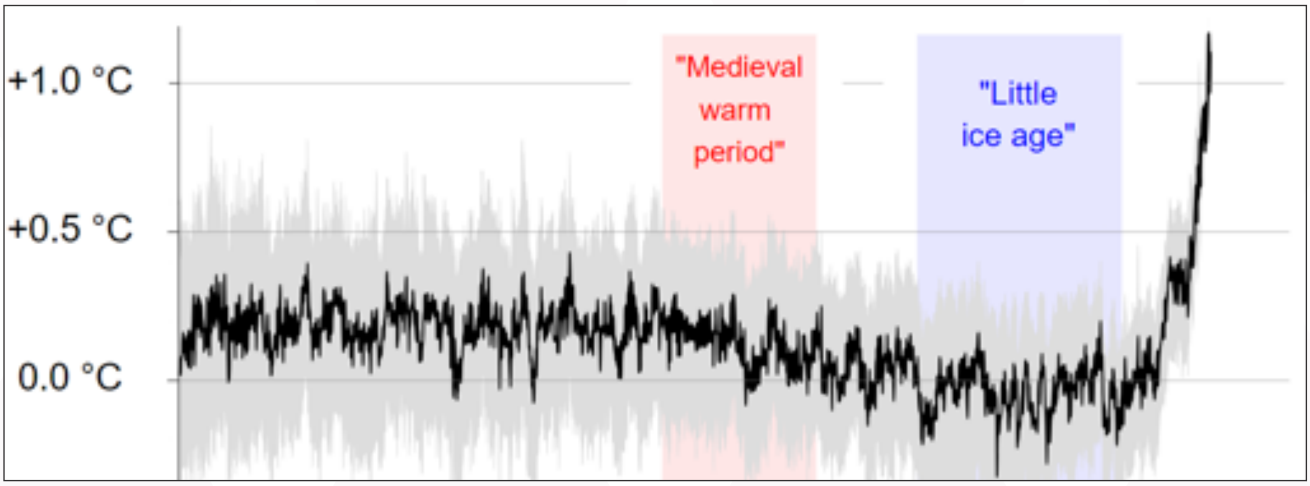

Figure 1: Global temperatures over the past 2000 years (Hawkins, 2024)

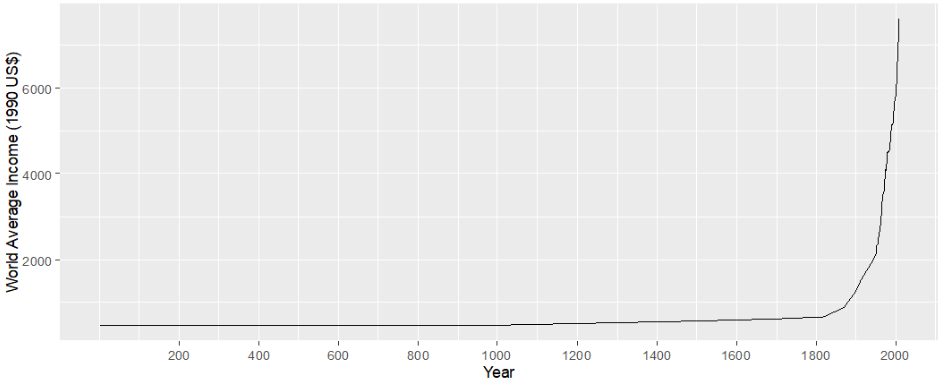

Figure 2: World average income over the past 2000 years. Data source: (Maddison, 2009)

There exist some possible trade-offs between economic activity and protection of the environment (Jones, 2017). This is because business activities typically involves many polluting processes including chemical processing, power generation and resource extraction. Such processes release pollutants such as carbon dioxide, raising the greenhouse levels in the atmosphere. The higher greenhouse levels traps heat. Thermal energy from the sun in the form of infrared radiation gets trapped in earth's atmosphere, leading to rising global temperatures (Costa, et al., 2023).

4. The use of cost-benefit analysis

Economists can use the cost-benefit analysis to evaluate the effectiveness of climate policies. It compares the costs and benefits of a certain policy by assigning monetary values to them (Stobierski, 2019), which helps to choose the most appropriate policy. A monetary value for pollution, the leading cause of global warming, can be estimated by considering the monetary costs of pollution control measures.

COSTS	CAPITAL COSTS one-time large purchases	OTHER COSTS	ANNUAL REVENUE COSTS recurring expenses	ANNUAL CAPITAL COSTS
Home Office Infrastructure Setup	6,000			6,000
Server	2,000			2,000
Server Maintenance	1,800		1,800	3,000
Software	2,000		200	2,200
Training	10,000		800	10,800
Remote Support	28,000		28,000	80,000
Headsets	1,000		200	1,200
Laptops	18,000	1,000	2,000	18,000
Home Office Furniture	16,000			16,000
TOTAL COSTS	$74,500	$1,000	$29,400	$108,900

BENEFITS	CAPITAL SAVINGS	OTHER SAVINGS	BENEFIT SAVINGS
Increased Staff Retention	11,000	4,000	15,000
Rent Savings	36,000		36,000
Utility Savings	12,000		12,000
Food Services Savings	9,000		9,000
Office Equipment Savings		2,000	2,000
Tax Savings	15,000		15,000
TOTAL SAVINGS	$83,000	6,000	$89,000

Table 1: Cost benefit analysis example

Table 1 shows an example of cost-benefit analysis. It shows the net value for the benefits and costs and allows comparisons of the benefits of discounted and undiscounted flows. Cost-benefit analysis can be used to decide whether certain policies should be implemented.

5. Policies used to control pollution

According to the Environmental Kuznets Curve, environmental pollution increases with income per capita up to a turning point after which pollution falls with income per capita (Pettinger, 2019). Income per capita represents a country's economic activity which is affected by the technological advances of a country. In the short term, there are two ways to reduce pollution. If a country's income per capita is far below the turning point (usually developing countries), it is recommended to implement policies that discourage economic activity. If a country's income per capita is closer to the turning point (usually developed countries), policies that encourage economic activities should be implemented.

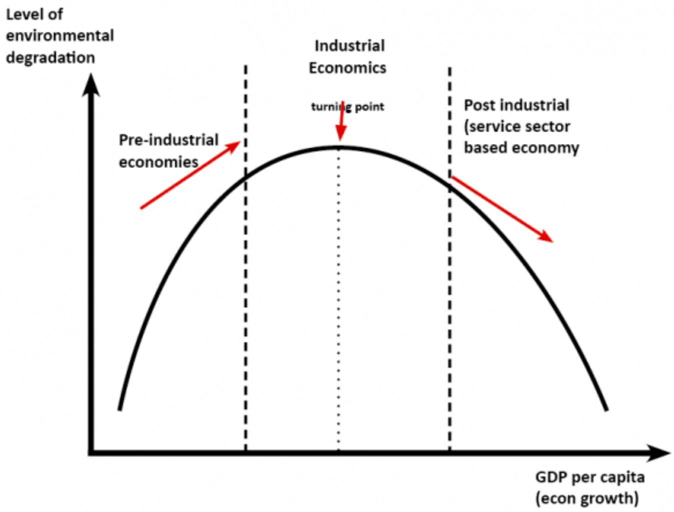

Figure 3: Environmental Kuznets Curve, (Kharitonov, Zakharchuk, & Mei, 2023)

There are several policies which can be used to encourage and discourage economic activity.

6. Fiscal policy

Fiscal policy refers to decisions about government spending and taxation (Jones, 2017). To discourage economic activity, contractionary fiscal policy can be used, which includes lowering government spending and increasing tax rates. Higher value-added tax on goods and services that create lots of pollution, such as cars, will increase the prices for consumers. The consumption of such goods and services will fall, which could lead to less pollution. To encourage economic activity, expansionary fiscal policy can be used, which promotes economic activity by lowering tax rates and increasing government spending.

7. Monetary policy

Monetary policy is the use of interest rates to control aggregate demand (Jones, 2017). To discourage economic activity, contractionary monetary policy can be used, which involves increasing interest rates. This increases the costs of borrowing and the rewards of saving, so consumers will spend more and save less. In the short term, consumption of polluting goods and services will reduce and thus reduce pollution levels. To encourage economic activity, expansionary monetary policy can be used, which involves reducing interest rates. This reduces costs of borrowing and rewards of savings, so consumers will spend less and save more in the short term.

8. Supply-side policy

Supply-side policy involves methods to affect supply (Jones, 2017). This could pollution permits and subsidies. Governments can implement such measures to directly reduce pollution. By setting pollution permits, which is the maximum amount of pollution firms are allowed to produce, firms might reduce pollution as they need to pay fines if they exceed the pollution limits. However, pollution levels could be hard to monitor as firms could dispose their waste secretly. Governments could also give subsidies as financial support to firms for investment in greener technologies.

9. Choosing the best policy

To summarize, I have suggested four different policies: fiscal policy, monetary policy, introduction of pollution permits and subsidies. Among those policies, the use of subsidies seems the most appropriate one. Fiscal policy and monetary policy mainly affect the consumption of non-environmentally friendly goods and services, which only works in the short term in reducing pollution. Pollution permits are hard to monitor and firms might still pollute. Subsidies can support the long term development of green technologies, which could reduce global warming and thus reducing the existential risk posed by climate change.

10. Conclusion

In conclusion, I have defined what existential risks are, the cause of climate change, the relationship between global warming and economic activity and suggested policies such as the use of subsidies to reduce pollution.

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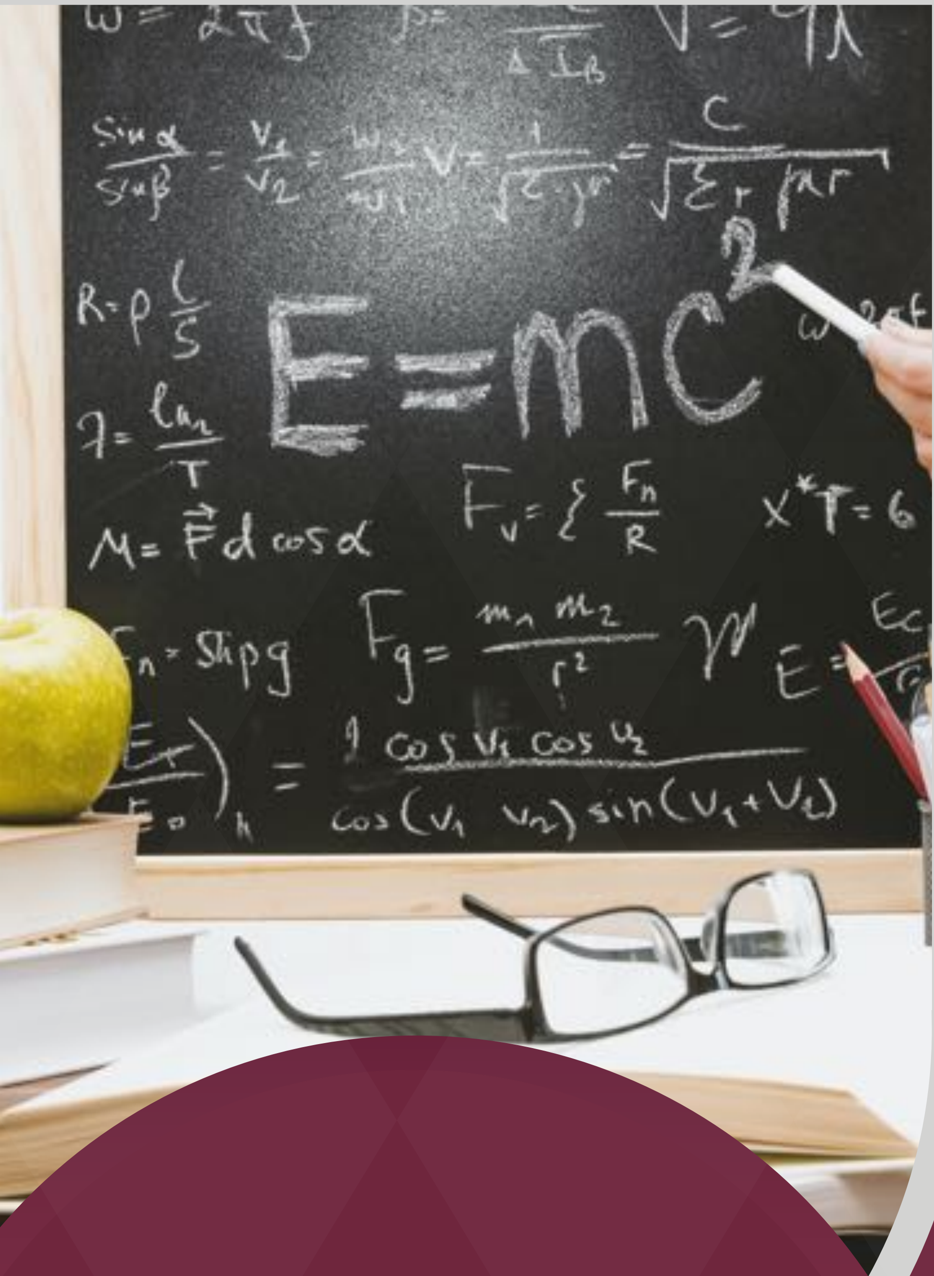

03

Physics

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The Study of the EPR Paradox

YIFAN CAO (Sinba)

Introduction: This passage aims to talk about the Einstein-Podolsky-Rosen paradox and the effects that they have caused. This is a paradox that started by the three people and against another famous physicist Bohr and his so called Copenhagen school's quantum theory. The paradox questions if the quantum mechanics provides a complete description of physics reality, and it was built on two assumptions, which are the principle of realism and the principle of locality is correct.

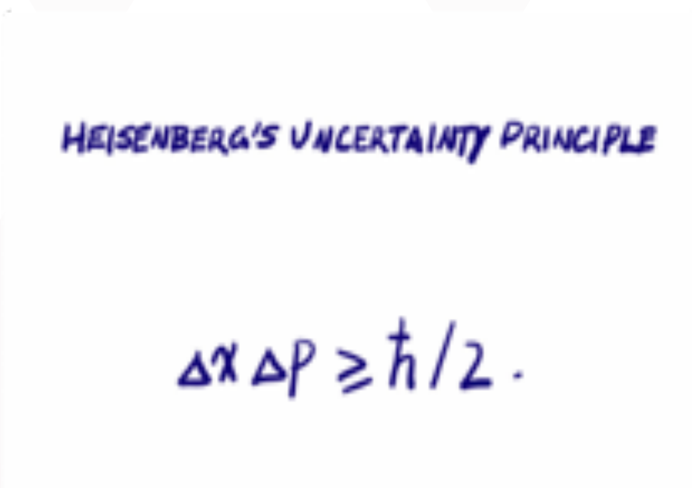
Before getting started into the famous EPR paradox, we will first discuss a little bit about both Einstein and Bohr's theories.

Let's take a look at the famous quantum theory first, after Tomas Young did his famous two-slits interference experiment, some physicists tried to do the same experiment with beams of electrons instead of light, and they got a very surprising result. The electrons shows the exact same interference patten as the light. Then, they tried to pass the electrons one by one, even though one electron could only form one single light dot on the light screen, when the number of electrons increased, the interference patten showed up again.

This result seems to be very confusing, does it mean that the electron is a kind of wave? What is even more surprising is that when the physicists tried to measure if the electrons could pass through one side or the other, the interference patterns kind of "magically " disappeared.

This surprising result soon led to a great number of discussion. Some physicists at that time even thought that electrons indeed are a kind of wave! Now we have known that the electrons are certainly not a kind of wave. However, the function of the possibility of where it falls behaves exactly like a wave, which can be expressed by the famous Schrödinger equation. When the electrons pass through the slit and eventually fall on some part of the screen, the wave function collapse and the possibility suddenly becomes one. So we can not get the same interference patten after putting a detector at one of the slits. Because after the function of possibility collapsed, the electrons no longer behaves like a wave. This means that we can never obtain the result of a particle even if we know everything about it, we can only calculate it's possibility, and "a particle's properties do not have definite value before measuring." since it is just a function of possibility.

This is simply shocking and hard to accept, because at that time before the quantum theory was discovered. The Newtonian physics could literally explain everything that happens. If with the calculation needed, we think that we can know what will going on exactly next day, month or even year! However, after the discovery of quantum physics, we have found that we can no longer predict precisely about what will happen exactly about a particle since the behavior of it before the measuring means nothing but simply a function of possibility.



However, what is even harder to accept has yet to come. In 1927 the German physicist Heisenberg gave his famous principle of uncertainty, which is shown in the figure on the left.

As you can see, this equation suggests that if we know everything about the position of a certain particle, which is equivalent to no errors in measurement. Which is when delta x equals to 0, the delta p, which is the errors in the measurement of momentum, will be infinitely big, and that means that we lose every information about the momentum.

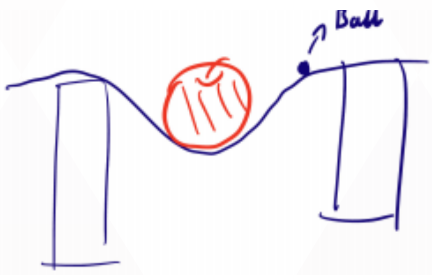
To conclude, this equation tells us that we can not even know every information about one particle, letting along calculating what will happen next.

These are the basic ideas of the quantum theory at that time, and let's do a small conclusion about that:

- Wave- particle duality of light
- We can only predict probability
- Principle of uncertainty
- Collapse of wave function after observation.
- Observer effect.

As you can see, these theories are very "aggressive" since they basically changed everything about physics. There were many people who refuse to accept it, including one of the best physicists of humanity history-Einstein, and he soon published a famous article now known as the EPR paradox, but before talking about that, let's take a look at his other ideas first.

In special relativity, Einstein stated nothing travels faster than the speed of light. While in general relativity, he stated that gravity is not a so-called action at a distance force. Instead, it is consider as the warp of space and time. Take this figure as the example. This is a situation where there is a thin paper on the two supporting rocks. While the massive apple makes the paper changes its shape. The tiny ball will fall towards it, and it seems like that the apple kind of "attracts" the ball. This is exactly what happens with gravity. The warp in space and time near a massive object make it seem like there is a attraction force. Additionally, Maxwell has already proved that the electromagnetic force is not an action at a distance force. So the scientists at that time believes there is no action at a distance force.



Now, we have already know two basic rules of relativity, before going to the EPR paradox, let's just first take a look at the two basic principles that it is built on, which are the principle of locality and the principle of realism.

The principle of locality are basically the ideas of the relativity, which are that nothing travels faster than light and the so-called action at a distance force doesn't actually exist. The principle of realism states that the act of observation will not have an influence in the properties of the particle, which is just the opposite as the observer effect.

In the original paper of the EPR paradox, it states that every successful physics theory must satisfy two basic conditions:

1. The theory must be correct
2. The theory must give a complete description about everything happened.

This means that as long as there are no measuring errors, the theory must give a complete description about the observations and the possibility predicted should always equals to 1 as long as we have the calculations needed.

In the following passage of the paradox, Einstein designed a mind experiment:

If there are two particles that each exerts a force on each other and they go in the opposite direction, when they are really far away from each other. If we measure the position of particle A, and let's say that it is x, the position of B must be -x. Same goes with the momentum, if the momentum of the first particle is p the one of the other should be-p. Since there is not an action at a distance force and nothing travels faster than the speed of light the second particle will not "know" what is happening with the first particle, which means that it will not be infected. In this way, we can calculate both the momentum and the position of the particle B, which is simply against the uncertainty principle of Heisenberg.

There's also a more easy way to explain it, which is when we consider the two particles as electrons. We know that the electrons have an angular momentum— they are always self-spinning, and they're either spinning up or spinning down. So an apparatus named the electron polarizer is designed. This kind of apparatus only allows the electrons with the certain spinning direction to pass through. Let's consider a experiment when the first polarizer only allows the electrons that are spinning up to pass. 50% of the electrons will manage to make it through since half of the electrons are spinning up. The second one only allows the electrons that are spinning rightward to pass. 50% of the electrons that have already passed the first one will pass the second one since for the electrons that are spinning up, they are either spinning leftward or spinning rightward. This is not very hard to understand. However, when the electrons pass the third polarizer which allows the electrons that are spinning upwards to pass. The shocking result is obtained, still only 50% of the electrons can pass. This means that the measurement done in different space and time will not obtain the same result. Which is exactly the same as the quantum theory— before measuring, the properties of the particles do not mean anything since they are only a function of possibility. When and only when the function collapsed, we can obtain a final result, and the final result is still not predictable. However, Einstein do not think so. He thought it is the measurement itself influences the system, and he gave another mind experiment to explain it.

There are still two particles moving away from each other. The only difference is that this time the 2 particles are electrons. They move so far away from each other when we use a electron polarizer to measure the spinning direction of particles A. If that is upward, the particle B's spinning direction must be downward according to the conservation of angular momentum. However, due to the explaining of the quantum theory. The particle B's rotational direction is only a function of possibility before it collapsed, which means that it still have a 50-50 chance of spinning upwards. Since there is no action at a distance force and nothing travels faster than the speed of light, which means that the particle B has no idea about what is happening with particle A. Particle B may turned out to have the same spinning direction as the particle A, which is simply not possible since it is against the conservation of angular momentum. Suggesting by this, the quantum theory seems cannot explain itself.

Although this seems to be so correct, Bohr successfully gave a explaining to it. He said that the two particles can not be considered separately, but only as one whole, and the so called "action at a distance force" kind of exists in the quantum world, which was soon known as the famous quantum entanglement. However, this is not considered against the special relativity, because though the signal seems to be traveling faster than the speed of light, it cannot carry any information.

However, Einstein still didn't accept this explanation, and he soon gave the hidden variables theory, which had been debated for years until the discovery of Bell's inequality.

Though the EPR paradox is not exactly correct, it still holds great significance, it leads to many mind experiments that challenge the quantum theory like the famous cat of Schrödinger, and it is those challenges that make the quantum theory more complete.

Is the cosmological constant theory the best solution for dark energy?

YUCHEN CHEN (Cobby)

1. The emerging of dark energy

Until 1998, people still generally agreed that the expansion of the universe is decelerating as the law of gravitation intuitively had told us that the gravitational force of attraction will pull everything together. However, S. Perlmuter's and B. Schmidt's groups had discovered that the universe is expanding even faster than it was in 1998. They induced this result by observing the redshift of the type 1a supernova "SNela"([1]Xin-zhou Li "Dark Energy" In *Science* no. 6 (2003)).

By the time people were confused about this shocking discovery, theoreticians started to put forward a brand new concept —- dark energy, which they predicted its existence a long time ago. Although theoreticians were really excited about the appearance of this result, they could not fully explain the essence of dark energy. This led to diverse opinions among theoreticians.

2. The widely believed theories of dark energy

Among a large number of hypotheses about dark energy, the theory of cosmological constant (usually represented by the Greek letter lambda: Λ)must be the most popular one. It is a century problem that Albert Einstein left to us in his general relativity theory. So, what is the cosmological constant?

At the time Einstein created his general relativity theory, he had believed that the universe is static, though his equation disagreed with that since the gravitational force will pull everything together causing a collapsing universe. As a result, he put a constant number in his equation to balance the gravitational force to let the universe be stationary, and this is how the cosmological constant was born. He soon reckoned the cosmological constant as "The biggest mistake he has made in his life"([2]Miao Li "Theoretical Issues of Dark Energy" In Chinese Journal of Nature Vol.27 No.1 (2005)) because the observation from Edwin Hubble showed that the universe is not static.

Despite all that, as we know that the universe is actually accelerating, people start to realise that Einstein might have come up with a super important physical constant in cosmology and believe that dark energy is the true cosmological constant, as the cosmological constant does the same function as dark energy. Then where does this energy come from and why can they explain the accelerating universe expansion?

To find out the nature of cosmological constant, scientists have their eyes on quantum physics, which considers the vacuum is full of energy that is invisible rather than empty space. This energy is well-known as the vacuum energy. It is a theoretical energy which is generated by a sea of ephemeral particle pairs of electrons, positrons or photons(virtual particles). Since the particles and the antiparticles will appear and annihilate each other producing energy in an extremely short time, the vacuum appears to be "nothing". This energy is created by vacuum fluctuation and this process was questioned owing to violation of conservation of energy because the virtual particles appear without a source of energy. This is why vacuum energy is still generally believed to be "theoretical".

Unlike common matters, dark energy exerts a repulsive gravitational force with its negative pressure, which is predicted to be the main reason for the accelerating expansion of the universe. This idea seems to be unreal since in Newtonian mechanics the gravitational force is directly related to its gravitational mass and it is always an attraction force. Nevertheless, Einstein had come up with his general relativity theory by comparing the difference between the inertial mass in Newton's second law and the gravitational mass in Newton's law of universal gravitation, which states that the gravitational force can be repulsive due to the pressure of the energy. In his theory, the mass can be converted to energy with equation E=mc^2 and when the pressure of the energy $p<-\rho/3$, it will exert a repulsive gravitational force.

Interestingly, in the dark energy theory of vacuum energy, the vacuum energy(dark energy) has a fixed density because it is mathematically the same as cosmological "constant", and adding a constant against the attractive gravitational force is exactly what Einstein had considered when he added the cosmological constant to his equation. The only difference between Einstein's cosmological constant and the cosmological constant nowadays is that the gravitational repulsive force exerted by the recent one in fact overtakes the gravitational attractive force induced by the total mass in the universe. This leads to the formulation of the theory of dark energy as a cosmological constant.

After speculating about the nature of dark energy, the next problem is how to show the cosmological constant, vacuum energy and dark energy have correlations. It is better to mention the inflationary universe scenario here, which suggests that the universe had been inflated to the size as today in a significantly short period and supports the CDM model. It is an important scenario that was first introduced by A. Guth, P. J. Steinhadt and A. D. Linde in 1980. The reason why cosmologists have trusted this scenario and studied in the direction of this scenario is that it successfully explains many phenomena and the observed microwave background radiation result from the BICEP2 telescope supports it.([3]Hai-peng Zhang, Li Zhang, Qing-yi Meng, Yan-an Luo, Dan-shen Zhang, Yu-qing Li, Ling Hua "Further discussion on the unification of dark matter, dark energy, gravitational waves, neutrinos and forces —— Start with the physical significance of the discovery of B-mode polarisation of the cosmic microwave background radiation.") Therefore, based on this scenario, the inflation also smoothed the bending of space creating a relatively flat universe. The idea that the universe is flat on a large scale was evidenced by the measurement of the cosmic microwave background radiation. According to Einstein's theory, the spatial curvature depends on U(average energy density), and if the universe is flat where spatial curvature equals 0, "U should equal a critical energy density. In cosmological terms, it requires $\Omega 0=1$, where $\Omega 0$ is the ratio between U and critical energy density."([1]Xin-zhou Li "Dark Energy" In Science no. 6 (2003)) However, the calculations indicated that the average energy density of all the matter in the universe(including dark matter) is only one-third of the critical energy density. Therefore cosmological constant is used to make the average energy density equal the critical energy density($\Omega\lambda= 2/3$).

Although this theory seems to be a perfect explanation for dark energy, is the ratio between the cosmological constant(dark energy) and the critical energy density really equal to $2/3$? The theoretical calculation from quantum field theory in quantum physics overthrew this result. None of the quantum physics theories are able to give an appropriate magnitude of the cosmological constant because its value is way too tiny. As vacuum energy is the same as zero point energy which is the lowest possible energy that a quantum mechanical system may have, it has a dimension. This means that we can only get a fixed number with no dimension by comparing cosmological constant with other constants that have the same dimension as itself, just like that it is meaningless to ask how long is one second unless we compare it with one minute, sixty seconds. The sum of the zero point energy is divergent, so we can only calculate it using truncation of an energy scale, but this leads to a complicated problem. "For example, if we using a truncation of a 100 GeV, then the result is $\Omega\lambda=10^{55}$; if we using a truncation of Planck energy scale, then the result is $\Omega\lambda=10^{120}$; if we using a truncation of the breaking scale in the supersymmetry theory, then the result is $\Omega\lambda=10^{60}$." ([1]Xin-zhou Li "Dark Energy" In Science no. 6 (2003)) Unfortunately, as we can see, it does not matter which truncation we are using, the observed result that we have expected is preposterously smaller than the theoretical result, which is known as"fine-tuning problem". If we put the actual result in the theory, the universe would be blown up a long time ago. This problem not only confuses everyone, but also shakes the base of the dark energy theory of cosmological constant as the appearance of this problem directly tells us that there must be something wrong with this theory.

The confusing small value of cosmological constant is not the only challenge that the cosmologists are facing. One of the famous cosmological problems — — the cosmic coincidence problem also makes them feel distressed. The cosmic coincidence problem is asking: If the dark energy density has behaved very differently compared to the matter density since the early universe, and their orders of magnitude were far from each other in the early universe, then why do they have the closest orders of magnitude today when human beings just started to evolve?

3. Does dark energy really exist?

Not all the cosmologists think the presence of dark energy which no one knows where it is from is acceptable. Like many cosmologists who believe in the existence of dark energy, cosmologists who do not believe in it have also given various hypotheses and theories to the accelerating expansion of the universe without the dark energy or even reject the accelerating expansion of the universe. In addition to dark energy which is an abstract concept that is full of mysteries, those cosmologists are more willing to deduce the answer for the accelerating expansion of the universe from what we have already worked out. One of the generally agreed theories is about the conjecture of the inhomogeneous universe.

According to the Cosmological principle, the laws of physics are universal, and on a large enough scale the universe should be homogeneous and isotropic(there are inhomogeneities on scales less than 150 Mpc, though). Besides, the Copernican principle states that human beings on the Earth where it is in the Solar System, are not privileged, which means that observations from the Earth are representative of observations from any random position in the universe. Most of the cosmological theories and hypotheses follow these two principles, but definitely not the conjecture of the inhomogeneous universe, as it negates them fundamentally. It is really hard to say that the universe is exactly homogenous if we can not actually observe the whole of it.

Before discussing the possibility of the presence of the inhomogeneous universe, let us go back to the start where cosmologists realised that the universe is accelerating. How did cosmologists get this result then? Redshift is the answer. The redshift can tell us the speed of the travelling celestial bodies moving away from the Earth and the distance between those celestial bodies and the Earth by looking at the change in the wavelength, frequency and the photon energy of electromagnetic radiation (usually the visible light).([4]Riess, Adam G., and Mario Livio. "The Puzzle of Dark Energy.") The redshift means an increase in the wavelength, and corresponding decrease in the frequency of the electromagnetic radiation during the travelling, which makes the visible light appear to be dimmer(The blueshift is opposite of the redshift representing the celestial bodies moving toward the Earth). In 1998, the redshift result from the type 1a supernova was dimmer than what cosmologists had predicted, leading to a conclusion that the universe is accelerating. However, is this conclusion the only way to explain this redshift result?

If considering the Cosmological principle and the Copernican principle, the accelerating universe with dark energy is the most reasonable speculation, but in the conjecture of the inhomogeneous universe in which the two principles are absent, it may not be the best solution. The space will be unevenly expanded in an inhomogeneous universe due to the uneven distribution of the matter, and this makes many gargantuan voids which are places where the average matter density is much less than the other areas causing a much faster expanding speed. The difference in the expanding rate will stretch the electromagnetic radiation after it enters the gargantuan voids, influencing the behaviours of the electromagnetic radiation significantly. Imagining human beings living in such a place, does not necessarily have to be at the centre of the void, but somewhere close to it. While the electromagnetic radiation is passing through the void zone, it is going to be elongated by a fixed amount in each region as the void is rapidly expanding. Therefore, we would probably observe a dimmer redshift from the electromagnetic radiation emitted by the distant supernova explosion that is similar to what we actually have observed. To make this hypothesis work, the distance between the Earth and the supernova explosion in this hypothesis should be extremely longer than in a uniform universe(in a scale of billion lightyears), and the size of the void should be approximately the same scale. This is a truly astronomical scale as it is incredibly large, and this induces the main problem in this theory that how we can find a void with this size which is beyond common sense to replace the function of dark energy.

This seems to be impossible at first glance, and it actually almost is. The theoretical size of the void is nearly on the same scale of the observable universe(the observable universe has a diameter of 93 billion lightyears). "The probability of a void big enough to mimic dark energy is less than 1/100^100." In the 1990s, Andei Linde pointed out that there is a possibility in which the observers might discover that they are living in such a gargantuan structure. This shows that we may not definitely live in a typical region even though we are typical observers. His point of view gives hope to the existence of the void that is able to mimic the dark energy. Unfortunately, the recent observational data does not fit this hypothesis at all, so before more evidence is actually discovered, the conjecture of the inhomogeneous universe is still remaining controversial. ([5]]Clifton, Timothy, and Pedro G. Ferreira. “Does DARK ENERGY Really Exist?”)

The conjecture of the inhomogeneous universe is not the only explanation for the accelerating expansion of the universe apart from the presence of dark energy, but in addition to solving the puzzle of the accelerating universe, some cosmologists also start thinking about whether the universe is really accelerating or not. For example, the cosmologists from Spanish universities consider the redshift result as a effect of the time dilation, which is the difference in elapsed time either caused by a relative velocity between them that can be explained in the special relativity theory, or a difference in gravitational potential between their locations that can be explained in the general relativity theory. ([6]Jian-sheng Chen “Scientists refute the theory of universe expansion, saying time is getting slower or going to standstill”)The idea was first introduced by Professor Jose Senovilla and colleagues Marc Mars and Raul Vera of the University of the Basque Country, Bilbao, and University of Salamanca. Since the time is getting slower on an astronomical scale, the visible light will take longer to travel from the supernova explosion to the Earth leading to a dimmer appearance. In their scenarios, time might even disappear in the future, “We believe that time emerged during the Big Bang, and if time can emerge, it can also disappear – that’s just the reverse effect,” said Gary Gibbons who is a cosmologist at Cambridge University. ([7]Paul Ratner “Time is actually slowing down and will come to a halt, says a radical theory” *Big Think*) However, the absence of actual observational data makes this hypothesis suspicious.

Similarly, another idea also considers the accelerating expansion of the universe as an illusion with a new understanding of evolution of the galaxies which reveal the structure of the galaxies. The scenario suggests that the descendant planets in a galaxy always revolve around the predecessor planet, which also known as the satellites revolve around the planet, the planet revolves around the star, and the star revolves around the parent star of the previous generation, until the daughter galaxy in the centre of the galaxy revolves around the centre of the galaxy. The redshift results of the daughter galaxies seem to tell us that they are all fast moving away from us. The scenario points out that daughter galaxies are under the gravitational pull of these parent stars that they each rotate rapidly around the parent star.

Moreover, the speed of these daughter galaxies rotating around the parent star is greater than the speed of the Earth rotating around the sun, this is why observers feel that they are all rapidly moving away from us. It also gives explanation to the dimmer visible light that S. Perlmuter’s and B. Schmidt’s groups have observed, in which a supernova will quickly consume the atmosphere around it and the sedimentary layer on its surface when it explodes, leading to a gradual decrease in the brightness of the supernova explosion. As a result, the dark energy which is a mysterious invisible energy that can stretch the fabric of space and cause the accelerated expansion of the universe no longer exists in this scenario, instead, it can be replaced by the centrifugal force acting on the star at the centre of the daughter galaxy. When a star evolves into a more massive star, it must undergo multiple supernova explosions and they compress the star more densely. The supernova will remain its original angular momentum during this contraction process, its self-rotation will be accelerated, causing the revolution of its daughter galaxy to accelerate, so the centrifugal force will push the daughter galaxy to move outward along the spiral leading to the expansion of the structure of galaxies. This scenario has logic self-consistency and the author has proved the Hubble law which makes his scenario really reliable.([8&9] Cui-xiang Zhong “The formation and evolution of galaxies and the expansion of the universe and Dark matter and dark energy” In Science & TechnologyVision and “Proof of Hubble's law and the truth about the expansion of the universe and dark matter and dark energy” In *Scientific and Technological Innovation*)

As for the challenge to Einstein’s theory. Some cosmologists indeed have made some efforts on it, but they soon realise that any other change in the theory has the similar effect as the cosmological constant and all of them will finally be stopped by problems like fine-tuning problems.([2]Miao Li "Theoretical Issues of Dark Energy" In Chinese Journal of Nature Vol.27 No.1 (2005))

Inhomogeneous universe theory used to be a strong competitor to the cosmological constant theory, but unfortunately, it is extremely hard to prove that such a large void exists. What's more, the recent observational data does not support the existence of the inhomogeneous universe, compared to the cosmological constant theory which makes a considerable close prediction to the recent observational data. Therefore, the cosmological constant theory is more convincing than the inhomogeneous universe theory. The time dilation theory is really suspicious, as time is a subjective concept defined by human beings, and it is not fundamentally reckoned as existing in absolute sense. Besides, the missing in experimental proofs makes this even worse, so clearly the time dilation theory is not able to be more convincing than the cosmological constant theory. Compared to the new understanding of galaxy formation, the cosmological constant theory is far more popular. The logic of this theory is complete and it has made many theoretical proofs, but there are only a small fraction of cosmologists working on it so relative experimental proofs are deficient. As a result, in terms of the reliability, it is not as convincing as the cosmological constant theory. Changing the equation of Einstein is a reasonable way of solving the puzzle of dark energy to consider, however, cosmologists working on this way eventually find that they obtain a similar result to Einstein, which means that the new theory faces the same or even more problems as the cosmological constant theory. Obviously, it is not really convincing.

4. Other explanations for dark energy

Instead of focusing on the cosmological constant or vacuum energy(zero point energy), some physicists have pointed out that dark energy can be varying over time. The most popular theory about the changing value of dark energy is the quintessence theory of dark energy.

The quintessence theory of dark energy suggests that dark energy is quintessence, a "dynamical, evolving, spatially inhomogeneous component with negative pressure".([10]Steinhardt, Paul J. "A Quintessential Introduction to Dark Energy.") The word quintessence comes from the ancient world, when Greeks thought that the world is formed by five elements: earth, water, fire, wind and quintessence. In this theory, the energy density of the dark energy is associated with a scalar field that only interacts with repulsive gravitational force, whose pressure is negative when it rolls slowly enough that kinetic energy density is less than potential energy density.

To work out the other properties of dark energy, calculating the parameter of dark energy w might be useful. The parameter of dark energy w is the ratio between the pressure of the dark energy and the energy density of dark energy($w=p/\rho$) and is generally agreed to follow the state that $w<-\frac{1}{3}$ as the dark energy needs to produce a repulsive gravitational force which requires $p<-\rho/3$(see the content above). If the dark energy is the vacuum energy, then the value of $w=-1$(cosmological constant theory of dark energy). In the theory of the quintessential dark energy, the energy density of the dark energy is evolving and is directly related to the value of w following the equation $\rho \propto 1/R(t)^{3(1+w)}$ where R(t) is the cosmic scaling factor which is a function of time and the unit of t is in epoch. As we have observed that the universe is accelerating and expanding, the average energy density of all the matter in the universe should be decreasing overtime. By comparing the equation above with the equation for the energy density of mass, which is $\rho \propto 1/R(t)^3$, we know that the rate of decreasing of energy density of dark energy is much less than the rate of decreasing of the energy density of mass.

To make the universe flat, for the same reason mentioned in the first chapter of this essay, dark energy is still required to combine with the mass to reach the critical energy density, but it is uniformly distributed which means that it might interrupt the function of dark matter in the early universe. In addition, according to the observations we have made in the past, dark energy was relatively less important in the early universe so it did not affect the formation of the structure of the universe, which is the job for dark matter. However, physicists have noticed that dark energy has become far more important than it was in the past, and it will continue to become more and more important in the future. Obtaining the result that the dark energy is negligible in the early universe requires w<-½, which follows the result from Einstein's equation to let dark energy have negative pressure(w<-⅓).

The quintessential dark energy theory is convincing because it has given solutions to many vexing problems including the cosmic coincidence problems. Astrophysicists have come up with various solutions to deal with the cosmic coincidence problem, and the sum up of those creative ideas is the k-essence field. It is a kind of quintessence model in which the scalar field acts without potential terms but totally with the nonlinear kinetic terms. The nonlinear kinetic term is expected to be significantly small and does not play an important role as a result of Hubble expansion in most cases, apart from the situation that there is an attractor solution. This attractor solution is dynamical and it changes its value with the conditions of the universe. During the epoch when the universe is radiation-dominated, the k-essence(dark energy) acted like a radiation component with w=⅓ and its density has decreased at the same rate of decreasing of the dominant radiation component. The name of the quintessence models with similar properties is "trackers". Therefore, the tracker successfully explained why the dark energy density is negligible in the early universe(radiation dominated universe appears in the first 10000 years after the birth of the universe). At the end of the radiation dominated universe, the energy density of matter overtook the energy density of radiation, the previous attractor solution was no longer stable, leading to a huge decline on the orders of magnitude of the k-essence field's energy density. A new matter-like attractor solution is discovered at the onset of the matter-dominated universe and this attractor solution makes the k-essence field stay constant at w=-1, which does the similar function as the cosmological constant. Whereas, the k-essence field only has negative pressure after the beginning of the matter-dominated universe. The reason why human evolution and the accelerating expansion of the universe happen in the same epoch is sorted out as well, in which human evolution is of course started after the onset of the matter-dominated universe when the stars and galaxies have been formed.

The existence of quintessence as dark energy is persuasive, even though it is quite similar to the cosmological constant theory. This is not only because it solves the cosmic coincidence problem, but also because it "has different implications for fundamental physics and may fit the observation data better than the cosmological constant".([10]Steinhardt, Paul J. "A Quintessential Introduction to Dark Energy.") However, it can not explain the ridiculous smallness of dark energy theory as well. Paul J. Steinhardt, the author of the quintessence theory of dark energy, and N. Turok has suggested a new quintessence model called cyclic model to try explaining this smallness, but unlike k-essence model, this cyclic model is not able to address the cosmic coincidence problem and is not generally agreed yet([11]Vilenkin, Alexander. "The Vacuum Energy Crisis."). Also, the k-essence model had predicted that the upper limit of w is roughly -⅔, which was proved to be -0.82, so cosmologists have to study deeper about the scalar field that represents the dark energy to find out where this decline in the upper limit comes from. Nevertheless, the quintessence theory of dark energy has a relatively well-developed system and is supported by many measurements like the observations from cosmic background radiation, gravitational lensing, supernovae and so on. Whereas the fine-tuning problem is really tricky for the quintessence theory of dark energy to explain, cosmologists place the hope on the anthropic principle.

The anthropic selection theory, also known as the anthropic principle, sounds really subjective as a scientific theory since it explains the cosmological problem in a precondition of the existence of living creatures like human beings. Though putting human beings in such places when discussing cosmological problems seems to be arrogant, the anthropic principle does not place the existence of the human beings (or other living beings) in the position of the reason why our universe has life-encouraging properties. Strictly speaking, it is using the result of the universe, the existence of human beings in this case, to speculate the causes instead of treating the result as a cause, which is logically appropriate. "Being a wife is a casual consequence, often, of being a woman. Being a woman is a logical consequence of being a wife(generally speaking)."([12] Leslie, John. "Anthropic Explanations in Cosmology.")

The anthropic principle is a larger scale form of teleology, which thinks the observable universe is purposive and its purpose is to create intelligent living organisms like human beings. This thought looks like an opposition to atheism and the

Copernican revolution, because it is too anthropogenic. Yet "Anthropic Cosmology tends to be excessively anthropocentric only in the sense that it exhibits a definite bias toward intelligence". Surprisingly, it does not reject either atheism or the Copernican revolution. Instead, many of the anthropic cosmologists do not take the existence of God as the factor of the purposiveness of our universe at all. Also, just like cosmologists John D. Barrow and Frank J. Tipler said, "Although we do not regard our position in the Universe to be central or special in every way, this does not mean that it cannot be special in any way." According to different versions to this theory, three main meanings are induced, The Weak Anthropic Principle, The Strong Anthropic Principle and The Final Anthropic Principle.

The Weak Anthropic Principle stands for the fact that this theory will patently not be proposed by human beings with a universe that is not compatible with and supports the presence of human beings. In other words, our universe is compatible with and supports the presence of human beings with no reason. For instance, the only explanation we can give to the question "why the distance between the sun and the earth is this certain value?" is that only the temperature provided in this distance from the sun enables human beings to survive. Obviously, it is true, but it is meaningless and uninspiring as well. The Strong Anthropic Principle, as Brandon Carter said, "The Universe must be such as to admit the creation of observers within it at some stage." The emphasised word "must" has a debatable meaning, and John D. Barrow and Frank J. Tipler have made three possible explanations for the Strong Anthropic Principle. The first explanation is the existence of God, or some impalpable presences that create us. This explanation is apparently disapproved by atheistic cosmologists including John D. Barrow and Frank J. Tipler themselves. The second and third explanations are not relevant to Divinity, one suggests that observers exist because they are important to the formation of the world as some quantum theories elaborate(e.g. Quantum Mechanics;Quantum Observership), the other one suggests that the Strong Anthropic Principle follows the Principle of Plenitude where there are infinite number of other universes which have different or similar physical laws and all possible value of constants, and we live in one of them with the physics laws and constants that we are familiar with. The third explanation is the most widely agreed upon in atheistic cosmologists since it is a satisfactory solution to the fine-tuning problem.(These two paragraphs are summarised from [13]Edwards, Rem B. “ATHEISTIC ANTHROPIC COSMOLOGY.”)

However, in the third explanation with the infinite universe cosmology, among all the theories, none of them give observational evidence, but end up with a result that we live in a universe that is compatible with and supports conscious, intelligent living beings by just accident. This makes no difference to the presence of an invisible, extraordinary God, since we are not able to see or prove both of them, although atheistic cosmologists argue that the infinite universe gives the universe purpose without God. "Infinite" is a super strong word in mathematics, just like the "infinitely" repeating decimals 0.999... can equal to 1 in the form of fraction 3/3, it is pretty reasonable to think that there are definitely some universes which have sufficient conditions to support the evolution of the living beings. Of course, this is intuitively true, but it is not true in terms of science. Infinite universe does not necessarily mean that there is infinite diversity, the infinite universe can have all of them with the same physical laws and constants, or even our universe the only one that has an epoch when intelligent living beings are able to evolve. More importantly, the anthropic principle as a whole is really controversial in cosmology and many cosmologists consider it as an unscientific principle, though it can be used in the observation data of string theory.([11] Vilenkin, Alexander. “The Vacuum Energy Crisis.”) Overall, it is a good principle to apply to the quintessence theory of dark energy solving the fine-tuning problem, but it also has many questions that are difficult to solve.

For the anthropic principle theory, even though it has a relative logic self-consistency, most of the cosmologists still can not really accept it due to its lack of evidence in experimental data compared to the cosmological constant theory. As a result, the cosmological constant theory is surely more convincing than the anthropic principle theory. Among all of the theories above, none of them gives us a more reasonable answer to either the accelerating expansion of the universe or dark energy than the cosmological constant theory. However, compare the quintessence theory with the cosmological constant theory, it is obvious that the quintessence theory has more sufficient evidences than the cosmological constant theory such as the better fit with the recent observational data and the sensible explanation to address the cosmic coincidence problem by the k-essence model. Also, the quintessence theory seems to be more suitable to give the cosmologists an estimation of the early universe. In my opinion, these can be reliable reasons for me to say that the quintessence theory is more convincing than the cosmological constant theory.

5. Conclusion

Is the cosmological constant theory the most convincing solution for dark energy?

This is a tricky question to answer, as Shakespeare said, "There are a thousand Hamlets in a thousand people's eyes." Owing to the different version of the same problem about the results from the redshift of the type 1a supernova in 1998, cosmologists have come up with so many different theories and hypotheses. In my opinion, the best way to answer this question is to show a counter example — — A theory that is more convincing. Generally speaking, the cosmological constant theory of dark energy must be the most well-known one, but it can not address either the cosmological coincidence problem or the fine-tuning problem, which makes many cosmologists start to look for other possibilities. Some of them even doubt the existence of dark energy and make hypotheses without it. Although there are hypotheses with trustworthy bases, most of these hypotheses do not fit with the observational data afterwards, which means that they can not shake the cosmological constant theory's position at all. Another group of cosmologists decided to study dark energy in other ways. The quintessence theory of dark energy can solve both the cosmological coincidence problem and the fine-tuning problem, though there are many theoretically unstable parts in this theory. In conclusion, due to the cosmological coincidence problem and the fine-tuning problem, cosmologists do not largely acknowledge the cosmological constant theory of dark energy anymore when comparing it with the more complete quintessence theory of dark energy. However, scientists should respect any possibility especially when they are studying something mysterious. Also, many theories including the quintessence theory of dark energy are inspired based on the cosmological constant. In the future, it may still help us figure out the nature of the dark energy, and understand the mysterious universe.

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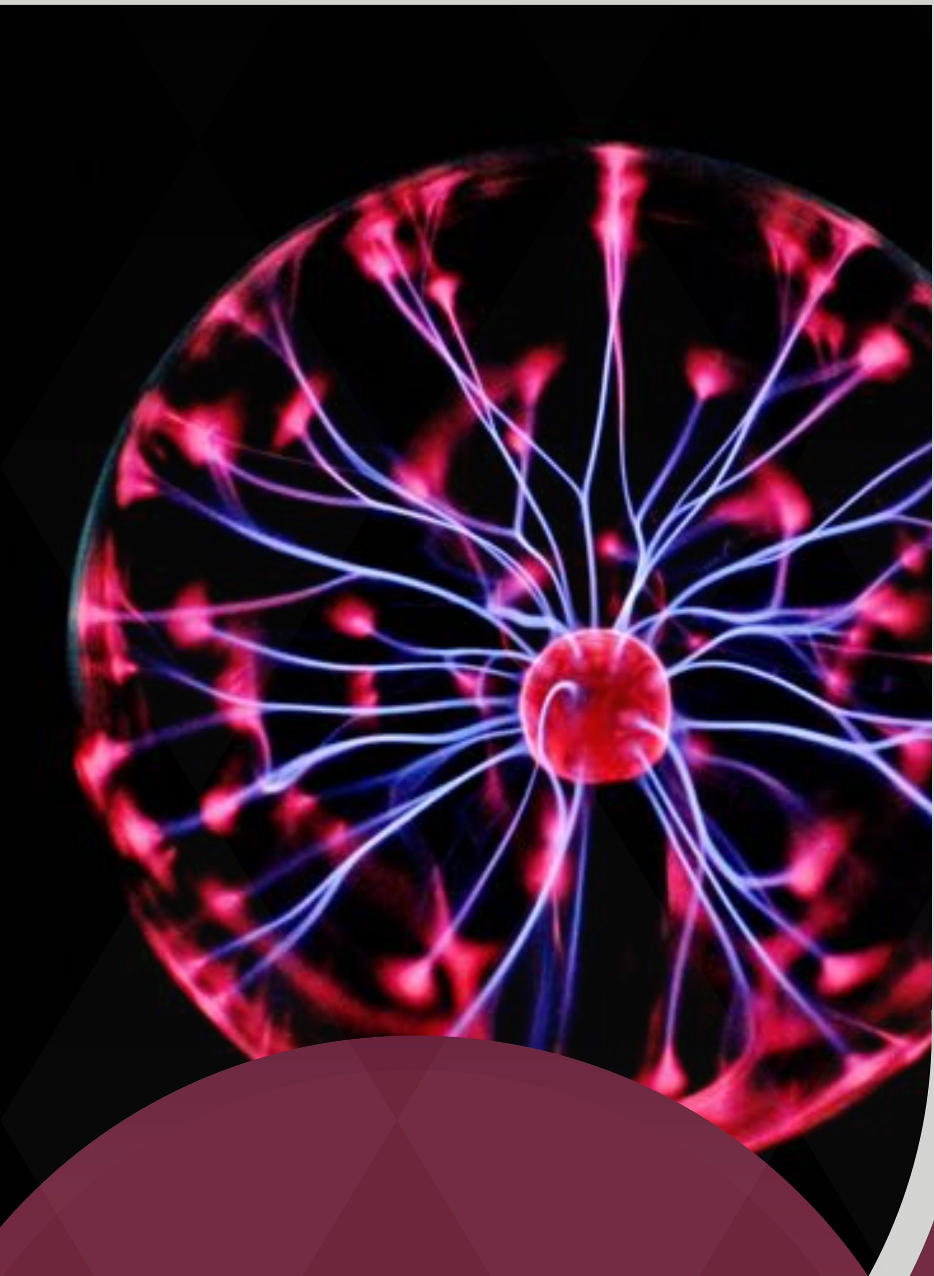

Psychology and Neuroscience

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Discussion on Electrical and Chemical Synapses and the Differences between them

QINGSHU WU (Cindy)

1. Introduction

When we accidentally touch a sharp object, the mechanical stimulus on the skin result in a generation of action potential by signal sensory neurons. The signal is then relayed through synapses to the central nervous system, triggering a reflex or pain perception.

In the late 19th century, it was recognized that such information transfer between neurons occurs at specialized contact points. In 1897, British physiologist Charles Sherrington named these points synapses. Synaptic transmission is the process of information transfer at synapses. A synapse is a specific connection site where the axon terminal of one neuron contacts another neuron or cell. The normal flow of information is from the axon terminal to the target neuron; thus, the axon terminal is called presynaptic, and the target neuron is called postsynaptic. I will further analyze different types of synapses below.

2. Electrical synapse

Most synapses in mammals, including humans, are chemical. However, there is a simpler, older type of synapse called the electrical synapse. Electrical synapses allow ions to pass directly from one cell to another. These synapses occur at specific sites known as gap junctions. At a gap junction, the space between the presynaptic and postsynaptic membranes is about 3 nm. This narrow gap is bridged by proteins called connexins. Six connexins come together to form a channel known as a connexon, which allows ions to flow directly between the cytoplasm of adjacent cells. Unlike most chemical synapses, electrical synapses are bidirectional, meaning ions can flow in both directions. Cells connected by gap junctions are called electrically coupled cells.

Transmission through electrical synapses is extremely fast. When the synapse is large, transmission is smooth, allowing an action potential in a presynaptic neuron to induce an almost simultaneous action potential in a postsynaptic neuron. In invertebrates, electrical synapses are commonly found between sensory and motor neurons in escape reflex pathways, enabling rapid responses to threats. In the adult mammalian central nervous system, electrical synapses are present in specific locations where normal physiological functions require highly synchronized neuronal activity.

3. Chemical synapses

By contrast, Chemical synapses are more prevalent, with synaptic transmission in the adult nervous system being primarily chemical. Chemical synapses exhibit a series of common features. The presynaptic and postsynaptic membranes of a chemical synapse are separated by a synaptic cleft, which is 20-50 nm wide—ten times wider than the gap in electrical synapses. This cleft is filled with a fibrous extracellular protein matrix that helps adhere the presynaptic and postsynaptic membranes together.

The presynaptic side, also known as the presynaptic terminal, is typically the end of an axon. This terminal contains numerous small, membrane-bound vesicles, approximately 50 nm in diameter, called synaptic vesicles. These vesicles store neurotransmitters, which are the chemical substances used to convey information to the postsynaptic neuron. Many axon terminals also contain larger vesicles, around 100 nm in diameter, known as secretory granules or large dense-core vesicles. These granules contain proteins and appear dark under an electron microscope.

On either side of the synaptic cleft, there are densely packed proteins within or adjacent to the membranes, collectively referred to as membrane differentiations. These appear as cone-shaped areas and are the sites where neurotransmitters are released, known as active zones. Synaptic vesicles cluster in the cytoplasm adjacent to these active zones.

In the postsynaptic region, the protein structures densely packed below the membrane are known as the postsynaptic density. This area contains neurotransmitter receptors that convert the extracellular chemical signal (the neurotransmitter) into an intracellular signal within the postsynaptic cell (such as changes in membrane potential or intracellular chemical changes). The nature of the postsynaptic response can vary greatly, depending largely on the type of receptor proteins activated by the neurotransmitter.

4. Categorization of synapses in the central nervous system

But where do synapses exist in the body, what differences do they have?

In the central nervous system (CNS), synapses are classified based on the contact points between the axon terminal and the postsynaptic neuron. When the postsynaptic membrane is located on a dendrite, the synapse is referred to as an axodendritic synapse. If the contact occurs on the cell body, it is termed an axosomatic synapse. Additionally, synapses can form between dendrites, known as dendroid synapses. These CNS synapses exhibit significant variation in both size and shape.

Examined under high-powered electron microscopy, CNS synapses are further categorized by the thickness of their membrane differentiations. Synapses where the postsynaptic membrane differentiation is thicker than that of the presynaptic membrane are identified as asymmetric synapses or Gray's type I synapses. Conversely, those with equal thickness in both presynaptic and postsynaptic membrane differentiations are known as symmetric synapses or Gray's type II synapses. Typically, Gray's type I synapses function as excitatory synapses, while Gray's type II synapses serve as inhibitory synapses.

5. Neuromuscular junctions

Synaptic connections are not exclusive to the brain and spinal cord——chemical synapses also exist between spinal motor neurons and skeletal muscles. These synapses are known as neuromuscular junctions, sharing many structural characteristics with central nervous system synapses.

Neuromuscular junctions facilitate fast and reliable synaptic transmission. Typically, a single action potential in the motor neuron axon induces an action potential in the muscle cell it innervates. This reliability is partly due to the unique structure of the neuromuscular junction. One of the most important features is its size: the neuromuscular junction is one of the largest synapses in the body. The presynaptic terminal usually contains many active zones. Additionally, the postsynaptic membrane (also called the motor end-plate) has a series of shallow folds densely packed with neurotransmitter receptors. The presynaptic active zones are precisely aligned with these folds, ensuring that a large number of neurotransmitter molecules are released onto a large chemically receptive membrane surface.

6. Conclusion

In conclusion, electrical and chemical synapses differ in several key ways. Electrical synapses transmit signals through direct electrical currents via gap junctions, allowing for rapid and bidirectional communication, and are typically used for synchronizing activities among groups of cells. In contrast, chemical synapses use neurotransmitters to convey signals across a synaptic cleft, resulting in slower but more versatile and unidirectional transmission. Chemical synapses are capable of amplifying signals, integrating multiple inputs, and exhibit synaptic plasticity, essential for learning and memory. These differences make electrical synapses suitable for rapid, coordinated responses and chemical synapses for complex signal processing and adaptability.

Understanding electrical and chemical synapses is a fundamental step in comprehending how the brain functions. By organizing the basic knowledge of these synapses, I have gained a better understanding of how signals are transmitted in the brain, laying a foundation for further studies in neuroscience.

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An Experiment to Investigate Genes as the Potential Vulnerability Factors Responsible for Dissociative Identity Disorder

CHUANQI REN (Chelsea)

1. Introduction

"Who am I speaking to now?"This is a conversation between a doctor and Billy Milligan. Tommy is one of his 24"personalities". He was the first person diagnosed with Dissociative Identity Disorder (DID). There had been debates on DID's existence. Historically "multiple personalities" was the name for DID. However, the term was too vague and unclear, as to whether it refers to the division of a system or a multiplication (1). Until multiple cases since the 17th century confirmed DID's existence, this particular mental health disorder was officially named Dissociative Identity Disorder (3). Dissociation refers to a transdiagnostic phenomenon (2), a disruption of discontinuity in normal psychological functioning (3), which includes identity as one's self-acknowledgment. It is often trigued by stressful events in childhood, most notably traumas, sexual abuse, and etc (1). Patients develop independent identities with different roles and power over the body. DID comprises 1% of the population (4), but related research is very limited due to its complexity. And it is important to find a way to prevent more people from expressing DID. This is where vulnerability steps in. Vulnerability factors do not directly affect the expression of disorders but indirectly make the patient more prone to expressing certain disorders. The factors often include genetics, environment, and etc. By acknowledging the vulnerability factors of DID, we will be able to pay more attention to potential patients and help to prevent them from developing DID. Unfortunately, The vulnerability factors of DID are still yet to be discussed. This article aims to address one potential vulnerability factor of DID. It is widely recognized that DID is affected by the patient's environment and childhood. But genetics has not been explored yet. Therefore we choose genetics as the potential vulnerability factor and explore the possibilities and influence through experiments.

2. Samples

In this research, 70 DID patients will be included. Each of them was diagnosed with DID by the SCID-D-R questionnaire (Structured Clinical Interview for DSM-IV Dissociative Disorders), which covers five primary symptoms of DID, the most practical tool in the form of surveys (5). There will also be 70 undiagnosed volunteers, both physically and mentally healthy, as the control group. The two groups will both have 1:1 of men and women, in the range of 30 to 50 years old, with the same culture and ethical background. They are all from North America since the prevalence of DID in North America is 1%-5% (6). The control group is recruited by volunteers that suit the criteria and the diagnosed group is recruited by communicating with the local psychiatric hospitals and asking for volunteers. Additionally, because Adverse Childhood Experiences (ACEs) are very important factors that affect DID (1), the control group is also required to have childhood trauma experiences.

3. Ethics and safety

All of the participants in the experiment volunteer to participate. And they are all comfortable talking about their past traumas and abuses. Researchers are strictly prohibited from bringing ACEs up unless it is experimentally needed; should all pay respect to both groups, and treat them all equally. There will be doctors around to prevent any incidents. The participants' privacy will be protected and their data will be used only for this research.

4. Genes

In this experiment, the genes are chosen considering their expression associated with the syndromes of DID, disorders related to DID, and potential vulnerabilities for DID. The ones that will be discussed are ADYC8, DPP6, and APBB2 genes (7). We found in past research that these genes might affect dissociative disorders, but they are not directly proven to be vulnerability factors of DID. ADYC8 encodes for adenylyl cyclase which is an enzyme that catalysis the conversion of adenosine triphosphate to 3',5'-cyclic AMP (10) which is an important second messenger for hormones like glucagon and adrenaline. Glucagon is used to regulate blood sugar of the body. If the blood sugar drops to a low level, patients might feel dizzy or even pass out, which is a common symptom of DID. Adrenaline is a stress hormone, and DID patients are often anxious or nervous before expression. DPP6 encodes a potassium channel subunit, relevant to the excitability of dendrites and synaptic integration. APBB2 encodes amyloid beta precursor protein and amyloid beta precursor-like protein 2, which function in signal transduction. ADYC8 and DPP6 have also been linked to brain development in childhood (8, 9).

5. Methods

Gene panel sequencing is usually done using next-generation sequencing (NGS) technology (12).

1. Genotyping

Blood samples will be collected from two groups for gene expression. Then genomic DNA will be extracted from the blood. The DNA will be checked to make sure it is pure and undeteriorated. The DNA will then be fragmentized into small pieces. Then polymerase chain reaction (PCR) will be performed. They will then be loaded into a sequencer and analyzed (11).

2. Genetic sequencing and multi-gene panel testing (13)

A panel of 3 genes (ADYC8, DPP6, and APBB2) which are associated with the vulnerability of DID is tested. Next-generation sequencing is performed using the Illumina. Deletions and duplications are identified using a custom microarray comparative genomic hybridization (CGH) (15).

3. Statistics

When the results are out, a T-test will be used on the data of the tests to find if there is a difference between the two groups' genes. The p-value will then be examined to see how significant the difference is. If the value is lower than 0.05, the vulnerability towards DID might be due to chance instead of genetic reasons.

6. Conclusion

In this article, we intend to use multi-gene panel testing to analyze the effect of ADYC8, DPP6, and APBB2 genes on the vulnerability of Dissociative Identity Disorders. We've analyzed two groups of people, one diagnosed with DID and one not diagnosed. Apart from that, they all have the same age, gender, culture, ethnicity, and childhood tragedies. We expect to see the deletion or certain mutation of these three genes in DID patients. The misexpression of the genes should affect patients' emotions and brain development such as the decrease of the size of amygdala, which makes patients feel more stressed and anxious. These will all make one more vulnerable to DID.

DID is a rare mental disorder but an important one because it brings suffering to both the patients and the society. So finding the vulnerability factors of DID is important. This article's experiments focus solely on the genetic aspect. There are many other factors. Some are mostly discussed such as the attachment dynamics between a caregiver and a child (1); some are yet to be explored. Lastly, the sample size of this experiment is limited, which might affect the result's accuracy. We hope to find ways to improve the research method in the future.

7. Citations

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