

# The GH-Method

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## **Viscoelastic or Viscoplastic Theory (VGT #84): A Comparison Study of the Influences on the Gross Domestic Product (GDP), Inflation Rate, and Consumer Price Index (CPI) in the USA Resulting from Consumer Psychological Reactions and Spending Behavior Changes Over 9-Quarters During the COVID-19 Pandemic Period from Y2020Q1 to Y2022Q1 Based on GH-Method: Math-Physical Medicine, Especially the VGT Energy Tool (No. 674)**

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### **Abstract**

The author is a mathematician and engineer who has conducted medical research work over the past 13 years. Thus far, he has written 670 medical research papers. Beginning with paper No. 578 dated 1/8/2022, he wrote a total of 80 medical research articles using the viscoelasticity and viscoplasticity theories (VGT) from physics and engineering disciplines on 80 different medical problems with their associated data. These papers aim to explore some hidden biophysical behaviors and provide a quantitative understanding of the inter-relationships of a selected medical output (symptom) versus either singular input or multiple inputs (root causes, risk factors, or influential inputs). The hidden biophysical behaviors and possible inter-relationships exist among lifestyle details, medical conditions, chronic diseases, and certain severe medical complications, such as heart attacks, stroke, cancers, dementia, and even longevity concerns. The chosen medical subjects with their associated data, multiple symptoms, and influential factors are “time-dependent” which means that all biomedical variables change from time to time because body living cells are dynamically changing. This is what Professor Norman Jones, the author’s adviser at MIT, suggested to him in December 2021 and why he utilizes the VGT tools from physics and engineering to conduct his medical research work since then. From 1980 to 1981, the author attended a college in California for his MBA degree, emphasizing finance and marketing. In addition, he spent many years managing a successful high-tech semiconductor business in Silicon Valley, where it involved many key factors of economics and finance, such as gross

domestic product (GDP), inflation rate, consumer price index (CPI), NASDAQ stock performance, price/earnings ratio (P/E ratio), various investment decisions, return on investments (ROI), etc. As a result, he has a strong background in money topics associated with finance and economics. In addition, during the 9 years from 2002 to 2010, he self-studied psychology and established 4 psychotherapy centers to take care of 200+ abused women and abandoned children. Therefore, he has accumulated a considerable amount of knowledge on psychological behaviors, especially in the field of clinical psychology of abused victims. During his recent medical research work using the tool of viscoelastic or viscoplastic behavior theory, he suddenly realized a strong similarity between medicine and economics. The behaviors and patterns of economics variables (inputs and outputs) he observed are comparable to the behaviors and patterns of medical variables he studied and researched (causes and symptoms) in terms of their curve shape & waveforms, fluctuation patterns, moving trends, physical behaviors, etc. For example, he has applied the candlestick chart or K-line diagram from Wall Street as an effective glucose representation tool in medicine. Most importantly, variables in both medicine and economics possessed the common “time-dependent” characteristics. The recent COVID-19 pandemic is a severe and unique experience to worldwide people that is comparable to the Spanish Flu that happened over a century ago. He wondered what type of economic impact or inter-relationship from this pandemic had on some of the current economic indices. Therefore, in this article, he selects the GDP, inflation rate, and CPI

of the USA as the output variables and the COVID-19 infection in the USA as the key input variable to conduct his combined study of economics and medicine. The author conceived the idea of using mathematics, physics, and engineering in medical research while he was learning and practicing psychological care approximately 20 years ago. Due to the protection of his psychological patients' clinical data, requiring privacy and confidentiality, he decided not to use the patients' collected data in his research work. In addition, most published psychological papers are "subjective and language descriptive" rather than "objective and equation/number descriptive" like most papers on science and engineering. As a result, he will describe the interconnection between human psychology and COVID fear using descriptive language, instead of using analytical equations and numbers in this economics analysis. However, regarding the connections or relationships between economic indices, such as GDP, Inflation, and CPI versus COVID infection, he will utilize the VGT equations and his extracted economics data. Initially, the author Googled the US national data about economic indices, especially the GDP, inflation, CPI data, and the COVID pandemic data. It should be mentioned that his COVID data are rough "rounded-off" numbers that are directly extracted from the published "graphic charts (not from data tables)" from the Center for Disease Control (CDC) and Johns Hopkins University. The COVID data are simplified with rounded numbers to thousands for death and millions for infection because using the precise digits would not improve the accuracy of results much or change the observed physical characteristics of the results. Next, he searched for and reviewed a few economic articles related to GDP, inflation, CPI, etc. as shown in the section of references. Over the past 2 years, due to his medical research interest, he has already been exposed to many news and articles in the media, as well as published medical research papers with clinical data regarding the COVID pandemic. This study is of particular interest to him since it links the US national economy with a severe infectious disease in modern human history. This article is one of his first attempts to link COVID disease with some key economic measurements. The established theory of viscoelasticity and viscoplasticity (from the physics branch of science) should not only be limited to a smaller scope of engineering applications. Its ability to link certain variables' time-dependent characteristics and their associated energy estimation via the hysteresis loop area is equally powerful for applications in both medicine and economics. The author would like to describe the essence of the VGT in 6 simple steps using the English language instead of mathematical equations for readers who do not have an extensive academic background in engineering, physics & mathematics - an excerpt from Wikipedia is still included in the Method

section of the full-text article. The first step of VGT is to collect the output data (strain or  $\epsilon$ ) on a time scale, e.g. quarterly GDP, inflation rate, CPI. The second step is to calculate the output change rate with time ( $d\epsilon/dt$ ), e.g. the change rate of GDP, Inflation, and CPI for each quarter. The third step is to collect the input data (viscosity or  $\eta$ ) on a time scale, e.g. quarterly numbers of COVID infections. The fourth step is to calculate the time-dependent input (time-dependent stress or  $\sigma$ ) by multiplying  $d\epsilon/dt$  and  $\eta$  together. (This "time-dependent input equation" is stress  $\sigma =$  strain change rate of  $d\epsilon/dt *$  viscosity  $\eta$ ). The fifth step is to plot the input-output (i.e. stress-strain or cause-symptom) curve in a space domain (x-axis versus y-axis) with strain (output or symptom) on the x-axis; and stresses (time-dependent inputs, causes, or stresses) on the y-axis. The sixth step is to calculate the total enclosed area within these two input-output curves (or hysteresis loop areas) which is also the indicator of associated energies (either created energy or dissipated energy) of this dataset of input and output. These energy values can also be considered as the degrees of influence on output by inputs. After providing this description, he would like to use the following re-defined VGT equation from engineering and physics to address the unique "time-dependency characteristic" of both economics and medical variables. He can then establish a stress-strain diagram in a space domain (SD) where: Strain =  $\epsilon =$  individual strain value at the present quarter. Stress =  $\sigma$  (based on the change rate of strain multiplying with a chosen viscosity factor  $\eta$ , e.g. COVID infection case) =  $\eta * (d\epsilon/dt) = \eta * (d\text{-strain}/d\text{-time}) = (\text{viscosity factor } \eta \text{ using individual viscosity factor at present quarter}) * (\text{strain at present quarter} - \text{strain at previous quarter})$ . These inputs (causes or viscosity factors) are further normalized by dividing them by the average viscosity factors. This normalization process can remove the dependency of the individual unit or certain characteristics associated with each viscosity factor. This process allows him to modify the variables into a set of "dimensionless variables" for easier comparison and interpretation of results. There are 4 observed VGT analyses: (1) GDP as the strain versus two stresses of Inflation and COVID infection. (2) Inflation as the strain versus two stresses of CPI and COVID infection. (3) CPI as the strain versus two stresses of COVID death and COVID infection. (4) GDP as the strain versus three stresses of Inflation, CPI, and COVID infection. The reason he conducts two different VGT analyses regarding GDP is to assess the different percentages or the different degrees of influence on GDP via COVID infection for 2 inputs case versus 3 inputs case. In summary, there are 5 observations listed from this combined study of GDP, Inflation, and CPI (economic indices) versus the COVID infection numbers: (1) From the time domain analysis results, as shown in Figure 2, the correlations are: GDP vs. Inflation = 84%; GDP vs.

CPI = 80%; Inflation vs. CPI = 98%. These 3 economic indices have high correlations among them, especially Inflation vs. CPI (98%). These kinds of high correlation findings are not surprising since high CPI leads to high inflation which further contributes to higher GDP. Although a higher GDP is good for a nation, a higher CPI and higher inflation will hurt the living conditions of the people. (2) Researching the part of strains from the VGT results, we have seen that the GDP started from \$18.95 trillion in Y20Q1 and continuously increased to \$19.81 trillion in Y21Q4. The Inflation rate started from 2.1% in Y20Q1 and then dropped to 0.3% in Y20Q2 before continuously increasing to 7.97% in Y22Q1. The CPI started at 258 (1982-84 as 100) in Y20Q1 and then decreased slightly to 257 in Y20Q2 before continuously increasing to its peak at 284 in Y22Q1. Generally speaking, all 3 economic indices, GDP, Inflation, and CPI, are increasing quarter after quarter within these 2+ years (i.e. 9-quarters). In addition, the 3 strain change rates determine the basic waveform patterns of the 3 stress-strain curves. (3) Researching the stress-strain diagrams from the first 3 VGT analysis results, the 3 stress-strain waveform patterns are different from each other due to their different strain change rates. Furthermore, the magnitude difference among the three stresses decides the final shapes and areas of the 3 stress-strain curves. The combination of strain and stress components determines the actual size of the hysteresis loop area or its associated energy level, i.e. the degree of influence of the stresses on the strain. All of the stress-strain curves and their respective hysteresis loop areas have shown that the COVID pandemic has indeed contributed to the US economy, GDP, Inflation, and CPI, with different degrees of influence. Among these 3 diagrams, the COVID infection has generated the largest share of energy (66%) in the GDP case. In comparison with the other two cases, COVID infection contributes almost half of the total share of energy (~50%) in both Inflation and CPI cases. (4) For the fourth case of GDP versus Inflation, CPI, and COVID infection, the VGT study results show that COVID infection area of 1.28 (37%) versus Inflation area of 0.65 (19%) and CPI area of (44%). CPI has the biggest influence on GDP (matches with most of the findings from many

economic studies), while COVID infection has a higher influence on GDP than Inflation on GDP. For comparison purposes, in the case of GDP versus Inflation and COVID infection, the VGT study results reflect that COVID infection area of 1.28 (66%) versus Inflation area of 0.65 (34%). (5) A moderately high correlation of 61% between COVID death and COVID infection is observed with a more visible shape in the Y2020 sub-period. During the Y2020 period, the initial shock from COVID deaths, lacking mRNA vaccine, effective urgent care treatment methods, and insufficient healthcare staff and facilities have resulted in a linear correlation between death and infection. In other words, in Y2020, higher death rates are associated with a higher infection rate without other significant perturbation factors. However, after Y21Q2, the combination of availability of mRNA vaccine, an approach to herd immunity, an improvement in urgent care treatments, and sufficient healthcare staff and facilities have reduced the death rate significantly. However, at the same time, the arrival of different COVID variants with different contagious strengths and mortality rates have changed the outcomes. For example, the delta variant has a higher mortality rate, while the omicron variant has a higher spread rate with a lower mortality rate which has changed the relationship between COVID death rate and COVID infection rate in Y2021. From the angle of other influential factors, the psychological fear of COVID, large US government relief funds, and unexpected supply-chain disruptions have also added to the behavior changes in US consumer spending. Particularly, both the supply-chain disruption and the psychological behavior changes would cause CPI to shift between different economic segments but still cause overall inflation. For example, consumer spending has changed from closures of many small businesses and “real” shops to increased online ordering and delivery services via Amazon, UPS, etc. This VGT energy tool adopted from engineering and physics disciplines can indeed provide some interesting clues for useful interpretation of results from this particular research work of combined economics (three economic indices) and medicine (COVID infection). In conclusion, COVID has interrupted the US economy.

**Keywords:** Viscoelastic; Viscoplastic; Gross domestic product; Inflation rate; Consumer price index; COVID-19

**Abbreviations:** CPI: consumer price index; GDP: gross domestic product; SD: space domain; TD: time domain; MPM: math-physical medicine

## 1. INTRODUCTION

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considerable amount of knowledge on psychological behaviors, especially in the field of clinical psychology of abused victims.

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The recent COVID-19 pandemic is a severe and unique experience to worldwide people that is comparable to the Spanish Flu that happened over a century ago. He wondered what type of economic impact or inter-relationship from this pandemic had on some of the current economic indices. Therefore, in this article, he selects the GDP, inflation rate, and CPI of the USA as the output variables and the COVID-19 infection in the USA as the key input variable to conduct his combined study of economics and medicine.

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=  $\epsilon$

= individual strain value at the present quarter

Stress

=  $\sigma$  (based on the change rate of strain multiplying with a chosen viscosity factor  $\eta$ , e.g. COVID infection case)

=  $\eta * (d\epsilon/dt)$

=  $\eta * (d\text{-strain}/d\text{-time})$

= (viscosity factor  $\eta$  using individual viscosity factor at present quarter) \* (strain at present quarter - strain at previous quarter)

These inputs (causes or viscosity factors) are further normalized by dividing them by the average viscosity factors. This normalization process can remove the dependency of the individual unit or certain characteristics associated with each viscosity factor. This process allows him to modify the variables into a set of “dimensionless variables” for easier comparison and interpretation of results.

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The reason he conducts two different VGT analyses regarding GDP is to assess the different percentages or the different degrees of influence on GDP via COVID infection for 2 inputs case versus 3 inputs case.

## 2. METHODS

### 2.1 GDP, inflation, CPI & COVID

The author takes a few excerpts from several articles he has read recently and listed them below:

“Over time, the growth in GDP causes inflation (the author’s note: There is a +84% correlation existed between GDP and inflation within these 9 quarters). However, inflation, if left unchecked, runs the risk of morphing into hyperinflation. If the overall economic output is declining, or merely holding steady, most companies will not be able to increase their profits (which is the primary driver of stock performance); however, too much GDP growth is also dangerous (From Reference 1).

Higher production leads to a lower unemployment rate, further fueling demand. Increased wages lead to higher demand as consumers spend more freely. This leads to higher GDP combined with inflation (From Reference 2).

There is a negative relationship between inflation and GDP in the UK, at least in the short run (the author’s note: this may result from one of the shortcomings, time-window size, of using statistics tools), which is consistent with most of the theories that have been developed throughout the years (From Reference 3).

The US Consumer Price Index (CPI) may understate the rate of inflation during the

COVID-19 crisis because it does not reflect pandemic-induced shifts in spending patterns (the author’s note: the correlation between CPI and COVID infection is 67%) according to findings reported in *Inflation with COVID Consumption Baskets* (NBER Working Paper 27352) (From Reference 4).

“We are experiencing this sudden surge in inflation for two main reasons,” says Craig Kirsner, President of Stuart Estate Planning Wealth Advisors in Coconut Creek, Florida. “First, for the past year and a half due to Covid, hardly anyone was spending money. Now that the economy is back open, people are spending and traveling and, as such, there is a bottleneck with very high demand. Our system isn’t set up for this high demand level, so that causes inflation in the short term. Second, with interest rates lowered to almost zero since March of 2020, these low-interest rates have spurred demand in housing which is experiencing a large backlog as well as adding to inflation worries.”

“It’s largely due to a perfect storm of supply chain disruption from Covid, government spending to fill the economic void, and a synchronized global recovery driven by vaccine rollout and economies re-opening,” says John P. Micklitsch, Chief Investment Officer at Ancora in Cleveland. “The pandemic is probably just the event that exposed over a decade of underinvestment in the global commodity supply chain and the vulnerability of ‘just-in-time’ inventories to this sort of supply shock.”

“A large portion of what we are experiencing in inflation is due to the deflation which we saw in 2020 during the Covid shutdowns,” says Mike Windle, CEO at Custom Wealth Solutions in Plymouth, Michigan. “As prices work to normalize, it is causing inflationary pressure. Add to that the pent-up demand caused by the Covid lockdowns; we are seeing prices rise quickly.”

If many point a finger at Covid causing inflation, many point a second finger at national leadership.

“Legislation from Washington has likely played a role in increasing demand for goods over the last year,” says Saunders. “The CARES Act distributed direct cash payments to individuals and also increased unemployment benefits. These had a direct

impact on increasing the incomes and savings rates of many individuals. Along with these transfer payments, the Act also allowed for those in need to defer payments on mortgages and student loans, ‘freeing up’ more cash for individuals to spend on goods and services.”

“Injecting large amounts of cash into an economy through stimulus and other spending programs like the proposed trillion+ dollar ‘infrastructure’ bill will ramp up economic growth, and will certainly not decrease inflationary pressures,” says Taddei. “It is a combination of issues, fiscal stimulus, the Federal Reserve’s loose monetary policy and the subsequent increase in the money supply that creates more money chasing fewer goods and services.” (From Reference 5).

The US Consumer Price Index (CPI) may understate the rate of inflation during the COVID-19 crisis because it does not reflect pandemic-induced shifts in spending patterns, according to findings reported in *Inflation with COVID Consumption Baskets* (NBER Working Paper 27352) From Reference 10.

Over time, the growth in GDP causes inflation—inflation, if left unchecked, runs the risk of hyperinflation which hurts the living standards of common people.

Inflation is an increase in the overall price level. The official inflation rate is tracked by calculating changes in a measure called the consumer price index (CPI). The CPI tracks changes in the cost of living over time.

However, unlike the CPI, the GDP price index does not measure price change for imports. Although the GDP price index and the CPI both measure changes in the prices of goods and services purchased by consumers, the GDP relies on the PCE price index as its measure of change in consumer prices. The PCE price index is known for capturing inflation (or deflation) across a wide range of consumer expenses and reflecting changes in consumer behavior which is a measure of the prices that people living in the United States, or those buying on their behalf, pay for goods and services.

The personal consumption expenditure price index in the United States rose by 6.1% year-on-year in January of 2022, the highest since

February of 1982, and above 5.8% in December, reflecting increases in both goods (8.8%) and services (4.6%). Energy prices increased 25.9% while food prices were up 6.7%, from US Bureau of Economic Analysis (<http://www.bra.gov/>).

## 2.2 MPM background

To learn more about his developed GH-Method: math-physical medicine or MPM methodology, readers can select the following three articles from the 400+ published medical papers.

The first paper, No. 386, describes his MPM methodology in a general conceptual format. The second paper, No. 387, outlines the history of his personalized diabetes research, various application tools, and the differences between the biochemical medicine (BCM) approach versus the MPM approach. The third paper, No. 397, depicts a general flow diagram containing ~10 key MPM research methods and different tools.

All of the listed papers in the Reference section are his written and published medical research papers.

## 2.3 Elasticity, plasticity, viscoelasticity, and viscoplasticity (LEGT & VGT)

The difference between elastic materials and viscoelastic materials (from “Soborthans, innovating shock and vibration solutions”).

What are elastic materials?

Elasticity is the tendency of solid materials to return to their original shape after forces are applied on them. When the forces are removed, the object will return to its initial shape and size if the material is elastic.

Medical analogy: The medical application is when cause or risk factors are reduced or removed, the symptoms of certain disease would be improved or ceased.

What are viscous materials?

Viscosity is a measure of a fluid’s resistance to flow. A fluid with large viscosity resists motion. A fluid with low viscosity flows. For example, water flows more easily than syrup because it has a lower viscosity. High viscosity materials might include honey,

syrops, or gels – generally things that resist flow. Water is a low viscosity material, as it flows readily. Viscous materials are thick or sticky or adhesive. Since heating reduces viscosity, these materials don't flow easily. For example, warm syrup flows more easily than cold.

What is viscoelastic?

Viscoelasticity is the property of materials that exhibit both viscous and elastic characteristics when undergoing deformation. Synthetic polymers, wood, and human tissue, as well as metals at high temperature, display significant viscoelastic effects. In some applications, even a small viscoelastic response can be significant.

Medical analogy: Viscoelastic behavior means material has “time-dependent” characters. Biomedical data, i.e. biomarkers, are time-dependent due to body cells are organic which changes with time constantly.

Elastic behavior versus viscoelastic behavior

The difference between elastic materials and viscoelastic materials is that viscoelastic materials have a viscosity factor and the elastic ones don't. Because viscoelastic materials have the viscosity factor, they have a strain rate dependent on time. Purely elastic materials do not dissipate energy (heat) when a load is applied, then removed; however, a viscoelastic substance does.

Medical analogy: Most of the biomarkers display time-dependency; therefore they have both change-rate of time and viscosity factor behaviors. Viscoelastic biomarkers do dissipate energy when a cause force is applied on it.

The following brief introductions are excerpts from Wikipedia:

“Elasticity (physics):

The physical property is when materials or objects return to their original shape after deformation.

In physics and materials science, elasticity is the ability of a body to resist a distorting influence and to return to its original size and shape when that influence or force is removed. Solid objects will deform when

adequate loads are applied to them; if the material is elastic, the object will return to its initial shape and size after removal. This is in contrast to plasticity, in which the object fails to do so and instead remains in its deformed state.

Hooke's law states that the force required to deform elastic objects should be directly proportional to the distance of deformation, regardless of how large that distance becomes. This is known as perfect elasticity, in which a given object will return to its original shape no matter how strongly it is deformed. This is an ideal concept only; most materials that possess elasticity in practice remain purely elastic only up to very small deformations, after which plastic (permanent) deformation occurs.

In engineering, the elasticity of a material is quantified by the elastic modulus such as the Young's modulus, bulk modulus or shear modulus which measure the amount of stress needed to achieve a unit of strain; a higher modulus indicates that the material is harder to deform. The material's elastic limit or yield strength is the maximum stress that can arise before the onset of plastic deformation.

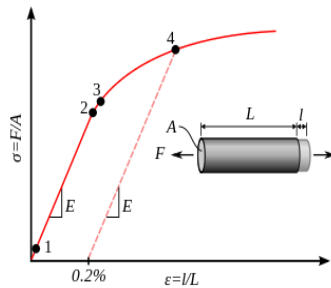
Medical analogy: The elastic behavior analogy in medicine can be expressed by the metal rod analogy for the postprandial plasma glucose (PPG). Consuming carbohydrates and/or sugar acts like a tensile force to stretch a metal rod longer, while post-meal exercise acts like a compressive force to suppress a metal rod shorter. If lacking food consumption and exercise, the metal rod (analogy of PPG) will remain its original length, for a non-diabetes or less severe type 2 diabetes (T2D) patient.

Plasticity (physics):

Deformation of a solid material undergoing non-reversible changes of shape in response to applied forces.

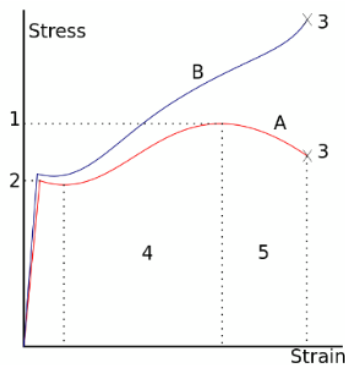
In physics and materials science, plasticity, also known as plastic deformation, is the ability of a solid material to undergo permanent deformation, a non-reversible change of shape in response to applied forces. For example, a solid piece of metal being bent or pounded into a new shape displays plasticity as permanent changes occur within the material itself. In engineering, the

transition from elastic behavior to plastic behavior is known as yielding. Plastic deformation is observed in most materials, particularly metals, soils, rocks, concrete, and foams.



A stress-strain curve showing typical yield behavior for nonferrous alloys.

1. True elastic limit
2. Proportionality limit
3. Elastic limit
4. Offset yield strength



A stress-strain is typical of structural steel.

- 1: Ultimate strength
- 2: Yield strength (yield point)
- 3: Rupture
- 4: Strain hardening region
- 5: Necking region
- A: Apparent stress ( $F/A_0$ )
- B: Actual stress ( $F/A$ )

For many ductile metals, tensile loading applied to a sample will cause it to behave in an elastic manner. Each increment of load is accompanied by a proportional increment in extension. When the load is removed, the piece returns to its original size. However, once the load exceeds a threshold – the yield strength – the extension increases more rapidly than in the elastic region; now when the load is removed, some degree of extension will remain.

Medical analogy: A plastic behavior analogy in medicine is the PPG level of a severe T2D patient. Even consuming a smaller amount of carbs/sugar, the patient’s PPG will rise sharply which cannot be totally brought down to a healthy PPG level even with a significant amount of exercise. This means the PPG level has exceeded its “elastic limit” and entering into a “plastic range”.

Viscoelasticity:

Property of materials with both viscous and elastic characteristics under deformation.

In materials science and continuum mechanics, viscoelasticity is the property of materials that exhibit both viscous and elastic characteristics when undergoing deformation. Viscous materials, like water, resist shear flow and strain linearly with time when a stress is applied. Elastic materials strain when stretched and immediately return to their original state once the stress is removed.

Viscoelastic materials have elements of both of these properties and, as such, exhibit time-dependent strain. Whereas elasticity is usually the result of bond stretching along crystallographic planes in an ordered solid, viscosity is the result of the diffusion of atoms or molecules inside an amorphous material.

In the nineteenth century, physicists such as Maxwell, Boltzmann, and Kelvin researched and experimented with creep and recovery of glasses, metals, and rubbers. Viscoelasticity was further examined in the late twentieth century when synthetic polymers were engineered and used in a variety of applications. Viscoelasticity calculations depend heavily on the viscosity variable,  $\eta$ . The inverse of  $\eta$  is also known as fluidity,  $\phi$ . The value of either can be derived as a function of temperature or as a given value (i.e. for a dashpot).

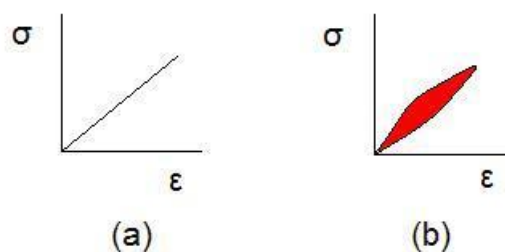
Depending on the change of strain rate versus stress inside a material, the viscosity can be categorized as having a linear, non-linear, or plastic response. In addition, when the stress is independent of this strain rate, the material exhibits plastic deformation. Many viscoelastic materials exhibit rubber-like behaviors explained by the thermodynamic theory of polymer elasticity.

Cracking occurs when the strain is applied quickly and outside of the elastic limit. Ligaments and tendons are viscoelastic, so the extent of the potential damage to them depends both on the rate of the change of their length as well as on the force applied.

A viscoelastic material has the following properties:

- hysteresis is seen in the stress-strain
- stress relaxation occurs: step constant strain causes decreasing stress
- creep occurs: step constant stress causes increasing strain
- its stiffness depends on the strain rate or the stress rate.

Elastic versus viscoelastic behavior:



Stress-strain curves for a purely elastic material (a) and a viscoelastic material (b). The red area is a hysteresis loop and shows the amount of energy lost (as heat) in a loading and unloading cycle. It is equal to  $\oint \sigma d\epsilon$  where  $\sigma$  is stress and  $\epsilon$  is strain. In other words, the hysteresis loop area represents the amount of energy during the loading and unloading process.

Unlike purely elastic substances, a viscoelastic substance has an elastic component and a viscous component. The viscosity of a viscoelastic substance gives the substance a strain rate dependence on time. Purely elastic materials do not dissipate energy (heat) when a load is applied, then removed. However, a viscoelastic substance dissipates energy when a load is applied, then removed. Hysteresis is observed in the stress-strain curve, with the area of the loop being equal to the energy lost during the loading cycle. Since viscosity is the resistance to thermally activated plastic deformation, a viscous material will lose energy through a loading cycle. Plastic deformation results in lost energy, which is uncharacteristic of a

purely elastic material's reaction to a loading cycle.

Viscoplasticity:

Viscoplasticity is a theory in continuum mechanics that describes the rate-dependent inelastic behavior of solids. Rate-dependence in this context means that the deformation of the material depends on the rate at which loads are applied. The inelastic behavior that is the subject of viscoplasticity is plastic deformation which means that the material undergoes unrecoverable deformations when a load level is reached. Rate-dependent plasticity is important for transient plasticity calculations. The main difference between rate-independent plastic and viscoplastic material models is that the latter exhibit not only permanent deformations after the application of loads but continue to undergo a creep flow as a function of time under the influence of the applied load.

Medical analogy: In viscoelastic or viscoplastic analysis, the stress component equals the strain change rate of time multiplying with the viscosity factor, or

$$\begin{aligned} \text{Stress } (\sigma) &= \text{strain } (\epsilon) \text{ change rate} * \text{viscosity factor } (\eta) \\ &= d\epsilon/dt * \eta \end{aligned}$$

$$\begin{aligned} \text{The hysteresis loop area} &= \text{the integrated area of stress } (\sigma) \text{ and strain } (\epsilon) \text{ curve} \\ &= \oint \sigma d\epsilon \end{aligned}$$

**Note:** For a more detailed description, please refer to the “consolidated method” section which is given at the beginning of the special issue.

### 3. RESULTS

Figure 1 shows photographically the US economic sector shifting due to the COVID pandemic.

Figure 2 displays the time-domain analysis results of GDP, Inflation, and CPI with 3 correlations.

Figure 3 reflects the 4 data tables of this article.



quarters). In addition, the 3 strain change rates determine the basic waveform patterns of the 3 stress-strain curves.

(3) Researching the stress-strain diagrams from the first 3 VGT analysis results, the 3 stress-strain waveform patterns are different from each other due to their different strain change rates. Furthermore, the magnitude difference among the three stresses decides the final shapes and areas of the 3 stress-strain curves. The combination of strain and stress components determines the actual size of the hysteresis loop area or its associated energy level, i.e. the degree of influence of the stresses on the strain. All of the stress-strain curves and their respective hysteresis loop areas have shown that the COVID pandemic has indeed contributed to the US economy, GDP, Inflation, and CPI, with different degrees of influence. Among these 3 diagrams, the COVID infection has generated the largest share of energy (66%) in the GDP case. In comparison with the other two cases, COVID infection contributes almost half of the total share of energy (~50%) in both Inflation and CPI cases.

(4) For the fourth case of GDP versus Inflation, CPI, and COVID infection, the VGT study results show that COVID infection area of 1.28 (37%) versus Inflation area of 0.65 (19%) and CPI area of (44%). It is obvious that CPI has the biggest influence on GDP (matches with most of the findings from many economic studies), while COVID infection has a higher influence on GDP than Inflation on GDP. For comparison purposes, in the case of GDP versus Inflation and COVID infection, the VGT study results reflect that COVID infection area of 1.28 (66%) versus Inflation area of 0.65 (34%).

(5) A moderately high correlation of 61% between COVID death and COVID infection is observed with a more visible shape in the Y2020 sub-period. During the Y2020 period, the initial shock from COVID deaths, lacking mRNA vaccine, effective urgent care treatment methods, and insufficient healthcare staff and facilities have resulted in a linear correlation between death and infection. In other words, in Y2020, higher death rates are associated with a higher infection rate without other significant perturbation factors. However, after Y21Q2, the combination of availability of mRNA vaccine, an approach to herd immunity, an

improvement in urgent care treatments, and sufficient healthcare staff and facilities have reduced the death rate significantly. However, at the same time, the arrival of different COVID variants with different contagious strengths and mortality rates have changed the outcomes. For example, the delta variant has a higher mortality rate, while the omicron variant has a higher spread rate with a lower mortality rate which has changed the relationship between COVID death rate and COVID infection rate in Y2021. From the angle of other influential factors, the psychological fear of COVID, large US government relief funds, and unexpected supply-chain disruptions have also added to the behavior changes in US consumer spending. Particularly, both the supply-chain disruption and the psychological behavior changes would cause CPI to shift between different economic segments but still cause overall inflation. For example, consumer spending has changed from closures of many small businesses and “real” shops to increased online ordering and delivery services via Amazon, UPS, etc. (see Figure 1).

This VGT energy tool adopted from engineering and physics disciplines can indeed provide some interesting clues for useful interpretation of results from this particular research work of combined economics (three economic indices) and medicine (COVID infection). In conclusion, COVID has interrupted the US economy.

## 5. REFERENCES

For editing purposes, the majority of the references in this paper, which are self-references, have been removed. Only references from other authors' published sources remain. The bibliography of the author's original self-references can be viewed at [www.eclaircmd.com](http://www.eclaircmd.com).

Readers may use this article as long as the work is properly cited, their use is educational and not for profit, and the author's original work is not altered.

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# Viscoelastic and Viscoplastic Glucose Theory Application in Medicine

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