PSYCHOLOGY MISCELLANY

No.220 - May 2025

The Year After The End (Covid-19: May 2024 to End of April 2025)

Kevin Brewer

ISSN: 1754-2200

orsettpsychologicalservices@phonecoop.coop

This document is produced under two principles:

1. All work is sourced to the original authors. The images are all available in the public domain (most from http://commons.wikimedia.org/wiki/Main_Page). You are free to use this document, but, please, quote the source (Kevin Brewer 2025) and do not claim it as you own work.

This work is licensed under the Creative Commons Attribution (by) 3.0 License. To view a copy of this license, visit http://creativecommons.org/licenses/by-nc-nd/3.0/ or send a letter to Creative Commons, 171 2nd Street, Suite 300, San Francisco, California, 94105, USA.

2. Details of the author are included so that the level of expertise of the writer can be assessed. This compares to documents which are not named and it is not possible to tell if the writer has any knowledge about their subject.

This document is presented for human readers.

Kevin Brewer BSocSc, MSc

An independent academic psychologist, based in England, who has written extensively on different areas of psychology with an emphasis on the critical stance towards traditional ideas.

A complete listing of his writings at http://psychologywritings.synthasite.com/. See also material at https://archive.org/details/orsett-psych.

CONTENTS

1. THE FUTURE

1.1. INTRODUCTION

On the 5th May 2023, the WHO announced that covid-19 was no longer a public health emergency. Maria Van Kerkhove of the WHO stated: "But that's not the end of the story. While the crisis is over, the virus is still with us" (quoted in Wade 2023).

The overall death toll is estimated at seven million people globally, but less than 4% of these occurred in 2023 (Wade 2023).

There is the view that covid-19 is now endemic and should be classed like seasonal flu. But SARS-CoV-2 is still evolving. In early 2023 variant "XBB.1.5" was dominant, but later in the year it was the more transmissible "EG.5" variant (Wade 2023).

Jian et al (2025) pointed out: "Since the emergence of the SARS-CoV-2 BA.2.86 lineage in July 2023, its sub-variants, especially JN.1, have continued to circulate and evolve rapidly, outcompeting the previously prevalent XBB sub-variants. By June 2024, the JN.1 lineage accounted for more than 93% of newly observed sequences" (p921). They noted that a new sub-variant KP.3 has also been detected with an unprecedented mutation. Immediately, there is concern that these sub-variants may be able to evade the immune system (and vaccines) [1].

Jian et al (2025) compared the newer lineages in mice, and SARS-CoV-2-naive humans. KP.3 was found to evade "a substantial sub-set" of anti-bodies, such that "vigilant monitoring" is required, and specific vaccine boosters could be considered.

[1] A single mutation in the SARS-CoV-2 virus appears to have produced the JN.1 sub-variant of the omicron variant. This sub-variant was first identified in Luxembourg in August 2023, and by the start of 2024 was the dominant form of the virus (eg: over 80% of recorded infections in the USA and UK) (Wong 2024).

Paciello et al (2024) analysed around 900 types of anti-bodies from blood samples from fourteen vaccinated people, and found that the JN.1 sub-variant was better (than the BA.2.86 sub-variant) at evading anti-bodies. The individuals whose blood was used had "super hybrid" immunity from three mRNA vaccine doses, and infection by the original virus (Wuhan strain) and an omicron variant (Wong 2024).

1.2. LOSS OF INTEREST

Cohen (2025) reflected: "The covid-19 pandemic, as best as we can tell, took more than 20 million lives, cost $16 trillion, kept 1.6 billion children out of school, and pushed some 130 million people into poverty. And it's not over: In October 2024, at least 1000 people died from covid-19 each week, and that's relying only on data, some questionable, from the 34 countries that still report deaths to the World Health Organisation (WHO)" (p10).

But, at a conference on future pandemics in December 2024, WHO epidemiologist Maria Van Kerkhove lamented: "The world I live in right now, no one wants to talk about covid-19... Everyone is acting as though this pandemic didn't really happen" (quoted in Cohen 2025).

Researchers are continuing to study SARS-CoV-2 and covid-19, while the world (everybody else) has turned a blind eye and gone back to doing other things (Cohen 2025).

SARS-CoV-2 has "extraordinary viral evolutionary speed", explained immunologist Yunlong Cao, which "not only means fresh variants are 'continuously causing reinfections', but that anti-body treatments and vaccines quickly lose effectiveness. None of the first approved monoclonal antibodies and vaccines work against current circulating strains. Cao noted that only two of 140 anti-bodies his lab identified in early 2020 as able to neutralise the first variant of SARS-CoV-2 could protect against the virus in circulation 2 years later" (Cohen 2025 p11).

Unpublished work from China has focused on an anti-body named "SA55" as a preventive nasal spray (with claims of 80% efficacy) (Cohen 2025).

Concerns for researchers are predicting the direction of evaluation of SARS-CoV-2, particularly in individuals with weakened immune systems who can be the sources of "variants of concern", and the risk from other coronaviruses (nine identified in mink, pigs, and bats, for instance) that could spillover to humans (Cohen 2025).

Van Kerkhove (2025) summarised her concern: "Just over 5 years ago, on New Year's Eve 2019, the World Health Organisation (WHO) became aware of the first cases of pneumonia of unknown aetiology in Wuhan, China. A massive global infectious disease storm was already brewing — one that would shut down the world, with profound economic, social, and political impacts that

still reverberate today. It's understandable that governments and individuals may want to forget that the covid-19 pandemic ever happened, but such collective amnesia prevents humanity from being ready for the next pandemic. The world did the same in the 1920s, eager to move on from the devastation of the 1918 influenza pandemic. A repeat of this behaviour squanders opportunities right now to institutionalise and embed best practices for current and future threats" (p229).

She continued: "Not only is covid-19 still a global health threat, but last year, the world saw the resurgence, emergence, or geographic expansion of avian influenza, mpox, cholera, dengue fever, Oropouche fever, Marburg virus disease, and others infectious diseases. Climate change and increasing interactions between animals and humans are boosting the risks of new or re-emerging diseases" (Van Kerkhove 2025 p229).

In the sixth year of circulation, SARS-CoV-2 "continues to evolve and infect people", including with an average of 4000 deaths per month worldwide (as of early January 2025), and "long covid" or "post-covid-19 condition" (Van Kerkhove 2025).

1.3. READY FOR THE NEXT ONE

In reference to preparation, specifically for a potential H5N1 influenza pandemic, Goodman et al (2025) recommended: "To streamline vaccine development, assessment, production, and access, industry, governments, and regulators should enhance collaboration on new technologies, such as mRNA-based vaccines and vaccines using novel antigens; align regulatory pathways and requirements; and modernise immunogenicity assessment and lot release tools. To ensure equitable access, a global access framework should be established, including an entity that can provide financing and advanced vaccine purchases for low- and middle-income countries" (p1047). Three general proposals were made - develop rapidly scalable vaccines, have a communications programme to rebuild public trust of vaccines, and have transparent response plans.

Concerning the risk of H5N1 influenza mutating to survive in humans, Wen et al (2025) advocated: "A broader investigation of the molecular mechanisms that underlie H5N1 receptor binding evolution is urgently needed to understand the drivers of this adaptation and to develop targeted interventions. Enhanced global surveillance, cross-species monitoring, and development of broadly

neutralising therapeutics are essential to mitigate the risk of future pandemics. The evolving receptor binding specificity of H5N1 viruses constitutes an imminent public health risk that demands immediate international attention and collaborative research" (p1048).

To help in understanding the dynamics of pathogen transmission, Kendall et al (2024) analysed digital contact tracing data from the "NHS Covid-19 app" in England and Wales. The blue tooth-based app included exposure notification, and user-reported positive covid-19 test results, and it was launched on 24th September 2020 and decommissioned on 27th April 2023. The researchers analysed data from 1st February 2021 to mid-February 2022.

A "contact rate" (CR) was calculated, which was defined as "the mean number of contacts notified per positive test reported through the app on day t, normalised by the proportion of the population using the app and the proportion of test-positive users that consented to contact tracing that day. This measure estimates the average number of people (with or without the app) who came into close contact with a test-positive app user in a time window of a few days before they tested positive" (Kendall et al 2024 p2). TPAEN (tested positive shortly after exposure notification) was also calculated.

Generally, increased contact was associated with increased speed of the infection. Specifically, for the period April 2021 to February 2022, "household contacts accounted for only 6% of contacts but 39% of transmission events, whereas fleeting interactions accounted for 48% of contacts but only 12% of transmission events" (Kendall et al 2024 p4). "Household contacts" was defined as at least eight hours' exposure on at least one day, while "fleeting contacts" was less than thirty minutes on one day. The researchers also distinguished "recurring contacts" (for less than eight hours per day but more than one day), and "single-day contacts" (between 30 minutes and eight hours on one day). These two types of contacts accounted for the increased spread of covid-19 during the 2020 UEFA European men's football championship held in June-July 2021. "Days on which the English and Welsh team played showed strong peaks in transmissions for app users registered as residing in England or Wales respectively" (Kendall et al 2024 p5).

It was noted overall that the "most prominent peaks in covid-19 transmissions correspond to days associated with nationwide decentralised gatherings [eg: Christmas].

While small gatherings are seen as less risky than large events because of their smaller scale and reduced chance for super-spreading, a large number of small decentralised gatherings involving a large fraction of the population may have a proportionately large impact on epidemic dynamics" (Kendall et al 2024 p6).

The main way to calculate the spread of the infection (or reproduction number over time; R(t)) is statistical modelling based on survey data, hospital admissions, and deaths. Data from digital contact tracing provided a comparable method, argued the researchers.

This method does depend on the voluntary use of the app. The analysed data were anonymised (except for postcode area), so it was not possible to assess the representativeness of the users. But Kendall et al (2024) noted agreement between their calculations and other methods, "suggesting that the sample of app users was sufficiently large and diverse to provide a reliable signal of epidemic dynamics at the population level..." (p2).

There was no obligation in the UK for app users to take a covid-19 test following exposure notification. The researchers admitted: "Therefore all our results concerning infections among notified app users are underestimates of the true amount of infection, due to under-ascertainment when considering only voluntarily reported positive tests. Infections may also have been caused by an interaction that was not detected by the app, particularly when background prevalence was high" (Kendall et al 2024 p2).

Kendall et al (2024) concluded that "digital contact tracing for SARS-CoV-2 can provide rich insights into epidemic dynamics with unprecedented time resolution, in addition to its primary purpose of reducing transmission. When decisions must be taken quickly, evidence must be available quickly, and digital contact tracing technologies have strong potential to support this real-time aspect of public health" (p7).

Reanalysis of data from a Wuhan market collected in the early days of the pandemic suggested that "animals there were infected with a virus - although they [researchers] could not confirm what exactly caused the infection" (Mallapaty 2024 p284). This work was presented at a conference ("Preparing for the Next Pandemic: Evolution, Pathogenesis and Virology of Coronaviruses") in Japan in early December 2024. The important point is

that infected animals were present at the time covid-19 emerged.

Canadian virologist Angela Rasmussen found RNA profiles that are produced in response to SARS-CoV-2 in racoon dogs and greater hog badgers at the market (ie: their immune system showed a reaction) (Mallapaty 2024).

This is indirect evidence of a zoonotic spillover origin for covid-19, but virologist Stanley Perlman noted that "it doesn't substitute for finding the virus in an infected animal" (quoted in Mallapaty 2024).

1.4. AVIAN INFLUENZA AND NORTHERN GANNETS

"High pathogenicity avian influenza virus" (HPAIV) H5N1 killed many wild birds across Europe and North America in 2021 and 2022 [2]. Lane et al (2024) concentrated on the impact on the Northern Gannet (Morus bassanus) (figure 1.1).

Unusually high numbers of dead Gannets were observed at their breeding colonies in Iceland in April 2022, followed by reported HPAIV outbreaks in Scottish colonies, then other areas [3]. High mortalities were recorded in 40 of the 53 global colonies (75%) in mid-2022. Dead birds testing positive for HPAIV H5N1 were associated with 58% of these 40 colonies.

At one site, Bass Rock (Scotland), the number of occupied nest-sites decreased by at least 71% between 2021 and 2022 (based on sampling 93 active nests), and breeding success by 66% compared to long-term averages. The researchers counted 370 colour-ringed birds on a weekly basis in June and July 2022.

Antibodies to HPAIV H5N1 were found in some birds indicating survival after infection.

"HPAIVs do not originate within wild bird populations but once they have spilled into wild populations, they are transmitted via infected saliva, nasal secretions and faeces; however, shedding methods differ between species and are not well understood" (Lane et al 2024 p635).

Note that not all deaths and breeding declines can be attributed to HPAIV as these birds face many challenges for survival (eg: mass stranding on Dutch North Sea coast in April and May 2022) (Lane et al 2024).

[2] HPAIV H5Nx has impacted birds for decades, and many species are reservoirs for "low pathogenicity avian influenza virus" (LPAIV) (ie: carried by individuals with little impact on health) (Lane et al 2024) (appendix 1A).

[3] Unusually high mortality was defined as "levels exceeding normal observable Gannet mortality during the breeding season" (Lane et al 2024 p636).

(Source: HLI-Photography; public domain)

Figure 1.1 - Northern Gannet colony.

1.5. APPENDIX 1A - BATS AS RESERVOIRS

Bats are believed to harbour more zoonotic viruses as reservoirs than other mammals (eg: viruses from 31 families) (Morales et al 2025). "The ability of bats to limit disease during viral infections is probably the result of immune system adaptations, which may be detectable as signatures of episodic positive selection in genes" (Morales et al 2025 p450).

The "Bat1K project" (Teeling et al 2018) analysed the genomes of 115 mammals, and found that the immune system of bats has adaptations that allow their viral tolerance and diseases resistance. Morales et al (2025) explained: "We uncovered an excess of immune gene selection in the ancestral chiropteran branch, raising the possibility that the evolution of flight is directly or indirectly linked to immune system changes. We highlight several regulators of inflammatory responses that inhibit pro-inflammatory cytokine production and participate in negative-feedback control of interferon signalling, indicating that these genes may contribute to preventing uncontrolled inflammation during viral infection in bats" (p457).

1.6. REFERENCES

Cohen, J (2025) Learning from a pandemic many are forgetting Science 387, 10-11

Goodman, J.L et al (2025) Letter: Prepare now for a potential H5N1 pandemic Science 387, p1047

Jian, F et al (2025) Evolving anti-body response to SARS-CoV-2 antigenic shift from XBB to JN.1 Nature 637, 921-929

Kendall, M et al (2024) Drivers of epidemic dynamics in real time from daily digital covid-19 measurements Science eadm8103 (https://www.science.org/doi/abs/10.1126/science.adm8103)

Lane, J.V et al (2024) High pathogenicity avian influenza (H5N1) in Northern Gannets (Morus bassanus): Global spread, clinical signs and demographic consequences Ibis 166, 633-650

Mallapaty, S (2024) Ill animals point to covid pandemic origin in Wuhan market Nature 636, 284-285

Morales, A.E et al (2025) Bat genomes illuminate adaptations to viral tolerance and disease resistance Nature 638, 449-458

Paciello, I et al (2024) SARS-CoV-2 JN-1 variant evasion of IGHV3-53/3-66 B cell germlines Science Immunity 9, eadp9279

Teeling, E.C et al (2018) Bat biology, genomes, and the Bat1K project: To generate chromosome-level genomes for all living bat species Annual Review of Animal Biosciences 6, 1, 23-46

Van Kerkhove, M.D (2025) Don’t pretend covid-19 didn’t happen Science 387, p229

Wade, G (2023) Covid-19 crisis phase ended but virus still lingers New Scientist 16th/23rd December, p19

Wen, F et al (2025) Letter: Evolving H5N1 receptor specificity Science 387, p1048

Wong, C (2024) One mutation spread covid-19 variant New Scientist 17th August, p12

2. CRISES, SUSTAINABILITY AND THE FUTURE: VIEWS DURING COVID-19

2.1. INTRODUCTION

The journal "Global Sustainability" published a series of articles in mid to late 2020 about covid-19 and the future, with particular reference to sustainability. The articles were written during lockdowns, it is imagined, and before vaccine development, and some feel "dated" (from the position of early 2025), but there is a reminder of the optimism and pessimism of the "early days" of covid-19.

2.2. CRISES AND RESET

Vine et al (2023) argued that the response to the "corona emergency" (as they called it) has a parallel to the "climate emergency". They used this formula to assess the crisis:

$$E = R \times U = p \times D \times t/T$$

where:
E = Emergency
R = Risk
U = Urgency
p = Probability
D = Damage
t = Reaction time
T = Intervention time

The impact of an emergency depends upon a number of variables related to the formula:

a) Mitigation - lowering the probability of damage.

b) Adaptation - limiting the experience of the

negative effects of damage.

c) Good governance - efficiently using the reaction time.

d) Science - to increase the perception of the remaining intervention time.

Another way of viewing an emergency is in terms of four steps (using a health model) - diagnosis, prognosis, therapy, and rehabilitation (Vinke et al 2023).

The pandemic has led to calls for a "global reset" to deal with the major global challenges, and to "build back better" [4](Hawkes 2020) [5].

Bezemer (2020 quoted in Bezemer 2021) coined the term "small-buffer capitalism" (similar to "money manager capitalism"; Minsky 1996), and the pandemic was an opportunity for change here. "Small-buffer capitalism" is "a variety of capitalism which has become dominant over the last few decades, in which pressures to reduce costs, shareholder capitalism, fiscal stringency, tax evasion, labour market deregulation and financial deregulations have combined to produce an economy with small financial buffers,
insufficient investment in capital goods and innovation, and too much investment in financial assets and real estate" (Bezemer 2021 p1).

To make the post-pandemic world a better place, six systems would need to change or reset, and these played a prominent part in relation to covid-19 (Hawkes 2020):

i) Environmental - eg: reduce deforestation, mining, and pollution.

ii) Health - eg: health system resource capacity.

iii) Political - eg: decision-making and implementation of policies.

iv) Social - eg: social support; individual attitudes and behaviours.

v) Economic - eg: "reopen" economies; cash transfers and benefits.

[4] The "great reset" is another term used (Fankhauser et al 2020).

[5] For example, the German government offered a subsidy to the car industry in 2020 for electric cars sold as part of a "rescue package" (Bezemer 2021).

vi) Food - eg: resilience; innovation; healthy diets.

While Bezemer (2021) noted the following possibilities for change:

a) Revamp urban transport systems - eg: encourage bicycle use.

b) Encourage adoption of ICT (information and communications technology) more - eg: online conferencing.

c) Energy transition to renewable sources.

d) "Slowbalisation" - ie: less globalisation.

e) Shrink the aviation industry.

Another proposal is a "green economic recovery" (GEC), but Taherzadeh (2021) argued that "the GER, as it is currently deployed, represents a trojan horse for the same ineffective environmental policy response which predated covid-19" (p1). His preference was a limit to economic growth.

The reason is this, Taherzadeh (20210 explained: "The growth imperative of the GER marks a continuity in the support for 'green growth' as a strategy to dematerialise and decarbonise the economy... The central tenet of green growth is that by full-pricing resource over-exploitation, greenhouse gas emissions and pollution in markets' economic progress and environmental protection can be achieved in tandem. Over the past few decades, such thinking has emerged as the dominant policy response to the climate and ecological crisis, replacing the idea that economic growth is bound by physical resource scarcity and biophysical limits" (p1). Put another way, the GER is nothing but the "market-driven" approach to economies under a different name.

Writing in mid-2020, Taherzadeh (2021) ended: "Against the backdrop of the current covid-19 crisis lies an opportunity for rebuilding a more sustainable and equitable society. If the GER is to respond to this need, it needs to manoeuvre humanity on a more decisive course. We must be open to the many pathways that exist, but also cautious of those that do not offer a turning point" (p5).

Bezemer (2021) ended: "Things usually have to get

worse before they get better. We managed the 'getting worse' part – for several decades past, and the process has accelerated since March 2020. The 'getting better' bit can only happen if opportunities for improvement are actually seized" (p4).

2.3. FOOD

The "International Panel of Experts on Sustainable Food Systems" (IPES-Food) [6] outlined, in early 2020 in the USA (and relevant to other countries), three major impacts of the pandemic on food: "First, it outlined the practices of industrial agriculture that contribute to the spread of viruses. Second, it anticipated that the pandemic would test the resilience of the industrial food supply-chain, forecasting logistical bottlenecks, export and sales restrictions, and food- and farm-worker vulnerabilities. Third, it highlighted the increased precarity of the quarter of the human population already 'living permanently on the cusp of hunger, malnutrition, and extreme poverty'" (Robinson et al 2021 p1).

The need for a resilient food system has become an important point. In the USA, migrant labour pick fruit and vegetables, and this was not possible leading to the destroying of healthy crops, while food processing plants (crowded environments and prime areas of covid-19 spread) were closed, and livestock and poultry farmers had to euthanise animals (Robinson et al 2021). One estimate suggested that over 350 food processing workers in the USA had died from covid-19 by November 2020 (Robinson et al 2021).

There are two possibilities for food production after the pandemic - a return to "normal service", or "a transition from one food regime to another with potential for a more secure and sustainable food future" (Robinson et al 2021 p2). Industrial food production in high-income countries is a dominant global force for nearly fifty years, but the crisis of the pandemic "opens at least the possibility" of change (Robinson et al 2021 p2).

Robinson et al (2021) addressed three problems with a move from the "industrial food system" (IFS) to the "sustainable food system" (SFS):

i) If the SFS grows, it could lose its "local feel" and/or "agro-ecological principles" (p3).

ii) SFS is based on the principle of "fair price"

[6] See https://ipes-food.org/.

(or "farm justice"), which is usually more expensive than IFS products, and so SFS products are beyond the financial reach of many consumers ("food justice"). Thus, farm justice is pitted against food justice.

iii) Alternative foods are limited in their geographical reach because they tend to be produced on a small scale and locally. For example, "Amish communities, whose faith limits technology use and who are predominantly located in the states of Indiana, Ohio, Michigan, Wisconsin (in the Midwest) and Pennsylvania and New York (in the East), are vital medium-scale producers of local and regional speciality crops and dairy products" (Robinson et al 2021 p4).

2.4. ZOONOTIC DISEASES

Tounta et al (2022) outlined this situation: "Humans with their activities invade the wild and disrupt the natural ecosystems, thus fuelling the emergence of zoonotic diseases, as they come into direct contact with wild animals infected with viruses. These diseases rapidly spread to the human population through travel, trade, urbanisation, migration, and human behaviour, causing epidemics or pandemics that in turn result in human losses and huge social and economic implications" (p1).

SARS-CoV-2 was not the first nor last potential zoonotic disease. Transmission of zoonoses (ie: from animals to humans) occurs in the following ways (Tounta et al 2022):

i) Human direct contact with animal - eg: bite, urine or faeces of infected animal.

ii) Indirect contact - objects contaminated by animals (eg: plants; barns; pet food utensils).

iii) Carrier - eg: bite of an insect like mosquitoes.

iv) Consumption of contaminated food.

v) Consumption or contact with contaminated water.

"A dominant role in the transmission of zoonoses is played by 'natural' hosts that act as reservoirs of pathogens, such as various species of bats, rodents, and

birds that are natural reservoirs of viruses (chanterelles, arenaviruses, arboviruses, and coronaviruses). A key link in the transmission chain is the 'intermediate' hosts (wild, domestic animals, and arthropods) through which pathogens can evolve and pass from the 'natural' hosts to humans" (Tounta et al 2022 p2).

Wolfe et al (2007) described a five-stage model of a pathogen that initially infects only non-humans (stage I) to becoming an infection of only humans (stage V). Stage II is transmission from an animal to a human, but not human to human transmission (eg: West Nile virus), while stage III involves limited transmission in humans (eg: Ebola). Stage IV is self-sustaining transmission in humans (eg: pandemic influenza) (Tounta et al 2022).

Tounta et al (2022) outlined two sets of factors related to humans that contribute to the emergence and spread of zoonotic diseases:

a) Factors that favour the appearance of zoonotic diseases - human activities leading to direct contact with hosts (eg: deforestation); indirect contact (eg: climate change); and anti-microbial resistance to anti-bodies (and poor hygiene and health systems).

b) Factors that contribute to the transmission of new diseases - travel and trade; intense urbanisation; and human behaviour (eg: sexual activity).

Ortiz et al (2021) stated clearly the situation: "The covid-19 pandemic is just the tip of the iceberg, preceding complex issues of an ongoing economic recession, climate change, and biodiversity loss. Covid-19 is itself an environmental problem brought by unsustainable human practices. The transmission of most known zoonotic diseases happens indirectly, and is interlinked with the biodiversity crisis and food systems... The major drivers of zoonotic disease transmission are: (1) increasing human demand for animal protein, (2) unsustainable agricultural intensification, (3) increased use and exploitation of wildlife, (4) unsustainable utilisation of natural resources accelerated by urbanisation, land-use change, and extractive industries, (5) increased travel and transportation, (6) changes in food supply, and (7) climate change" (p2). These drivers are interconnected, which Ortiz et al (2021) argued using "systems thinking".

2.5. THE FUTURE AND CLIMATE GOALS

"2020 was touted as a 'super-year for the environment' (The Lancet Planetary Health 2020) for setting ambitious policies and targets for global conservation and greenhouse gases (GHG) for future decades. However, due to the covid-19 pandemic, the 15th Conference of the Parties (COP) of the United Nations Convention on Biological Diversity (UNCBD) and the 26th COP of the UN Framework Convention on Climate Change (UNFCCC), which were due to take place in October and November 2020 were eventually postponed" (Ortiz et al 2021 p1). The uncertainty of the pandemic raised challenges for environment-related targets, though some saw opportunities (eg: GER).

Fankhauser et al (2020) assessed the readiness of manufacturing industries in fourteen high- and middle-income countries for a GER using two indicators (the extent to which the move to zero-carbon production had occurred before covid-19, and the ability of the industries to gain and maintain market share). It was found that "all countries have zero-carbon growth opportunities post-covid and comparative advantages in some sectors, but industrialised countries and the East Asian economies, especially South Korea, appear best positioned, thanks a push in low-carbon innovation that predates the pandemic" (Fankhauser et al 2020 p1).

Global CO_2 emissions were 8.8% lower in the first half of 2020 (during lockdowns) than for the same period in 2019 (Diesendorf 2020) [7]. This was a "small benefit" of the pandemic, but Diesendorf (2020) worried about the "return to work" and "normal society", and the impact on climate targets. The author proposed ways for governments to encourage post-covid-19 economic recovery in a sustainable way (eg: sustainable energy sources; "low-carbon jobs"), and even policies of "degrowth". This article was written in mid-2020, and looking back from early 2025 the suggestions, sadly, appear idealistic, particularly when the new US President is quoted as saying "drill, baby, drill" (ie: more fossil fuel use) [8].

Baldwin and Lenton (2020) stated, even in mid-2020: "The fundamental reason that we are not solving the climate crisis is not a lack of green energy solutions. It is that governments continue with energy strategies

[7] Samani et al (2021) calculated a reduction in deaths related to air quality in France, for example, at the highest of 30 per 100 000 population in 2020 compared to 2019.

[8] See https://www.whitehouse.gov/remarks/2025/01/the-inaugural-address/.

that prioritise fossil fuels. These entrenched energy policies subsidise the discovery, extraction, transport and sale of fossil fuels, with the aim of ensuring a cheap, plentiful, steady supply of fossil energy into the future" (p1).

The risk of the "rebound effect" was noted by Samani et al (2021). They worried in late 2020 that it was possible that "the GHG emissions might go back to previous or higher levels if governments do not see this pandemic as an opportunity to promote the use of renewable energies, which are becoming cheaper than non-renewables" (Samani et al 2021 p1).

Baldwin and Lenton (2020) were hopeful: "Every nation can contribute to solving the climate crisis by: (1) changing their energy strategy to green energy sources instead of fossil fuels; and (2) critically reviewing every law, policy and trade agreement (including transport, food production, food sources and land use) that affects the climate crisis" (p1). These authors wanted to be positive, and noted that, for example, "reversing damage to the ozone layer is one of humanity's greatest environmental success stories" (Baldwin and Lenton 2020 p1). It is possible to learn from this success to deal with covid-19, and climate change generally. The approach should "(1) identify the precise cause of the problem through expert scientific advice; (2) with support by the public, pass legislation focused on the cause of the problem; and (3) employ a robust feedback mechanism to assess progress and adjust the approach" (Baldwin and Lenton 2020 p1).

2.6. INFORMATION PROCESSING AND CRISES

van der Leeuw (2020a) began: "The current covid-19 crisis is one of a succession of crises that have shaken our world since 2000. The first was the attack on the Twin Towers in New York, concerning the political and religious domains. It was followed by the financial crisis of 2008–2009. The covid-19 pandemic is the third major crisis in 20 years, concerning human health. This succession of crises is not accidental – it confronts us with the fact that our global 'system' is showing major fracture lines" (p1). This author viewed societies' experiences and causes of such crises as "driven by an increasing maladaptation of our societies' information processing capabilities to the dynamics in which our societies find themselves" (van der Leeuw 2020a p1).

The information processing capacity (ie: knowledge

accumulation and understanding) of societies is key. A crisis is "a (temporary) incapacity of a society's information processing to deal with the dynamics in which that society is involved" (van der Leeuw 2020b quoted in van der Leeuw 2020a).

Specifically in the case of the covid-19 pandemic crisis, "before it occurred, available information was ignored, not (yet) available or unobtainable, so that the society's information processing was not in tune with the dynamics that were occurring in its environment. Rather than attempting to transform the environment, the way to deal with such a tipping point is therefore the adaptation of the society's information processing to the dynamics causing the crisis. Societies need to learn from events and change how they interact with their environment. When viewed from this angle, the reorganisation of our societies' current information processing apparatus, based on learning from the events that have occurred, will be determinant for the future of our societies" (van der Leeuw 2020a p2).

The ability to achieve societies' reorganisation of information processing apparatus takes place in a specific context today with information and communication technology (ICT), demography, globalisation, and climate change as important factors.

van der Leeuw (2020a) speculated about post-covid-19 changes, for example, related to ICT - the movement from cities into the country as people "work from home" with ICT tools, and the use of ICT to improve health control.

Hensher et al (2020) argued for co-operation as the way to deal with crises. It is, the explained, "an anti-fragile strategy (Taleb 2012) in which each challenge we collectively confront stimulates the trust and reciprocity required to address more difficult future challenges. Co-operative generation and sharing of knowledge, stimulated by playful curiosity, trust and reciprocity, will not only help us to solve the covid-19 crisis, but also enhance our ability to solve the numerous other crises we currently face" (Hensher et al 2020 p4).

Specifically, in relation to knowledge, is the problem of "artificial scarcity" due to patent and intellectual property protections (which in non-co-operation). "Conventional theory claims that only guaranteed monopoly profits can incentivise entrepreneurial firms to make the investments required to develop new technologies and products... Yet concerns have been growing for years that traditional patent

protections actually slow innovation and increase research costs by forcing researchers to negotiate licensing fees with holders of related patents (including many held by patent trolls), and that these protections reduce social welfare through monopoly pricing" (Hensher et al 2020 p2).

2.7. CITIES

Urban density is "the number of people per unit area" (Khan et al 2021 p1), which is different to crowding (a number of people living in a space designed for a smaller number of individuals). "In the realm of public health, density has always been a cause of concern as 'negative effects of proximity if not properly managed can destroy the quality of life in any urban area' with contagious diseases as an ''urban externality''' [Glaeser 2011]" (Khan et al 2021 p2).

Density was initially believed to be linked to the spread of covid-19, but data quickly showed that this was not so (eg: Hamidi et al 2020). "So, if urban density is not the cause of concern, what are some other factors that can result in the spread of covid-19? Literature suggests that household composition, income inequalities, and inadequate infra-structure for lower income neighbourhoods, social class, race, and the intersection of all the aforementioned factors have helped increase the transmission of the virus. Both infections and death are disproportionately related to class and race" (Khan et al 2021 p2).

Indorewala and Wagh (2020 quoted in Khan et al 2021) stated that "our cities are vulnerable, not because they have high aggregate densities, but because they are highly unequal in terms of living conditions, services, incomes and access". These authors argued that "the covid-19 crisis is not a crisis of the city but a crisis for a certain kind of city. This kind of city is steeped in inequality and has weak public sector institutions that have failed to account for citizen's problems and anticipate their needs" (Khan et al 2021 p2).

2.8. MISCELLANEOUS

(1) Lim et al (2020) asked this question: "Can the changes in work and family arrangements brought on by the covid-19 pandemic alter the persevering gendered division of paid work and household work?" (p1). These researchers

looked for an answer in a survey of over 1300 adults in South Korea in July 2020.

The key statement here was that "the gendered division of paid work and household work will decrease" [9], with the response options of "strongly agree" (1) to "strongly disagree" (5). Overall, 48% of men strongly or somewhat agreed (scores of 1 and 2) compared to 37% of women.

The mean score for female respondents was 2.83 compared to 2.66 for males (a statistically significant difference at $p<0.01$). "In other words, compared to men, women are more likely to disagree with the statement that the gendered division of labour will decrease" (Lim et al 2020 p2). Younger women were most sceptical about positive change.

(2) Kye and Hwang (2020) examined social trust early in the pandemic in South Korea with data from the "Korean Academic Multi-mode Open Survey" (KAMOS). KAMOS has been conducted annually since 2016, and in 2020 it took place between 24th March and 25th April. Ten measures of social trust were analysed.

Between 2016 and 2019, KAMOS had shown a general deterioration in social trust, but this changed in the 2020 survey. "Although social trust sharply improved in some domains (Korean society, the Korean people, the central government, and the local government), the deterioration accelerated in others (judicature, the press, and religious organisations)" (Kye and Hwang 2020 pp2-3). The perceived response to covid-19 appeared to explain this pattern, as Kye and Hwang (2020) outlined: "Improvement in trust in the central and local governments was associated with proactive responses to the pandemic crisis, and failure to take appropriate actions was responsible for the deteriorating trust in religious organisations" (p1).

(3) "Fair Trade" (FT) is an approach that helps reduce poverty for farmers and producers in the least developed countries (Dangol and Chitrakar 2021). Put simply, a set (or fair) price is paid even if the "market price" is lower, and this can mean that FT products are more expensive to consumers than non-FT ones.

What has been the impact of covid-19 on FT enterprises? An early answer was found by Dangol and

[9] Traditionally, gendered division of labour describes men doing paid work and women doing household chores (even if also doing paid work).

Chitrakar (2021). They collected data from a focus group discussion via Zoom in October 2022 with seven respondents from six member countries of the "World Fair Trade Organisation".

"All the participants outlined similar challenges when asked about the effects of covid-19 on their business. Some of the key challenges expressed are the shutting down business, revenue plunging which resulted in severe financial problems and market collapse affecting demand. This has reduced livelihood opportunities for poor and vulnerable communities" (Dangol and Chitrakar 2021 p50). The loss of income was described as a decline in export sales by two-thirds by one participant, and a loss of US $100 000 in that year by another participant.

"Entire business operations have been halted, producers were not able to work and the market was closed, creating survival threats. Besides financial and operational problems, the staff and producers have also experienced emotional health issues. A discussant said that: 'We had to reduce our work time and the artisans had to work from home. There were also some challenges in arranging and carrying of the required raw materials for our productions'" (Dangol and Chitrakar 2021 p50).

Overall, the aim of reducing poverty through FT had slowed down, and, in fact, the risk of increasing poverty was reported by respondents with fears of a global economic downturn to come. Bello (2020 in Dangol and Chitrakar 2021) outlined three areas impacted: "(i) the disruption of global and regional supply chains, (ii) distorted development and (iii) the problem of growth" (Dangol and Chitrakar 2021 p51).

2.9. REFERENCES

Baldwin, M.P & Lenton, T.M (2020) Solving the climate crisis: Lessons from ozone depletion and covid-19 Global Sustainability 3, article e29

Bezemer, D.J (2021) Seize the day: Opportunities and costs in the covid-19 crisis Global Sustainability 4, article e10

Dangol, J & Chitrakar, S (2021) Challenges of covid-19 for Fair Trade enterprises in attaining Sustainable Development Goals 2030 Journal of Fair Trade 3, 1, 44-53

Diesendorf, M (2020) Covid-19 and economic recovery in compliance with climate targets Global Sustainability 3, article e36

Fankhauser, S et al (2020) The readiness of industry for a transformative recovery from covid-19 Global Sustainability 3,

article e37

Glaesar, E.L (2011) The challenge of urban policy Journal of Policy Analysis and Management 31, 1, 111-122

Hamidi, S et al (2020) Does density aggravate the covid-19 pandemic? Journal of the American Planning Association 86, 4, 495-509

Hawkes, C (2020) Five steps towards a global reset: Lessons from covid-19 Global Sustainability 3, article e30

Hensher, M et al (2020) Open knowledge commons versus privatised gain in a fractured information ecology: Lessons from covid-19 for the future of sustainability Global Sustainability 3, article e26

Khan, I et al (2021) Cities and covid-19: Navigating the new normal Global Sustainability 4, article e12

Kye, B & Hwang, S-J (2020) Social trust in the midst of pandemic crisis: Implications from covid-19 of South Korea Research in Social Stratification and Mobility 68, 100523

Lancet Planetary Health (2020) A "super-year" for the environment Lancet Planetary Health 4, 1, e1

Lim, Y et al (2020) Men and women's different dreams on the future of the gendered division of paid work and household work after covid-19 in South Korea Research in Social Stratification and Mobility 69, 100544

Minsky, H (1996) Uncertainty and the institutionalised structure of capitalist economies Journal of Economic Issues 30, 2, 357-368

Ortiz, A.M.D et al (2021) Implications of covid-19 on progress in the UN Conventions on biodiversity and climate change Global Sustainability 4, article e11

Robinson, J.M et al (2021) Food after the covid-19 pandemic and the case for change posed by alternative food: A case study of the American Midwest Global Sustainability 4, article e6

Samani, P et al (2021) The impact of the covid-19 outbreak on climate change and air quality: Four country case studies Global Sustainability 4, article e9

Taherzadeh, O (2021) Promise of a green economic recovery post-covid: Trojan horse or turning point? Global Sustainability 4, article e2

Taleb, N (2012) Anti-Fragile: How to Live in a World We Don't Understand London: Allen Lane

Tounta, D.D et al (2022) Human activities and zoonotic epidemics: A two-way relationship. The case of the covid-19 pandemic Global Sustainability 5, article e19

van der Leeuw, S.E (2020a) Covid-19 and the role of information processing Global Sustainability 3, article e27

van der Leeuw, S.E (2020b) Social Sustainability Past and Future: Undoing Unintended Consequences for the Earth's Survival Cambridge: Cambridge University Press

Vinke, K et al (2023) Corona and the climate: A comparison of two emergencies Global Sustainability 3, article e25

Wolfe, N.D et al (2007) Origins of major human infectious diseases Nature 447, 279-283

3. LONG COVID RESEARCH

(1) Lau et al (2024) found a reduction in long covid symptoms in a group given a specially made mixture of probiotics compared to controls. The patients has positive changes also in their gut bacteria. But the mechanism of probiotics helping with long covid symptoms is unclear (Timothy Sampson in Wade 2024a).

Long covid (or post-acute covid-19 syndrome (PACS) as it is becoming more commonly called) has been observed to alter gut microbiota. "The gut microbiomes of patients with PACS were characterised by decreased microbial diversity and richness and reduced abundance of short-chain fatty-acid producing bacteria after SARS-CoV-2 clearance. Furthermore, metagenomic sequencing of faecal samples showed depletion of several beneficial bacteria, such as Bifidobacterium adolescentis, in association with specific PACS symptoms" (Lau et al 2024 p256).

The probiotic preparation used was known as "SIM01", and contained three bacterial strains - Bifidobacterium adolescentis, B.bifidum, and B.longum.

The study took place between June 2021 and August 2022 in Hong Kong with 463 adults with confirmed PACS (as measured by the specially created PACSQ-14). The PACSQ-14 included fourteen symptoms - fatigue, memory loss, difficulty in concentration, insomnia, mood disturbance, hair loss, shortness of breath, coughing, inability to exercise, chest pain, muscle pain, joint pain, gastro-intestinal upset (defined as having at least one of the following symptoms: diarrhoea, constipation, abdominal pain, epigastric pain, bloating, nausea, vomiting, or acid reflux), and general unwellness. At least one of these symptoms for four weeks or more after SARS-CoV-2 infection.

Participants were randomly assigned to SIM01 or placebo (vitamin C) powder sachets for six months. Symptom alleviation was the main outcome measure, and significantly more participants in the SIM01 group reported reported this than the control, particularly fatigue, memory loss, difficulty in concentration, gastro-intestinal upset, and general unwellness. "At six months, the faecal microbiota showed a higher richness and distinct composition in the SIM01 group compared with the placebo group" (Lau et al 2024 p261).

However, the researchers admitted that the study "did not identify a significant difference in quality of life and physical activity between the two groups at 6 months" (Lau et al 2024 p263).

(2) Using data on over 650 000 adults in the US National Covid Cohort Collaborative (N3C), Rahman et al (2023) found that individuals with severe covid-19 were more likely to be diagnosed subsequently with a psychotic condition than individuals unaffected by the virus. The explanation is hypothesised as increased kynurenic acid in the brain, which is elevated by inflammation of the brain (as in covid-19), and in individuals with psychosis (Sophie Erhardt in Wade 2024b).

From the total N3C (over 19 million adults), Rahman et al (2023) created three matched cohorts for comparison – covid-19-positive, covid-19-negative, and acute respiratory distress syndrome (ARDS) (but no covid-19). Individuals with pre-existing mental health problems were not included. New diagnoses of schizophrenia spectrum and psychotic disorders (SSPD) were measured at 0-21 days, 22-90 days, and beyond 90 days after covid-19 infection.

In all three time periods, the covid-19-positive group had "notably higher" (up to 4.5 times) rates of SSPD than the other two groups. There was evidence that the risk was higher for younger individuals. Note the percentage of new cases of SSPD was around 0.5% overall.

(3) One issue with long covid (and post-viral fatigue conditions generally) is whether to encourage individuals to build up their exercise levels or not, as this could worsen the condition (Wilson 2024).

The REGAIN study (McGregor et al 2024), however, has shown some benefits from an exercise-based programme for long covid.

The "Rehabilitation Exercise and psycholoGical support After covid-19 InfectioN" (REGAIN) study compared an eight-week online group rehabilitation programme (including group exercise sessions and psychological support) (intervention group) with a single online session of advice and support for individuals (usual care group) with post-covid-19 condition. Health-related quality of life (HRQoL) score was the main outcome measure at three, six and twelve months. The participants were 585 adults in England and Wales, who at least three months after discharge from hospital for covid-19, reported ongoing symptoms of the disease.

The HRQoL score was significantly better at the three measurement points in the intervention group. About half of the intervention group reported feeling "much better now" or "somewhat better now" compared to the control group. Specifically, for exercise, the intervention group had "higher odds... of being more

physically active compared with participants in the usual care group. At three months, compared with usual care, 7% more people in the REGAIN intervention group were achieving the UK Chief Medical Officers' physical activity guidelines of >150 minutes of moderate intensity activity per week... No effect was seen at six or 12 months" (McGregor et al 2024 p8).

Evaluation of methodology:

i) Multi-centre, randomised trial (+).

ii) Participants aged 26-86 years old who had been hospitalised with covid-19 (mean age 56 years) (+). Around half of the sample was female (52%) (+), but the vast majority of the sample was White (88%) (-). One third of the sample was obese or overweight at entry to hospital with covid-19.

iii) Inclusion criteria of ongoing "substantial" covid-19-related physical and/or mental health symptoms as defined by the individuals themselves (-). The researchers defended this decision as there are no agreed diagnostic criteria or clinical coding for post-covid-19 condition.

iv) Sessions delivered online, which "ensured accessibility for participants who would otherwise not have been able to take part in centre based rehabilitation programmes because of poor heath, costs, transport, and time pressures" (McGregor et al 2024 p11) (+). But this method excluded individuals without online access (-).

v) "The REGAIN intervention was co-created by our patient partners with post-covid-19 condition alongside a multi-disciplinary clinical and academic stakeholder group. Although the content and delivery of the REGAIN intervention was individualised, the programme was sufficiently standardised and thus reproducible, aided by the intervention team being located in a single trial hub supported by manuals for practitioners and participants, regular supervision, and quality assurance" (McGregor et al 2024 p11) (+).

vi) Outcome measures assessed by standardised self-report questionnaires (+/-). For example, HRQoL was scored using the "patient reported outcomes measurement

information system" (PROMIS) profile, developed by the US National Institutions of Health, and it is "reliable, genetic, and validated for online use" (McGregor et al 2024 p3). A score between 0 and 1 is created from seven sub-scores covering depression, fatigue, sleep disturbance, pain interference (with everyday life), physical function, social roles or activities, and cognitive function.

vii) Adherence to the intervention programme was rated at 47% (full) and 39% (partial) of the participants (+/-).

viii) The participants and practitioners delivering the programme were not blind to the study condition (intervention or usual care) (as that was not possible) (-).

ix) Eight-week programme (vs eg: 16-week; Longobardi et al 2023) (-).

x) Last follow-up at twelve months (+/-).

xi) Participants recruited at least three months post-hospital discharge (vs eg: five months minimum; Longobardi et al 2023) (+/-). The mean time between discharge and starting study was ten months.

xii) Nearly 40 000 patients approached to participate between January 2021 and July 2022, 725 agreed and were eligible, 585 began the study, and 442 completed at 12 months (-).

xiii) Possibility of placebo or expectation effects (-). McGregor et al (2024) commented: "We observed improvements in overall quality of life and in other indices of well-being with both the REGAIN intervention and usual care. The relative contributions of the brief intervention, the natural recovery from post-viral illness, and regression to the mean in the control group is unclear. Most likely natural recovery played an important part in the improvements witnessed in both groups, as identified in recent observational data [eg: Tran et al 2022]. The REGAIN intervention did, however, show an additional benefit above that which could be attributed to natural recovery and the best practice usual care intervention" (p8).

(4) The hashtag "#longcovid" appeared on Twitter in May 2020, attributed to Elisa Perego, and it began a "patient community" around the condition that was unrecognised by medical authorities at that time. Another hashtag "#longhauler" also appeared around the same time, coined by Amy Watson. Both tweets reported symptoms related to covid-19 that did not stop after a couple of weeks of infection (Turner et al 2023).

Turner et al (2023) analysed the tweets under the two above-mentioned hashtags for the period 20th May 2020 (when "#longcovid" first used) to 22nd August 2020 (when the WHO recognised long covid) (n = 31 016 tweets in total).

Six themes emerged from the analysis of a sample of 974 tweets:

i) "Individual long recovery" – "Twitter users described isolating, lengthy, and frightening experiences of long covid, which presented an array of physical and psychological symptoms..." (Turner et al 2023 pp4-5). This tweet is an example: "5 months. I still can't breathe. My heart rate hits 145 easy when I'm laying down multiple times a day If I dare eat anything with calorie intake. I'm on two blood pressure meds and I'm 24. I'm also severely anaemic. My body feels shattered" ("T322"; p5).

ii) "Invisible illness" – The lack of public acknowledgement and recognition was a concern as one tweet stated: "it makes me want to cry in frustration when workplaces, friends, family, and doctors say it's no big deal, that if you're young you'll be better in two weeks" ("T699"; p6).

iii) "Unexpected cohort" - "Participants described surprise and concern regarding their observations that many people who developed long covid, many of whom were severely affected, were young and previously 'fit and healthy'. Some participants commented that 'relatively young, formerly quite healthy friends' ('T58') and 'previously healthy and active people of all ages' ('T126') were contracting long covid. Furthermore, Twitter users emphasised that this was a shared experience, 'I have friends, including relatively young, formerly quite healthy friends, in the same boat' ('T58')" (Turner et al 2023 p6).

iv) Validation through quantification" – More sufferers responding to the hashtags gave individuals a

feeling of validation.

v) "The need for support and research" – Tweets advocating and demanding responses from health authorities.

vi) "Recognition from health services" – Tweets responding to the recognition of long covid by health authorities.

The researchers felt that "Twitter facilitated the formation of a collective social movement that reached social consensus on the meaning of the term long covid" (Turner et al 2023 p7). The public and open system of Twitter was important (compared to closed groups for long covid on Facebook, say) in raising awareness of the prolonged symptoms of covid-19 (remembering the limited medical knowledge in mid-2020), even when faced with stigma and discrimination. The early hashtags eventually lead to "social consensus regarding the symptoms of long covid. This social consensus played a vital role in gaining medical recognition for long covid, despite the initial limitations of traditional evidence-based medicine during the early stages of the pandemic" (Turner et al 2023 p9).

Table 3.1 outlines two similar studies of tweets and long covid. Turner et al (2023) covered a longer period than the other two studies, and analysed tweets earlier in the pandemic. All such studies, however, exclude individuals with long covid who do not use Twitter.

STUDY	PERIOD	NUMBER OF TWEETS
Awoyemi et al (2022)	25th March 2022 – 1st April 2022	10 670
Santarossa et al (2022)	18th February 2021 – 23rd February 2021	2500

Table 3.1 – Two studies of tweets and long covid.

(5) Persistent lung pathology is one characteristic of long covid, and Wei et al (2025) linked this problem to dysfunction in lung-resident immune cells involved in tissue repair based on post-mortem samples, and mouse studies.

Alveolar macrophages are the immune cells in question, and they have loss of peroxisomes ("organelles involved in oxidative reactions and metabolism"; Sariol

and Perlman 2025), which impairs regeneration of lung tissue. "Peroxisomes contain enzymes that facilitate oxidative metabolism of fatty acids as well as enzymes that can neutralise the toxic reactive oxygen species (ROS) that are produced by these metabolic processes. These organelles thus play a critical role in controlling oxidative stress in cells" (Sariol and Perlman 2025 p1039).

Peroxisome dysfunction has been found after various viral infections in other studies (eg: HIV; Xu et al 2017), and including in brain cells (eg: Syrian hamsters and SARS-CoV-2; Roczkowsky et al 2023).

REFERENCES

Awoyemi, T et al (2022) Twitter sentiment analysis of long covid syndrome Cureus 14, 6, e25901

Lau, R.I et al (2024) A synbiotic preparation (SIM01) for post-acute covid-19 syndrome in Hong Kong (RECOVERY): A randomised, double-blind, placebo-controlled trial Lancet Infectious Diseases 24, 3, 256-265

Longobardi, I et al (2023) Effects of a 16-week home-based exercise training programme on health-related quality of life, functional capacity, and persistent symptoms in survivors of severe/critical covid-19: A randomised controlled trial British Journal of Sports Medicine 57, 1295-1303

McGregor, G et al (2024) Clinical effectiveness of an online supervised group physical and mental health rehabilitation programme for adults with post-covid-19 condition (REGAIN study): Multi-centre randomised controlled trial BMJ 384, e076506

Rahman, A et al (2023) SARS-CoV-2 infection is associated with an increase in new diagnoses of schizophrenia spectrum and psychotic disorder: A study using the US National Covid Cohort Collaborative (N3C) medRxiv (https://www.medrxiv.org/content/10.1101/2023.12.05.23299473v1)

Roczkowsky, A et al (2023) Covid-19 induces neuroinflammation and suppresses peroxisomes in the brain Annals of Neurology 94, 3, 531-546

Santarossa, S et al (2022) Understanding the #longcovid and #longhaulers conversation on Twitter: Multi-method study JMIR Infodemiology 2, 1, e31259

Sariol, A & Perlman, S (2025) Lung inflammation drives long covid Science 387, 1039-1040

Tran, V-T et al (2022) Course of post-covid-19 disease symptoms over time in the ComPaRe long covid prospective e-cohort Nature Communications 13, article 1812

Turner, M et al (2023) The #longcovid revolution: A reflexive thematic analysis Social Science and Medicine 333, 116130

Xu, Z et al (2017) Micro-RNAs upregulated during HIV infection target peroxisomes biogenesis factors: Implications for virus biology, disease mechanisms and neuropathology PLoS Pathogens 13, 6, e1006360 (Freely available at https://journals.plos.org/plospathogens/article?id=10.1371/journal.ppat.1006360)

Wade, G (2024a) Probiotics seem to reduce long covid symptoms New Scientist 6th January, p15

Wade, G (2024b) Covid-19 linked to schizophrenia New Scientist 13th January, p16

Wei, X et al (2025) Macrophage peroxisomes guide alveolar regeneration and limit SARS-CoV-2 tissue sequelae Science 387, eadq2509

Wilson, C (2024) Exercising can help people with long covid – at least a bit New Scientist 17th February, p14

4. IMPACT OF COVID-19 RESEARCH

(1) Neva Corrigan reported at a "Society of Neuroscience" meeting in Washington DC in 2023 evidence of brain changes in adolescents during the covid-19 pandemic. Brain scans of 109 9, 11, 13, 15, and 17 year-olds taken in 2018 were compared to 54 12, 14, and 16 year-olds in 2021. The latter group had cortical thinning, more so for females, which suggested accelerated ageing of the brain. Exposure to stress could explain the findings, but it is unclear if the thinning was permanent (Wade 2024).

(2) Hampshire et al (2024) assessed the impact of covid-19 on memory, thinking and concentration with data from the "Real-Time Assessment of Community Transmission" (REACT) cohort in England. Nearly 2.5 million adults were recruited in 2020, and a sub-sample of 800 000 in 2022 were asked to complete eight computerised online cognitive tests (and around 113 000 took all the tests fully).

The sample was divided into six groups based on duration of SARS-CoV-2 infection (established by PCR or lateral flow test) and using a list of thirty symptoms:

- 1 - No infection (or unconfirmed - ie: self-report).
- 2 - Asymptomatic infection.
- 3 - Infection lasted less than four weeks.
- 4 - Lasting 4-12 weeks.
- 5 - Infection that resolved by lasted more than 12 weeks.
- 6 - Continuing symptoms for more than twelve weeks (ie: "long covid").

All infection groups had a deficit in cognitive scores compared to the no-infection group with a smaller deficit for a short infection and a larger deficit for the "long covid" group. At the extreme, the deficit was equivalent to nine IQ points, whereas the average was three. Memory, reasoning, and executive function tasks were impacted most. In terms of other variations, larger deficits were seen with the original SARS-CoV-2 virus and the B.1.1.7 variant compared to later variants, and those who had been hospitalised compared to non-hospitalised adults.

The study did not have pre-covid cognition data, and Hampshire et al (2024) admitted, "we could not assess cognitive change, and the observational nature of the

data means that we could not infer causality" (p816). Put simply, the study compared the mean cognition scores of the different groups at one point in time (ie: post-infection), but within each group there would have been a range of scores, and some individuals would not have shown a deficit. The average decline was very small, and so most people would not notice it, though there would be some individuals impacted more (Le Page 2024).

Continuing symptoms relied on self-reports, and the sample had a "degree of self-selection bias" (Hampshire et al 2024 pp817-818). The researchers explained that "persons with the most severe impairment may not have been able or willing to undertake a cognitive assessment. In addition, certain groups, including women and White persons, were slightly overrepresented in our study sample as compared with the base population, whereas younger persons and those from areas with greater levels of multiple deprivation were under-represented. However, the sample size in our study meant that all sectors of society were represented and contributed meaningful data to the findings" (Hampshire et al 2024 p817).

The researchers controlled for demographic characteristics, and specific pre-existing health conditions, though other confounders may have been missed. To overcome this risk, propensity-score matching was used in the analysis. This involves grouping participants based on demographic variables and matching them with no-covid participants.

(3) Setyorini et al (2024) conducted a phone survey between December 2020 and January 2021 in Indonesia on the impact of covid-19 on life and mental health. Social restrictions existed during 2020 including school and workplace closures. Over 90 000 random mobile phone numbers were dialled (of which 7955 were active), and 1082 respondents aged 15-65 years were recruited. Short measures were taken of mental health, social isolation, and work.

Overall, nearly half of the respondents reported horrified feelings and apprehension, one-fifth felt helpless, and over 40% stressed (from work and/or finances). Two-thirds of the sample had undergone social restrictions, and three-quarters had experienced some impact on their work (eg: loss; switch).

Negative mental health was associated with social isolation, and economic downturn. "Financial strain was linked to a decrease in perceived mental health (all indicators), but job loss was only correlated with

helpless feelings, and lower job status was unrelated to perceived mental health indicators" (Setyorini et al 2024 p1).

A general picture emerged of deteriorating mental health during the pandemic, linked to social isolation and financial strain in the main.

Table 4.1 lists the main strengths and weaknesses of this study.

STRENGTHS	WEAKNESSES
1. Large sample. 2. Use of phone interviews which allowed data collection during social restrictions and over the whole country. 3. It was the first such study in Indonesia, and one of a few in low- and middle-income countries (eg: Cheikh Ismail et al 2021 (United Arab Emirates); Zhang and Ma (2020) (China)). 4. Stratified random sampling using phone numbers from five cellular providers. The percentage of number of providers mirrored that providers market share. This method has been used in Indonesia before (Nurhasana et al 2022). 5. Trained interviewers used, and the interviews were recorded and sampled by supervisors.	1. A limited number of measures of mental health, for the past month, which were scored as yes or no. Though this method was used with previous epidemics (eg: SARS in Hong Kong; Lau et al 2006). 2. Cross-sectional data collected, so it is not possible to establish causality. 3. Some mediators not measured (eg: covid-19 infection severity). 4. The study population only included those with a mobile phone. 5. The sample was not representative of the general population of the country - eg: average age 36 years; twice as many males as females; two-thirds lived in Java.

Table 4.1 - Main strengths and weaknesses of Setyorini et al (2024).

(4) One of the elements of covid-19 shutdowns was school closures. "In public discussions on the potential impact of school shutdowns, concerns were expressed at an early stage that the lack of classroom instruction would lead to learning losses and put children's education at risk" (Vogelbacher and Schneider 2024 p2). Early research after covid-19 suggested negative impacts, but the "learning losses were not evenly distributed across students with different social backgrounds and also differed by school subject and age. Children from low socio-economic status

(SES) families were more affected than children from high SES families...; learning losses were higher in mathematics than in reading..., and younger students accumulated more learning deficits than older students" (Vogelbacher and Schneider 2024 p2).

The mechanisms of the impact were not only the school closures, but also the consequences of shutdowns on social relationships in the family. Elder (1998) observed that "historical forces shape the social trajectories of family, education, and work, and they in turn influence behaviour and particular lines of development" (quoted in Vogelbacher and Schneider 2024).

This idea is seen in life-course approaches like the "Family Stress Model" (FSM). Originating from a study of the effect of the "Great Depression" in the USA (1929-1933) on children's development, Elder (1988) found that "younger children were more vulnerable for long-term detrimental outcomes in comparison with those who experienced the economic crisis in late childhood or adolescence" (Vogelbacher and Schneider 2024 p2).

Changes in the parent-child relationship mediated the impact of the economic crisis for the children. The FSM (eg: Conger et al 1992) "assumes that economic hardships such as low income, high debts-to-assets ratios, and negative financial events place economic pressure on families, thus increasing parents' emotional distress and inter-parental conflicts. These difficult parental conditions result in a less nurturing environment for children, less parental involvement, and more inconsistent or strict parenting, ultimately impairing children's emotional, cognitive, and behavioural development" (Vogelbacher and Schneider 2024 p2).

Vogelbacher and Schneider (2024) applied the FSM to the covid-19 shutdown situation in Germany and proposed that working from home produced parental emotional distress, which impacted negatively on the development of (specifically) mathematical skills in primary school-age children. Data came from the "Newborn Cohort" of the German National Educational Panel Study, which began in 2012 with 3481 families randomly chosen. Children's cognitive skills and parent-child interactions were measured, and the caregiver interviewed at baseline and then annually. Data collected in 2020 covered the covid-19 shutdown period (ninth wave of data collection) (and were compared to 2018 and 2019).

The sample for Vogelbacher and Schneider's (2024) analysis was 1512 children (average age 8 years old) and

mostly their mothers. The outcome variables were child's mathematical skills (measured on a standardised twenty-item test), and parental (mother) emotional distress, self-reported with items like, "I was very stressed by the school closure and the demands of home-schooling", and "During this time [covid=19 shutdown], how often have you felt down and gloomy?". Other variables measured included changes in work situation of mother, mother's stress prior to covid-19, child's skills prior to shutdown, and socio-demographic factors.

Firstly, emotional distress of the mother (parent) was higher during the covid-19 shutdown for those working from home (compared to those not working before shutdown). Emotional distress was also higher where there was stress before the pandemic, and lower family income.

The next stage of statistical analysis found this negative relationship: "Higher parental emotional distress during the shutdown went along with lower mathematical skills after the shutdown..." (Vogelbacher and Schneider 2024 p7). The negative relationship was stronger for mothers (parents) who stopped working during the shutdown. The findings were taken as support for the FSM.

Put together, working from home during the covid-19 shutdown led to parental emotional distress, which created negative parent-child interactions that manifest in children's mathematical skills being impacted. "The covid-19 pandemic was a historic event which, at least in Germany, challenged the mental health of many parents and, in turn, impaired the skill development of primary school students" (Vogelbacher and Schneider 2024 p1).

This study had the key strengths of longitudinal data, including measures before the pandemic as a comparison, and a standardised test of mathematical skills was used throughout.

But there were key limitations with the research. Firstly, as the researchers admitted, "we did not have mathematical test data collected immediately before the shutdown. Therefore, the variance in the mathematical test after the shutdown might be partly due to influences prior to the shutdown, even when controlling for previous skills" (Vogelbacher and Schneider 2024 pp8-9).

Secondly, the measures of parent's stress differed slightly before and during the shutdown (ie: the items used). Also there may have been unobserved or uncontrolled variables that explained the relationship because parental distress and mathematical skills. For example, 97% of the interviewees were mothers, so there was no measures of co-residing father's emotional

distress, or other close family members (residing or non-residing), and the sample did not include non-co-residing parents (Vogelbacher and Schneider 2024).

(5) Chan et al (2025) compared immune cells from vaccinated and non-vaccinated individuals who had either mild or moderate covid-19. It was found that two types of immune cells (monocytes and natural killer cells) were more active in non-vaccinated individuals. This may seem counter-intuitive, but severe covid-19 and the negative consequences on the body may be the product of extreme action by the immune system. So, "covid-19 vaccines help to prevent the immune response to SARS-CoV-2 infection from running wild" (Research highlights 2025 p297).

(6) Household pets have been found to test positive for SARS-CoV-2 in households with people with covid-19. Pauvolid-Correa et al (2025) sampled 579 pets from 281 households with covid-19 in Texas between June 2020 and May 2021. Around 5% of dogs and 13% of cats were positive, while 25% of dogs and 36% of cats had SARS-CoV-2 neutralising anti-bodies. This is an example of spillback (human to animal transmission).

Other companion animals did not test positive (eg: lizards; birds), but the sample sizes were low for ten species (Pauvolid-Correa et al 2025).

In terms of pet-human interactions, sharing food with humans was a risk factor for both cats and dogs to be infected, while sleeping in the bedroom was a risk for dogs only. Bienzle et al (2022), in Canada, had found the latter a risk factor for cats only.

(7) Calculating population changes during the pandemic was not easy, especially in countries lacking high-quality data. Concentrating on India, Gupta et al (2024) found that life expectancy was 2.6 years lower in 2020 compared to 2019, and mortality was 17% higher. This translated into 1.19 million excess deaths in 2020. Life expectancy declines were higher for women than men, and for marginalised than privileged social groups. Gupta et al (2024) ended: "From a policy perspective, it is clear that the pandemic exacerbated longstanding inequalities in population health, particularly along dimensions of caste, religion, indigenous identity, rural or urban residence, age, and sex" (p7).

The data used for the calculations came from the

"National Family Health Survey-5" (NFHS-5), and a sub-sample of over three-quarters of a million individuals.

REFERENCES

Bienzle, D et al (2022) Risk factors for SARS-CoV-2 infection and illness in cats and dogs Emerging Infectious Diseases 28, 6, 1154-1162

Chan, L et al (2025) Prior vaccination prevents overactivation of innate immune responses during covid-19 breakthrough infection Science Translational Medicine 17, eadq1086

Cheikh Ismail, I et al (2021) Impact of the coronavirus pandemic (covid-19) lockdown on mental health and well-being in the United Arab Emirates Frontiers in Psychiatry 12, 633230

Conger, R.D et al (1992) A family process model of economic hardship and adjustment of early adolescent boys Child Development 63, 3, 526-541

Elder, G.H (1988) The life course as developmental theory Child Development 69, 1, 1-12

Gupta, A et al (2024) Large and unequal life expectancy declines during the covid-19 pandemic in India in 2020 Science Advances 10, eadk2070

Hampshire, A et al (2024) Cognition and memory after covid-19 in a large community sample New England Journal of Medicine 390, 806-818

Lau, J.T.F et al (2006) Positive mental health-related impacts of the SARS epidemic on the general public in Hong Kong and their associations with other negative impacts Journal of Infection 53, 2, 114-124

Le Page, M (2024) Does even a mild case of covid-19 effect your cognitive skills? New Scientist 9th March, p18

Nurhasana, R et al (2022) Public support for cigarette price increase in Indonesia Tobacco Control 31, 483-486

Pauvolid-Correa, A et al (2025) Active surveillance of cats and dogs from households with human covid-19 cases reveals over one quarter of pets infected with SARS-CoV-2 in 2020-2021 in Texas, United States bioRxiv (https://www.biorxiv.org/content/10.1101/2025.02.03.636361v1)

Research highlights (2025) How vaccines keep breakthrough covid in check Nature 638, p297

Setyorini, D et al (2024) Social isolation, economic downturn, and mental health: An empirical evidence from covid-19 pandemic in Indonesia Mental Health and Prevention 33, 200306

Vogelbacher, M & Schneider, T (2024) Parental stress and

working situation during the covid-19 shutdown - Effects on children's skill development Advances in Life Course Research 60, 100609

Wade, G (2024) The pandemic aged children's brains New Scientist 6th January, p15

Zhang, Y & Ma,Z (2020) Impact of the covid-19 pandemic on mental health and quality of life among local residents in Liaoning Province, China: A cross-sectional study International Journal of Environmental Research and Public Health 17, 7, article 2381

5. EVOLUTIONARY MEDICINE AND COVID-19

5.1. INTRODUCTION

Evolutionary medicine can help in understanding the covid-19 pandemic in a number of ways, including "identifying selective pressures that lead to the rise of new variants of concern, understanding human responses to disease in relation to past evolutionary pressures from other infectious diseases, and investigating the breadth of hosts that coronaviruses infect and the ecological context of their spillover among hosts" (Nunn 2023 p41). Henneberg and Ruhl (2020) confirmed the importance of evolutionary knowledge in "our co-evolutionary interactions with pathogens" (p145). Furthermore, the human evolutionary legacy becomes evident, including in the flight-or-fight reaction to danger.

"Humans are not evolutionarily programmed for sustainable behaviour reaching beyond a short time horizon. Thus, planning reserves in the medical care and political system are counter-intuitive and, in conjunction with constant pressures on institutional economies, fails in crisis situations" (Henneberg and Ruhl 2020 p145).

Meanwhile, micro-organisms evolve quickly due to short generation times and regular mutations. "A pathogen entering a local community elicits adaptive reactions. These are immune responses of individuals, and gene pool adaptations through fast-acting natural selection. Before the advent of effective preventive methods and therapies, opportunities for the operation of natural selection were very large — due to premature mortality, only about one-third of individuals born had an opportunity to pass their genes to the next generation. Thus, adaptations of

local gene pools to new pathogens were fast. Because pathogen transmission via human contact was slow, worldwide pandemics were rare" (Henneberg and Ruhl 2020 p146). That situation is obviously different today.

Nunn (2023) introduced a special virtual issue of the journal "Evolution, Medicine, and Public Health" entitled "Evolutionary Medicine and the Covid-19 Pandemic". Evolutionary principles can be applied to the virus and to the host (including the immune system, and behaviours).

5.2. SEVERITY OF SYMPTOMS

Turke (2021) stated: "Despite the many complexities that bear on infectious disease outcomes, it seems reasonable to suggest that greater focus on the contour of the force of natural selection over the course of the human lifespan will turn out to be broadly relevant to understanding age-related differences in host–pathogen interactions and outcomes, not just for SARS-CoV-2, but also for other crowd diseases of recent origin" (p116). In this context, he proposed five reasons why covid-19 was less severe among younger than older individuals:

i) Younger individuals are less likely to have conditions like hypertension, obesity, and type 2 diabetes, which can contribute to poorer clinical outcomes when infected by SARS-CoV-2.

ii) Children are more likely to catch colds, and other non-SARS-CoV-2 coronaviruses, and the immune response to these gives "protective cross-immunity" to SARS-CoV-2.

iii) Ageing impacts the body and makes it less resilient to biological impacts.

iv) Young children have "a broad array of naive T cells with unique receptors poised to recognise and respond to tens of millions of different antigens. This breadth of potential recognition and response narrows, however, over the life course, as responding naive T cells convert to memory T cells, and as the thymus involutes and becomes unable to replenish the supply" (Turke 2021 p114).

But, Turke (2021) pointed out, "as of now no direct evidence confirming (or contesting) the prediction that a

broad naive T cell repertoire confers an advantage in recognising and countering, specifically, SARS-CoV-2. There is, however, evidence of the importance of T cell breadth in dealing with novelty" (p114).

v) Both "theory and evidence establish that natural selection is most potent early in lifetimes. Theory and evidence also establish that many genes, both in humans and other organisms, have age-specific effects. Together, these two facts predict that when novel selection pressures arise, new mutations that produce an adaptive response in young bodies will spread more rapidly and assuredly than if the same response is expressed only in older bodies" (Turke 2021 p114).

5.3. BEHAVIOUR

Defence mechanisms have evolved against pathogens, most notably the immune system, but also the "behavioural immune system" (BIS) (Schaller 2011). "The human BIS comprises the avoidance of social interactions posing a potential infection risk, conformity and maintenance of cultural norms, ie: ingroup coherence, as well as neophobia. Activation of the BIS is thus associated with heightened vigilance toward and avoidance of outgroup members, with linkages to the fear system. Indeed, it has been shown that humans are able to recognise even subtle signs of sickness in others, which activates an immune response in the observer, and fosters rejection and avoidance of the sick individual" (Brune and Wilson 2020 p182). The emotion of disgust is also part of this system (Brune and Wilson 2020).

"Sickness behaviour" (SB) is another evolutionary system to prevent infection. It is "characterised by fatigue, loss of appetite and drive, psychomotor retardation and social withdrawal. SB is also frequently associated with loss of appetite, which reduces the exposure to toxic or infectious material, and heightened body temperature. As such, it reflects an adaptive evolutionarily conserved defence reaction to conserve energy and reduce the risk of being attacked in times of enhanced vulnerability" (Brune and Wilson 2020 p182).

"The coronavirus crisis has created a natural experiment that has put ancestral means of controlling the spread of contagious disease in small-scale communities to the test in contemporary mass societies. Individuals greatly differ with regard to their

susceptibility to covid-19 with a great many asymptomatic or only mildly ill, yet others with severe syndromes that have a wide range of dramatic organic disease" (Brune and Wilson 2020 p185). Co-operation by the majority, who mostly not ill, in social distancing measures, for example, can be viewed in terms of game theory (Brune and Wilson 2020). This has been studied generally with the "Public Goods Game" (PGG). Brune and Wilson (2020) explained: "The most common version of the PGG is played by an optional number of players who receive a defined amount of money or number of tokens at the beginning of the exchange scenario. Participants are asked to simultaneously invest their money in a common pool (the public good), usually without knowing the allowance of the other players. An experimenter multiplies the whole sum by a factor that is larger than one but smaller than the number of players, and returns an equal share of that money to each player. In other words, all players benefit equally, irrespective of how much they have invested before. If someone chooses a free-riding strategy while letting the others make their contributions, his or her return will exceed those of the other players. If played iteratively, investments usually decline over successive rounds, unless non-cooperative behaviour can be sanctioned by the other players" (p183).

Co-operation is restricting individual behaviour, while non-co-operation is ignoring the social distancing rules. Note that Brune and Wilson (2020) were writing before the development of a covid-19 vaccine.

Modelling of the evolution of SARS-CoV-2 by Gurevich et al (2022) showed that social and behavioural non-pharmaceutical interventions (NPIs), like mask wearing and social distancing, "could significantly affect the competition between viral strains, favouring the milder strain" (p179). Also, it was found that "a higher testing rate can select for a test-evasive viral strain, even if that strain is less infectious than the detectable competing strain" (Gurevich et al 2022 p179). The model assumed that symptomatic individuals were isolated and did not transmit the virus.

Two types of NPIs can be used with infectious diseases - mitigation and suppression. "The mitigation strategy aims to reduce transmission such that healthcare systems are not overwhelmed, while aiming to maintain the chain of transmission in order to achieve herd immunity. In contrast, the suppression strategy is aimed at virus elimination" (Saeidpour and Rohani 2022 p60). Suppression

is better (in terms of the public health and economic burden) if implemented in the early stages of an epidemic, and where citizens are not averse to strict controls on their behaviour (Saeidpour and Rohani 2022). Mitigation policies adopted early are also more effective, according to modelling by Saeidpour and Rohani (2022).

"Anxiety is an emotional response triggered in the anticipation of a possible threat. From an evolutionary perspective, anxiety can be seen as a detector that helps an individual to prepare for and deal with a dangerous situation" (Salali et al 2021 p394). How does anxiety relate to a situation like the covid-19 pandemic?

Salali et al (2021) conducted an online survey in the UK (1088 respondents) and Turkey (3935 respondents) in April and May 2020. Overall anxiety level was measured by the seven-item generalised anxiety disorder assessment (GAD-7; Spitzer et al 2006) (eg: "How often have you been bothered over the past two weeks with feeling nervous, anxious, on edge?"; "not at all" (0) to "nearly every day" (3)), and pandemic-related anxiety by six specific items (eg: "I am worried about my health"; "does not apply at all" (1) to "applies very much" (4)). Six items were created to measure risk avoidance behaviour during the pandemic (eg: "I stopped attending social gatherings"; "I stayed at home"; "I washed my hands frequently"). Other variables measured included future orientation (eg: "My behaviour is only influenced by the immediate (ie: a matter of days or weeks) outcomes of my actions"), mindfulness (eg: "I find myself preoccupied with the future or the past"), intolerance of uncertainty (eg: "When it is time to act, uncertainty paralyses me"), and risk perception (probability of catching covid-19, scored 0-100).

Pandemic anxiety in both countries was associated with risk avoidance behaviours, as well as generalised anxiety particularly in Turkey.

This supported the evolutionary benefits of anxiety as motivating behaviours to deal with risk, threat and danger. "Maintaining a healthy level of anxiety can promote engagement in protective behaviours" (Salali et al 2021 p393). But what is a healthy level is debated. Salali et al (2021) answered: An evolutionary perspective suggests that if a biological system is not producing the effects that it was selected for and is leading to harm, then it is not functioning normally and can be considered a disorder" (p403).

5.4. IMMUNE SYSTEM

"In the sickest covid-19 patients, pathology has been described as an immune system gone awry, with an out-of-control inflammatory response driven by an apparent cytokine storm" (Alcock and Masters 2021 p83). The "cytokine storm" is "a dysregulated, exaggerated and misdirected immune response accompanying excessive release of inflammatory cytokines" (Alcock and Masters 2021 p83).

How to understand this in terms of evolution? Alcock and Masters (2021) explained: "The idea that excess inflammation kills covid-19 patients is paradoxical because robust immunity has been linked with survival (ie: in young patients and female patients), while impaired immunity has been associated with higher mortality (ie: in immunocompromised patients and the aged). Furthermore, immune overdrive should tend to be uncommon because of strong selective pressures to pare back deleterious immune responses over time. The observation that dexamethasone is less effective in less severely ill patients, along with the failure of other anti-cytokine agents in covid-19, suggests that immune defences in covid-19 are complex and should be considered a double-edged sword. An immune response needs to be matched to the infectious challenge in order to maximise host fitness — too much or too little might result in the death of the host" (p84).

A number of theories have been proposed to explain immune over-reaction, including (Alcock and Masters 2021):

i) "Smoke detector principle" - It is better to react to a false alarm than to not react to an emergency because of the cost of the latter.

ii) "Immune brinkmanship" - This suggests that "the host undertakes a risky gamble when mounting an immune response against infection that involves substantial harm to both the host and the pathogen. However, the host gambles that those harms will be disproportionately directed to pathogens" (Alcock and Masters 2021 p86). Sometimes the death of the host is "an immune gamble gone bad" (Alcock and Masters 2021 p86).

iii) Mismatches - The cytokine storm evolved in human bodies without medical treatments that exist today, so there is a mismatch between the immune system and the modern world.

Another possible mismatch relates to novel pathogens. "Inexperience of the human immune system with novel coronavirus
is another mismatch that might lead to sub-optimal immune responses" (Alcock and Masters 2021 p87).

Alternatively, the human immune system has evolved to react to multiple pathogens together, and so responds for that, which is too much if only one pathogen in the form of SARS-CoV-2.

Fever is part of the body's response to infection called the "acute phase response". "Besides fever, other components include mobilisation of leukocytes; production of a variety of protective proteins (acute phase proteins); reduced blood levels of iron, zinc, and manganese; reduced erythrocyte production (beyond simple iron deficiency); reduced appetite (anorexia); breakdown of muscle protein and fat (cachexia or hypercatabolism); and the uncomfortable, motivation-sapping sickness symptoms and behaviours we associate with infection, including lethargy, depression and aches" (Wrotek et al 2021 p27). Fever can be viewed from the "immune brinksmanship" position.

Certain drugs used today suppress fever and its symptoms, but from the evolutionary point of view this is not necessarily helpful (table 5.1). There are studies showing that survival is not improved by interventions to suppress fever and lower body temperature (eg: Young et al 2019) (Wrotek et al 2021).

BENEFITS	COSTS
1. Heat stimulates many immune functions. 2. Heat inhibits or harms pathogens. 3. Fever can be used to identify sick individuals in a population.	1. Discomfort to the individual. 2. "Fever phobia" ((unfounded) fear that fever is harmful). 3. Metabolic costs of maintaining high temperature.

(Based on Wrotek et al 2021 figure 1 p32)

Table 5.1 - Key benefits and costs of allowing fever.

Bats are hosts for viruses that potentially are zoonotic, and for many of them bats are carriers. "A simple explanation for low virulence in bats, but high virulence following host-shifts to non-bats, is that bats

have been subjected to exceptionally strong selection from viruses throughout their evolutionary histories..." (Crespi 2020 p315). The evolutionary pressures can be seen from the divergence of bats from other mammals onwards (eg: less use of inflammation as anti-pathogen defence) (Crespi 2020).

The idea of mismatch can be used. Pathogens that evolved to live "peacefully" in bats when in non-bats have a more damaging effect on the host because the new immune system has not evolved to keep the pathogen in check (ie: to be a carrier).

5.5. THE VIRUS

The variants of SARS-CoV-2, like Delta and Omicron, are evidence of the evolution of the virus. Such (antigenic) evolution, which is studied in evolutionary epidemiology, occurs at a rate depending on "a balance between immune pressure and mutation supply. "The greater the proportion of the population that is immune, the greater the strength of selection for immune escape but mutation supply is constrained as few hosts can be infected. Conversely, if many hosts are susceptible to infection, then mutation supply may be plentiful but selection for immune escape is relatively weak. Hence, the rate of antigenic evolution should be maximized at an intermediate level of immune pressure, whereby moderate pathogen prevalence leads to a plentiful supply of mutations for selection to act upon, and the strength of selection for immune escape is reasonably strong" (Smith and Ashby 2023 p91).

After vaccines arrived in 2021, the dominant variant of SARS-CoV-2 was Delta, and "despite apparently favourable evolutionary conditions for immune escape, there were no indications of the Delta variant exhibiting antigenic evolution in the UK or elsewhere" (Smith and Ashby 2023 p91). Then, in 2022, Omicron became the dominant variant.

"Several hypotheses have been proposed for the sudden emergence of the Omicron variant from a distant clade. One possibility is that omicron evolved in an animal host following infection by a human, and then jumped back into the human population. Alternatively, it could have evolved in a remote population without being detected until it began to spread more widely in late 2021. However, neither of these explanations are especially convincing" (Smith and Ashby 2023 p91). More plausible, Smith and Ashby (2023) suggested, "Omicron was

able to substantially escape immunity in humans because it had experienced selection for immune escape in humans" (p91).

Or "the Omicron variant arose due to long-term within-host evolution in an immunocompromised individual, who was most likely infected between March and August 2021. While an immunocompetent individual would be expected to clear infection after a relatively short period, an immunocompromised person may fail to fully clear the infection, allowing the virus to co-evolve with the immune system" (Smith and Ashby 2023 p92). Smith and Ashby (2023) modelled antigenic evolution in an immunocompromised individual.

Amicone et al (2022) began: "Mutation is the principal process driving the origin of genetic diversity. The mutation rate is a function of replication fidelity and represents the intrinsic rate at which genetic changes emerge, upon which selection can act. The substitution rate, instead, is a measure of mutation accumulation in a given period of time and embeds the effects of selection. These rates and the spectrum of mutations that emerge and spread are fundamental to our understanding of how organisms evolve and how new variants are purged or established in natural populations" (p143).

Laboratory microbial evolution experiments allow researchers to calculate mutation and substitution rates. Amicone et al (2022) performed such research on two variants of SARS-CoV-2 isolated from African green monkeys. The mutation rate was calculated at 1.3×10^{-6} per-base per-infection cycle.

Dixson and Azad (2021) modelled the evolution of bat betacoronaviruses (of which SARS-CoV-2 is one) to understand their ability to bind to angiotensin-converting enzyme-2 (ACE2) receptors to enter human cells, and specifically the evolution of receptor binding domain (RBD) of the spike protein of SARS-CoV-2.

Voss et al (2021) analysed "Global Initiative on Sharing Avian Influenza Data" (GISAID), as of 21st October 2020, to understand the relationship between SARS-CoV-2 variants and patient outcomes. GISAID stores genomic data on SARS-CoV-2 and patient general information (eg: "recovered"; "mild symptoms").

5.6. LIFE HISTORY THEORY

Food insecurity (FI) is "a complex biosocial phenomenon that overlaps with but is distinct from related concepts such as food availability, famine and hunger. FI involves both an individual's access to food as well as supply, utilisation and stability of resources" (Kopels and Roulette 2023 p18). FI was worsened by the covid-19 pandemic.

Kopels and Roulette (2023) examined FI and the pandemic among 51 college students in southern California using life history theory (LHT). This theory describes an organism's allocation of biological resources to survive versus reproduce depending upon the current environmental demands. "If individuals live in harsh environments with few resources they are more likely to exhibit faster life history strategies, which prioritise quicker maturation, more abundant and faster reproductive effort, less somatic maintenance, and accelerated senescence" (Kopels and Roulette 2023 p19) [10]. The upshot is more present-oriented focus.

The participants in this study completed an online survey and a phone interview in late 2020. A key item was this: "If you made the maximum effort you could make to look after your health and ensure your safety, what do you think the chances would be that you would live to 75 or more?" (p20). This was asked in reference to prior to and during the pandemic. Individuals with present-oriented focus would estimate a lower chance of reaching 75 years old. FI was found to be significantly associated with present-oriented thinking. Use of campus-support services, and/or living with family or rent free "disrupted" this association.

5.7. NATURAL SELECTION IN UTERO

"Natural selection in utero" is the idea that pregnancies that would lead to preterm births are ended by spontaneous abortions (miscarriage) when the environment is harsh/stressful. This is particularly so for small male fetuses (Catalano et al 2021).

Catalano et al (2021) sought to test this idea during the pandemic (stressful environment), and via the

[10] Heightened awareness of mortality as in a pandemic, for example, "might promote a faster life history strategy, resulting in more risky behaviour and a decreased likelihood of compliance. A fast life history strategy has been linked to poorer health outcomes (such as obesity) and a lower socio-economic position, meaning the individuals for whom the health risk is highest might be those least likely to respond to public health measures" (Arnot et al 2020 p267).

odds of a live-born twin among male births in Norway. The researchers explained that studies have "used the frequency of twins among male live births as an indicator of the depth of selection in birth cohorts because gestations yielding a male twin have historically produced the fewest grandchildren per pregnancy. This low reproductive fitness arises, in part, because male twins die more frequently in infancy than do other male, and all female, infants. The low fitness of gestations that include a male twin may also reflect the fact that females in gestation with a male twin have fewer children than other females. Whatever its cause, the low reproductive fitness of gestations including a male twin makes them a likely target of selection in utero — particularly during stressful times" (Catalano et al 2021 p375). Twins represent an estimated 12% of conceptions, but only around 2% of pregnancies that produce live births, and it is calculated that about one-third of human pregnancies convert via spontaneous abortion to a singleton birth (Catalano et al 2021).

Catalano et al (2021) collected the monthly sex-specific data on singleton and twin births from January 2016 to November 2020 (ie: fifty pre-pandemic months and nine pandemic months). Using various statistical methods, it was found that there was a 27% downward shift in the monthly odds of a twin among male births from May 2020 onwards. The birth of fewer male twins than expected during the pandemic was taken as support for natural selection in utero.

5.8. VACCINES

Bull and Antia (2022) began with this observation: "A somewhat recent and unexpected discovery, one with potentially profound public health ramifications, is that the vaccine given to defend against symptoms of Marek's disease virus (MDV), administered on a global scale to billions of chickens in the poultry industry, has resulted in the evolution of a highly virulent wild-type virus. Not only did the evolved virus evade vaccine-immunity and cause disease in vaccinated birds, but it also killed unvaccinated birds far faster and with more certainty than did the original strain" (p203). This is an exception, but it clearly highlights that evolution is at work.

Modelling the evolution of pathogens in response to vaccines, and the possibility of increased virulence was the purpose of Bull and Antia's (2022) paper.

Models tend to assume evolutionary optima - ie: a virus evolves to maximise its descendents (overall transmission). "An optimum is a kind of endpoint of evolution, at which no further evolution occurs because changes in any direction leaves fewer descendents" (Bull and Anti 2022 p203). At the same time, there is a constraint, known as a trade-off (eg: mortality of host vs transmission).

Bearing in mind the different assumptions of models, Bull and Antia's (2022) view was that "imperfect vaccines [Gandon et al 2001] against many pathogens will not lead to the evolution of pathogens with increased virulence in unvaccinated individuals" (p202). One reason for this conclusion was that the MDV vaccine mentioned above was different to vaccines generally. Typical vaccines stimulate immunity that limits viral growth. "The original MDV vaccine was not the kind of vaccine to which we are accustomed with measles, flu or mumps. Its chief effect was to suppress symptoms, so that the infected chicken did not die but some transmission continued (newer MDV vaccines apparently block transmission)" (Bull and Antia 2022 p205).

5.9. HEALTH CARE

Therapeutic agents for infectious diseases can attack the pathogen directly ("through interference with the functions of the proteins that it codes for and the nucleic acids that it requires to survive and replicate"; p149), or modulate the immune system in some way (eg: dampen inflammatory activity), or use the changes in body which are the adaptive response to infection (eg: fever) (Crespi and Alcock 2021).

The first approach is "prone to the evolution of resistance, due to the strong selection imposed and the usual high numbers of genetically variable pathogens present in any given infection" (Crespi and Alcock 2021 p149).

The third approach can have a cost to the individual. "Cases of extreme and deleterious host defences... are also not unexpected, given that: (i) levels of expression of such defences should be adapted to ancestral human environments, and to the range and intensity of pathogens to which humans were formerly exposed, and (ii) some pathogens, such as SARS-CoV-2, are novel to humans such that some degree of initial host-pathogen adaptive mismatch is expected" (Crespi and Alcock 2021 p154).

Kessler and Aunger (2022) considered "the evolutionary context in which our healthcare systems evolved" (p88). "Healthcare system" here refers to behavioural strategies for controlling disease across species. "Humans, like all living things, have co-evolved with pathogens. Selection pressures to combat diseases are ubiquitous, stimulating species to evolve complex batteries of defences" (Kessler and Aunger 2022 p89).

Kessler and Aunger (2022) divided healthcare into two - "care behaviours", and "community health behaviours". "Care behaviours refer to behaviours that benefit the health of a targeted individual (who is often sick)" (Kessler and Aunger 2022 p89). This category can be sub-divided into "self-care", "kin care", and "stranger care".

"Community health behaviours generate indirect benefits for the group through actions which are not directly targeted at a sick individual" (Kessler and Aunger 2022 p89). This category is sub-divided into "environmental protection" (actions that make the environment more hygienic), and "organisational protection" (behaviour patterns that are organised to reduce the opportunities for transmission of a pathogen).

"Self-care" is the "oldest form of care" (Kessler and Aunger 2022 p90), and can be seen in self-grooming in different animals. "Kin care" evolved as a result of the benefits (in terms of genes) of helping those genetically related to the self. It may have evolved in humans from alloparenting (shared child caring) seen in many mammals.

"Stranger care" is "puzzling" in the sense of no genetic benefits to helping strangers. One possible explanation is "reputational benefits" - ie: a successful carer gains status or other fitness enhancing benefits in the group like power, wealth, or access to mates (Kessler and Aunger 2022).

The evolution of "environmental protection" can be seen in species that build anti-microbial secretions into the walls of their nests, for example, or eusocial insects that remove dead individuals from the nest.

"Organisational protection requires co-ordinated patterning of behaviours of individuals in space or time, often via involvement in some institution, which alter the distribution of pathogens, ie: division of labour or synchronised behaviours of groups" (Kessler and Aunger 2022 p95). For example, particular castes of eusocial insects remove the dead or diseased individuals.

"Because the different kinds of care evolved under different circumstances, at different points in our evolutionary history, as responses to different kinds of

problems, and under different selection pressures, they are unlikely to be perfectly co-ordinated in their current form" (Kessler and Aunger 2022 p96). This has led to three types of evolutionary conflict (Kessler and Aunger 2022):

i) Conflicting selection pressures on individuals - eg: individual behaviours (get food, find mate) vs reduce community transmission by isolating.

ii) Evolutionary mismatches between the context of the evolutionary behaviour and the world today - eg: concentrating on the local ingroup and ignoring distant threats.

iii) Evolutionary displacements where old forms of care are replaced by new forms - eg: self-care (older) vs stranger care (newer).

Hygiene helps in alleviating the risks of infectious diseases, but, on the other hand, "causes loss of some species from the ecosystem of the human body, which in turn leads to susceptibility to a range of chronic inflammatory disease" (Parker et al 2021 p121). The latter can be seen as the "dark side of hygiene" (Parker et al 2021), and was described originally by Barker et al (1988) as the "hygiene hypothesis". Modern life is more hygienic than the environment of human evolution and so there are less pathogens attacking the immune system, which leads to autoimmune conditions. In other words, there is a mismatch between the immune system that evolved and modern life. This is the current view captured by a "Biotic Alteration Theory" (eg: Parker et al 2012).

Parker et al (2021) distinguished "systems hygiene" (eg: clean water; sanitation; refrigeration of food) and "personal hygiene" (eg: washing hands; brushing teeth). The former tends to lead to the loss of diversity of symbiotic organisms (put simply, "good bacteria"). That is not to say that systems hygiene does not eliminate many harmful infectious diseases.

Cepon-Robins and Gildner (2020) talked of the "Old Friends hypothesis", which is similar to the "hygiene hypothesis". The emphasis is on "the co-evolutionary relationship humans share with certain commensal bacteria and macro-parasite species, pointing to a specific branch of our immune system (ie: Type 2 [TH2] immunity), which evolved specifically in response to macro-parasite

infection. According to this hypothesis, relatively recent medical, hygiene and sanitation advances limit exposure to these 'old friends', resulting in immune dysregulation that favours pro-inflammatory pathways and causes the body to overreact to harmless or self-produced stimuli. This dysregulation ultimately contributes to the high rates of chronic inflammatory diseases (eg: allergies, autoimmune diseases, cardiovascular disease) seen in high-income regions" (Cepon-Robins and Gildner 2020 p236). Bacteria and macro-parasite species (eg: helminths) that have evolved with humans can manipulate the immune system to create "balance" (appendix 5A).

5.10. CONCLUSIONS

"In theory, stopping the spread of viruses is simple: limit contact with other people and prevent transmission. In practice, this is hard. While many individuals promptly respond to social distancing measures, others are resistant to change, and even do things that make matters worse" (Arnot et al 2020 p265). Understanding behaviour change from an evolutionary viewpoint requires an understanding of "the currency determining the costs and benefits of behaviour" (Arnot et al 2020 p265), which is inclusive fitness. All behaviour is directly or indirectly related to that.

"Behavioural ecologists generally assume that in most cases our psychology is somehow equipped to evaluate inclusive fitness trade-offs through cues from our environment; our psychological preferences therefore guide us to behave in a broadly adaptive way. However, the assumption that fitness is maximised by our behaviour does not always hold. Evolution takes time to work, and full knowledge of what is happening may not be available. This is especially relevant when facing a new disease in a rapidly changing environment. Cultural transmission, which is an important evolutionary mechanism behind establishing our norms of behaviour, may not be as fast at spreading fitness-maximising behaviour as the spread of the virus" (Arnot et al 2020 p266).

Arnot et al (2020) produced three guiding conclusions for policymakers based on evolutionary theory:

i) "'Good of the group' arguments will not go far" (p273) because of the individual's concern with inclusive fitness (ie: their own and biological relatives' safety).

ii) "Behaviour is heterogeneous" (p273) as individuals will have their own experiences linked to LHT.

iii) "Behaviour change is linked to a change in ecology" (Arnot et al 2020 p273).

5.11. APPENDIX 5A - HOST BEHAVIOUR MANIPULATION BY PARASITES

Parasites can alter the behaviour of the host to their disadvantage, but to the benefit of the parasite [11]. Examples include crickets that jump into the water to allow the hair-worm parasite to continue its life cycle, rats and mice that are attracted to cat urine to facilitate capture as the parasite Taxoplasma requires cats as their final host, and cuckoo chicks raised by other species (Forti et al 2023).

The "extended phenotype" (EP) model (Dawkins 1982) has been proposed to explain this ability of parasites. It is "based on the idea of the selfish gene, implying that genes extend their effects beyond the boundaries of the organism's body... From this point of view, the behaviour of a host can be taken as an expression of particular parasite genes" (Forti et al 2023 p1). Riskin (2016) criticised this theory as presenting the organism as "a passive clockwork eternally ringing the bells of past selective pressures" (quoted in Forti et al 2023) [12].

An alternative explanation for the manipulation of host behaviour is "Niche Construction Theory" (eg: Lewontin 1983). This is "based on the idea that an organism, alone or as part of a group can actively change the environment with consequences on their and other organisms' fitness" (Forti et al 2023 p2). This theory has the advantage of "drawing attention to the connections among host manipulation, community ecology, ecosystem functioning, and the ecological engineering of fitness landscapes" (Forti et al 2023 p2).

Forti et al (2023) outlined three niche-construction based models to explain parasite manipulation of hosts:

i) The "central nervous system VIP (very important parasite) model" - How the host's behaviour is changed

[11] Eg: cause host to move location, drain their energy to cause immobility, inflammation of neural tissue, and alter biochemistry of host (Hartke et al 2023).

[12] Parasites have to deal with the host's immune system, and strategies include residing in body areas less targeted by the immune system, molecular mimicry, antibody trapping, and secreting proteins (Hartke et al 2023).

depends upon direct or indirect access to the central nervous system of the host by the parasite. Intestinal parasites are an example of indirect access as their absorption of nutrients in the digestive system can alter the body systems. Direct access is seen in parasites that reach the brain (eg: the hair-worm reaches the visual cortex of the cricket).

ii) The "Clock-is-Ticking model" - Manipulation of behaviour is a function of the time of infection (eg: during development or adulthood). For example, infecting intermediate hosts during their development leads to deformities which make them easier to catch by predators (the final host).

iii) An ecological approach - This includes the role of competition and co-operation by con-infecting parasites.

Putting these three theories together, Forti et al (2023) pointed out: "Parasites are often treated as pests, but they play an essential ecological role in communities, particularly by potentially modifying the size and relation among host populations and structuring intricate and complex food webs" (p9).

The researchers gave this example: "Trematode-infected Austrovenus stutchburyi cockle living in intertidal mudflats in New Zealand provide an example of these effects. The trematodes affect the foot of the cockle, reducing its digging ability and thereby survival... This behavioural alteration is density dependent, since heavier infection decreases burrowing ability to a larger degree... Heavily infected cockles are more exposed, being only partially buried in the mud, and therefore fall prey to the South Island oystercatcher (Haematopus finschi) more easily... As the birds only consume the soft interior, the shells of the predated cockle become available as a substrate for a rich community of epibionts... Therefore, parasites facilitate predator access and contribute to the engineering of a unique ecological niche" (Forti et al 2023 pp9-10).

5.11.1. Intermediate Hosts

Direct parasites, which move from one host to the next, and indirect or "complex" parasites that require an intermediate host both have in common that a host switch is required. "Although difficult to verify

experimentally, many of these parasites are thought to actively increase the likelihood of transmission. The malaria parasite Plasmodium falciparum alters the odour of their human hosts, possibly to increase their attractiveness towards mosquitoes during the infective stage... The fungus Ophiocordiceps unilateralis manipulates Camponotus leonardi ants to seek out sites that provide optimal conditions for fungal growth before they die from the infection" (Hartke et al 2023 p5878).

Hartke et al (2023) studied the cestode Anomotaenia brevis which develops into adult tapeworms in the definite host of two species of woodpecker, but the life cycle includes the acorn ant (Temnothorax nylanderi) as intermediate host. "The infection of the intermediate host happens when foraging ants bring bird faeces with cestode eggs into the nest and feed those to the developing larvae. Within the ant, the cestode eggs hatch into larvae and pass through the gut wall into the haemocoel [main body cavity], where they develop into cysticercoids [larval stage]. When a woodpecker opens acorns or sticks, in which T.nylanderi build their nests, and feeds on the infected ants, the cysticercoids develop into adult tapeworms and complete their life cycle" (Hartke et al 2023 p5878).

Infected ants are different from uninfected nestmates - for example, yellow colouration compared to the normal brown (ie: more visible to woodpeckers), less active (ie: easier to catch by woodpeckers), and live much longer. "The drastic increase in life expectancy naturally also extends the period during which an infected ant can be preyed upon by the final host, which increases the probability of transmission" (Hartke et al 2023 p5878).

Hartke et al (2023) found that the parasites secreted proteins that could explain the change in ants' behaviour and appearance.

The parasitic cestode Schistocephalus solidus has been described as having "an improbable life cycle" requiring three hosts (Mukurjee and Chung 2022). The adult tapeworm matures in the intestine of a fish-eating bird, like a kingfisher (the third host and "end point"). The larvae, released into the water in the faeces of the bird, are tiny (less than 1 mm long) and must first be ingested by a copepod (shrimp-like crustacean). Then the copepod is eaten by a three-spined stickleback fish (2nd host), which in turn is eaten by the bird. The first and second hosts are manipulated to make them vulnerable to predation - the copepod becomes more active and so draws

the fish's attention, while the fish becomes bloated with the mature larvae and swims slowly close to the water's surface (Mukurjee and Chung 2022).

5.12. REFERENCES

Alcock, J & Masters, A (2021) Cytokine storms, evolution and covid-19 Evolution, Medicine, and Public Health 2021, 83-92

Amicone, M et al (2022) Mutation rate of SARS-CoV-2 and emergence of mutators during experimental evolution Evolution, Medicine, and Public Health 2022, 142-155

Arnot, M et al (2020) How evolutionary behavioural sciences can help us understand behaviour in a pandemic Evolution, Medicine, and Public Health 2020, 264-278

Barker, D et al (1988) Appendicitis epidemic following introduction of piped water to Anglesey Journal of Epidemiology and Community Health 42, 144-148

Brune, M & Wilson, D.R (2020) Evolutionary perspectives on human behaviour during the coronavirus pandemic Evolution, Medicine, and Public Health 2020, 181-186

Bull, J.J & Antia, R (2022) Which "imperfect vaccines" encourage the evolution of higher virulence? Evolution, Medicine, and Public Health 2022, 202-213

Catalano, R et al (2021) Twinning during the pandemic Evolution, Medicine, and Public Health 2021, 374-382

Cepon-Robins, T.J & Gildner, T.E (2020) Old friends meet a new foe Evolution, Medicine, and Public Health 2020, 234-248

Crespi, B (2020) Evolutionary medical insights into the SARS-CoV-2 pandemic Evolution, Medicine, and Public Health 2020, 314-322

Crespi, B & Alcock, J (2021) Conflicts over calcium and the treatment of covid-19 Evolution, Medicine, and Public Health 2021, 149-156

Dawkins, R (1982) The Extended Phenotype: The Gene as the Unit of Selection Oxford: Freeman

Dixson, J.D & Azad, R.K (2021) A novel predictor of ACE2-binding ability among betacoronaviruses Evolution, Medicine, and Public Health 2021, 360-373

Forti, L.R et al (2023) Host manipulation by parasites through the lens of Niche Construction Theory Behavioural Processes 210, 104907

Gandon, S et al (2001) Imperfect vaccines and the evolution of pathogen virulence Nature 414, 751-756

Gurevich, Y et al (2022) Modelling the evolution of SARS-CoV-2

under non-pharmaceutical interventions and testing Evolution, Medicine, and Public Health 2022, 179-188

Hartke, J et al (2023) Long live the host! Proteomic analysis reveals possible strategies for parasitic manipulation of its social host Molecular Ecology 32, 5877-5889

Henneberg, M & Ruhl, F (2020) Covid-19 and evolutionary medicine Evolution, Medicine, and Public Health 2020, 145-147

Kessler, S.E & Aunger, R (2022) The evolution of the human healthcare system and implications for understanding our responses to covid-19 Evolution, Medicine, and Public Health 2022, 87-107

Kopels, M.C & Roulette, C.J (2023) Food insecurity, diet and mental distress among resource insecure students during covid-19 Evolution, Medicine, and Public Health 2023, 18-29

Lewontin, R.C (1983) Gene, organism, and environment. In Bendall, H.C (ed) Evolution From Molecules to Men Cambridge: Cambridge University Press

Mukerjee, M & Chung, D (2022) An improbable life cycle Scientific American October, p76

Nunn, C.L (2023) Covid-19 and evolution, medicine, and public health Evolution, Medicine, and Public Health 2023, 41-43

Parker, W et al (2012) A prescription for clinical immunology: The pills are available and ready for testing Current Medical Research Opinion 28, 1193-1202

Parker, W et al (2021) Between a hygiene rock and a hygiene hard place Evolution, Medicine, and Public Health 2021, 120-130

Riskin, J (2016) The Restless Clock Chicago: University of Chicago Press

Saeidpour, A & Rohani, P (2022) Optimal non-pharmaceutical intervention policy for covid-19 epidemic via neuro-evolution algorithm Evolution, Medicine, and Public Health 2022, 59-70

Salali, G.D et al (2021) Adaptive function and correlates of anxiety during a pandemic Evolution, Medicine, and Public Health 2021, 393-405

Schaller, M (2011) The behavioural immune system and the psychology of human sociality Philosophical Transactions of the Royal Society B 366, 3418-3426

Smith, C.A & Ashby, B (2023) Antigenic evolution of SARS-CoV-2 in immunocompromised hosts Evolution, Medicine, and Public Health 2023, 90-100

Spitzer, R.L et al (2006) A brief measure for assessing generalised anxiety disorder: The GAD-7 Archives of Internal Medicine 166, 1092-1097

Turke, P.W (2021) Five reasons covid-19 is less severe in

younger age-groups Evolution, Medicine, and Public Health 2021, 113-117

Voss, J.D et al (2021) Variants in SARS-CoV-2 associated with mild or severe outcome Evolution, Medicine, and Public Health 2021, 267-275

Wrotek, S et al (2021) Let fever do its job Evolution, Medicine, and Public Health 2021, 26-35

Young, P.J et al (2019) Fever control in critically ill adults. An individual patient data meta-analysis of randomised controlled trials Intensive Care Medicine 45, 468-476