# Proof of Heart Rate: Whitepaper
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## INTRODUCTION

The state of being lean, fit and vigorous is highly desired. Yet a high proportion of people never achieve this state. I live in the United States of America and will refer to this country in the following few paragraphs. Our advanced technology, wealth and healthcare capabilities haven't solved the problem of promoting leanness and fitness. The total expenditures for healthcare services in the United States were $4.1 trillion in 2020. ("National Health Expenditure Accounts") This amounted to 19.7% of the nation's gross domestic product. ("National Health Expenditure Accounts") To put this number into perspective, compare it to the United State's military spending in 2020 -  $0.766 trillion. (Duffin). Is our society receiving appropriate returns on this massive yearly investment? How much can the quality of life of the members of our society rise by creating novel incentives for leanness and fitness?

The prevalence of obesity in the United States has been rising and was 42% in 2018 per Center for Disease Control. (Center for Disease Control) Obesity is a risk factor for many diseases, suffering and a shorter life expectancy. Good physical activity and exercise habits are helpful in the quest to maintain a healthy weight.

What is the explanation for this phenomenon: "A highly desired outcome (leanness and fitness) becomes less common as a society becomes wealthier and better educated?" A conjecture to explain: "The complex ecosystems in which we live, and the repeated messaging our minds internalise create and hide powerful disincentives to fitness and health." Disincentives such as inexpensive unnatural "food," poor access to safe bicycle and pedestrian pathways, sleep deprivation among others are addressed elsewhere. This paper is not intended to parse the complexities of the problem, but rather to propose a novel action: creating a universally accessible technology to record and reward fitness activities. Personal liberty and free markets are clear priorities to any thriving society. Thus the best incentives will be fully voluntary, nonpunitive and provide intrinsically generated economic benefit.

My area of expertise as a board certified family physician (Medical Doctor) is healthcare. I am inspired by these promising technologies 1) secure, immutable and permissionless distributed ledgers, and 2) Highly secure and private facial scanning techniques. I believe they can be engineered to promote health. In the pages below, I propose a "Proof of Heart Rate" ecosystem. Since acronym use is a barrier to communication amongst people of diverse professions, I will minimise their use and define them here: NFT (non-fungible token), PPG (photo-plethysmography), ID (identification), dApp (decentralised application), DAO (decentralised autonomous organisation), API (application programming interface).

PROOF OF HEART RATE

Many people enjoy games and competition. Some fitness companies track performance and publish achievements on the user interfaces of their ecosystems. Additionally there are many electronic gaming companies who award cryptocurrency tokens in a "play to earn" environment. Several cryptocurrency protocols reward participants for *reported* exercise, but none claim a *proof* of exercise (yet). The proof of heart rate protocol described in this paper will generate a proof that the reported exercise was performed by the reporting individual.

Proving that an individual has performed aerobic exercise to a gaming ecosystem, fitness company, health coach, social media group, life insurance company or other organisation can give benefit to the individual and the other party.

The protocol underlying proof of heart rate combines two well established technologies and performs them *sequentially*. Firstly, smartphone operating system based *facial recognition* is performed on the participant. "The probability that a random person in the population could look at your iPhone or iPad Pro and unlock it using Face ID is less than 1 in 1,000,000 with a single enrolled appearance whether or not you're wearing a mask." (Apple) Secondly, *photo-plethysmographic measurement of facial blood vessel pulsations* using a smartphone camera to determine heart rate. Thirdly, a repeat smartphone operating system based *facial recognition* is performed. These three tasks are linked by the dApp in a secure fashion to prove the owner of the smartphone achieved a certain heart rate at a certain time. The security and privacy of facial recognition has been developed by and is the responsibility of the smartphone operating system. The proof of heart rate intellectual property as described in this paragraph is patent pending. (US patent application # 63/364,576)

Computer video camera based PPG algorithms to accurately determine heart rate are well documented. (Poh et al.) (Bush) (Ansari) (Kim) This technology uses colour fluctuations of facial skin that occur each time a pulsation of red blood cells courses through the tiny arterioles of the face. These colour fluctuations are invisible to the human eye, but detectable by inexpensive computer or smartphone cameras.

A heart rate **elevation** to 70% or more of a person's age predicted maximum for at least 20 minutes is a good proxy for a significant episode of aerobic exercise. ("Target Heart Rates Chart") Additionally, heart rate **recovery** is a good proxy for level of aerobic fitness. (Sydo) (Qie) The heart rate recovery is obtained by measuring the heart rate during exercise, then starting a rest period for 60 to 90 seconds, then recording a second heart rate. The second heart rate is subtracted from the first. The heart rate recovery assists in determining that an elevated heart rate was not due to unhealthy factors such as illness, chemical stimulants, etc. Heart rate **variability** is excluded from this protocol. It is often used as a proxy for aerobic fitness, but is inconsistently associated with aerobic fitness. (Souza)

ECOSYSTEM PROCESSES AND LOGIC
$HEART AND $HEALTH


Two wallet addresses, and an **ID NFT token** will be created on the same blockchain for each participant upon enrollment with the smartphone dApp. Note the use of the redundant phrase "ID NFT token." This is to avoid the common error of conflating NFTs and data/assets residing outside the blockchain associated with them. The ID NFT tokens are simply non fungible tokens containing an immutable data field on the blockchain.

Firstly, a **first wallet** will be created to store **$HEALTH**, the financial reward token of the ecosystem. Participants will need to send some $FET to this first wallet for initial fees (if the ecosystem is built on the Fetch.ai blockchain). $HEALTH will be minted ONLY in quantities of one in response to a successful **exerciseEpisode** being broadcast to the blockchain from the dApp on the participant's smartphone. Total ecosystem $HEALTH supply will be zero when the proof of heart rate ecosystem deploys.

Secondly, an ID NFT token representing the participant's proof of heart rate ID will be minted and placed in the first wallet. During the ID NFT token minting, a **second wallet** will be created. The private keys will be unknowable - the public address will be created but there will be no private keys. This public address will be written to the immutable data field of the ID NFT token as a permanent record of where to find the **$HEART** balance (the fitness scoring token) of the participant.

To create the second wallet, the following amount of $HEART tokens will be sent to the second wallet: the date and time expressed as a 14 digit number yyyymmddhhmmss /100,000,000,000,000. Division by 100,000,000,000,000 is performed to create a number that resides to the right of the decimal point and serves as a permanent record of the enrollment date and time. Future $HEART deposits are ONLY in quantity of one, so the record of enrollment date remains unchanged.

After enrollment, $HEART can only be minted in response to the broadcast of an exerciseEpisode from the smartphone dApp. The only quantity that can be minted is one $HEART. Thus the $HEART balance in the participant's second wallet will serve as a publicly readable cumulative exercise score. No one has the private keys to the second wallets so the token count in each second wallet can only remain the same or increase.

Attempts to "steal" a second wallet address with a high $HEART balance by minting a "fake" ID NFT token containing this public second wallet address will not succeed. The date/time stamp of the minting of the "fake" ID NFT token will be different from the date/time data stored in the second wallet $HEART balance.

Any data stored on public blockchains is publicly visible. Participants will be reminded of this and consent prior to enrollment. No identifying information will be stored on the blockchain, only the ID NFT token containing the public keys of the second wallet. Participants can prove their

association with their $HEART data, if they desire, by proving their ownership of the ID NFT token where the second wallet address is written to the immutable data field.

The strategy of minting an ID NFT token as the sole identifying information was developed with simplicity and immutability in mind. Adding more identifying data to the protocol in a secure fashion for interaction with third parties such as life insurance companies, and providing better personal data security is beyond the scope of this paper. Using a secure decentralised ID can be explored by the proof of heart rate DAO. A blockchain company such as Fetch.ai may provide consulting in this regard.

Proving the age of the participant in a trustless fashion is beyond the scope of this paper. Thus an arbitrary "age" will be assigned until trustless age protocols are established. An age that requires some aerobic activity for youth but is not too hard for older folks to achieve. The age of 52 years old produces a heart rate requirement of 120 beats per minute, and a heart rate recovery of 14 using calculations described below to achieve a successful exerciseEpisode. Note that youth with poor fitness who achieve 120 beats per minute with mild exercise may find it difficult to achieve the heart rate recovery criteria. The number 52 can be assigned to all participants' "age" variable until a trustless proof of age replaces this number.

The Proof of Heart Rate ecosystem will contain immutable code in addition to DAO regulated code. The immutable code will be written to the blockchain and remain unchanged during upgrades. The immutable code is the logic for determining the success or failure of an exerciseEpisode AND the algorithm in the smart contract for minting one $HEART and one $HEALTH per successful exerciseEpisode. Thus blockchain documented exercise in 2033 can be compared with that from 2023, like a batting average in baseball, or passes per match in football (soccer).

The governance DAO may change the methods for heart rate measurement, decentralised ID, trustless age verification, security features, etc. But the DAO can never change the rules for what heart rate numbers, and timing are needed for minting $HEART and $HEALTH. Nor can it change that only one $HEART and one $HEALTH can be minted per contract call. Thus, these rules must be chosen wisely at the inception of the ecosystem.

IMMUTABLE LOGIC

A successful exerciseEpisode requires all of the following:
1) Measured heart rate equivalent to 70% or more of age predicted maximum on two points of time separated by at least 20 minutes. Age adjusted predicted maximum heart rate is calculated with the Tanaka method $208 - (age*0.7)$ and multiplied by 70%: $(208 - (age*0.7)) * 0.7$ (Tanaka).

2) An additional heart rate reading at least 10 minutes after the initial reading OR at least 10 minutes prior to the last reading of at least 70% age predicted maximum. This prevents using only two brief workouts for the first and last readings - at least three heart rate measurements achieving 70% age predicted maximum are needed for a successful exerciseEpisode.

3) Heart rate reading at a point during 60 to 90 seconds rest after the final exercise heart rate reading that achieves heart rate recovery criteria as listed below.

Age adjusted heart rate recovery is calculated by taking the second to last heart rate measurement and subtracting the last heart rate measurement. This result is the heart rate recovery number. Then the results of this calculation: $((-0.1)*age)+19$ is subtracted from the heart rate recovery number. If the difference is greater than zero it indicates a successful heart rate recovery. This calculation was created by me, based on clinical judgement and review of heart rate recovery data from over 19,000 people aged 30 to 79 years without cardiovascular disease (Sydo). This calculation indicates success for heart rate recoveries that are a few beats per minute less than the median age specified heart rate recovery in Sydo's study.

It is unavoidable that heart rate recovery numbers can be improved by intentional stimulation of the vagus nerve (vagal manoeuvres). However the effects of these manoeuvres are less pronounced immediately after exercise due to override of the vagus nerve by sympathetic (adrenaline stimulating) nerves. Additionally knowledge of breathing techniques to improve vagus nerve function is an important tool in maintaining good health.

A successful exerciseEpisode broadcasts a contract call to mint one $HEART sent to the second wallet and one $HEALTH sent to the first wallet. Only one exerciseEpisode can be broadcast per participant per 20 hours. Twenty hours is chosen for two reasons: 1) To allow some leeway in daily exercise schedule, 2) To allow for a maximum yearly score that is greater than 365 by the least amount while still being a factor of 8,760 (which is 365 days x 24 hours). 8,760 divided by 20 equals 438 possible exerciseEpisode broadcasts per year.

Note that in order to score a full point per 20 hours there can be no rest days, and exercising sooner than 20 hours from the previous exerciseEpisode will result in no points. This is to simplify the protocol. Additionally, as fitness increases, a day containing a single 20 minute exerciseEpisode could be called a relative rest day.

FITNESS EXPLORER

Fitness represented by the $HEART balance in the second wallet can be read by a block explorer. A "fitness explorer" could be created on web3 to track fitness levels associated with second wallet addresses. Below are some examples of potential scoring algorithms.

**yearScore** - Score one year's worth of fitness data by reading the prior 365 days. A full score of 365 can only be attained 365 days after enrollment. The beginning of a "day" is the enrollment date/time. After 365 days, only the previous 365 days will be used in the calculation. The algorithm will follow these data points - a score of 365 for exercise in ⅔ of prior days, 274 for ½, 183 for ⅓, 91 for ⅙. The max score will be 365 and lowest score will be 0. A full score is given for ⅔ days exercised since this can result in excellent fitness, and daily vigorous exercise is sometimes detrimental.

**totalScore** - Cumulative fitness since enrollment in Proof of Heart Rate. The total exerciseEpisodes in any one year are counted and given *decreased weight* as years become more distant. Starting with the most recent 365 days, divide the number of $HEART deposited in a given year by the years elapsed since the given year and repeat through the enrollment date. Add these together for the healthScore.

For instance y = round up (365 day intervals since enrollment).  Loop y times starting with 1 → healthScore = healthScore + (year y number of $HEART deposits / y). Year 1 number of $HEART deposits will be the prior 365 days.

TOKENOMICS

$HEART and $HEALTH tokenomics have unique attributes. Some of these may create enthusiasm and promote the adoption of this ecosystem.

1) Its initial supply of each token is zero representing a fair beginning as found in the ethos of the Bitcoin protocol.
2) The circulating supply can increase **exponentially** in response to protocol adoption. But the doubling time of the token amount created by ONE PERSON can only increase **logarithmically**. Thus the deflationary forces of individual minting efforts will be countered by the inflationary forces of ecosystem adoption.
3) Minting only occurs in response to work. Thus the protocol is a subtype of **proof of work** reflecting the Bitcoin protocol ethos. The velocity of minting responds to **heart rate** instead of **hash rate**.
4) Fitness, life insurance, social media and gaming ecosystems may want to utilise $HEALTH tokens, $HEART balance readings and ID NFT tokens.
5) The total number of $HEART tokens in circulation is a measure of accumulated fitness in a given population.
6) The maximum supply is 100,000,000,000,000 $HEART and 100,000,000,000,000 $HEALTH. (This is enough for 2.7 billion participants to mint one token per day for 100 years each)

ECONOMICS

$HEART balances in second wallets will be cumulative over time. Thus, similar to an individual's credit score predicting future economic behaviour, an individual's $HEART balance may be useful to predict future fitness levels and general health. Degenerative processes of ageing may be reduced with regular (injury free) exercise. Thus a cumulative $HEART value can be a proxy for a slower ageing process.

Participants will pay enrollment fees and transaction fees to unlock the benefits conferred by the ecosystem. These benefits might be of the following types: social connectivity, motivation, economic (i.e. reduced life insurance costs) or gaming. Additionally, participants will accumulate $HEALTH as they accumulate $HEART as described above. $HEALTH tokens may eventually hold significant financial value.

Fees to register in the ecosystem and utilise the smart contracts are paid in $FET (or the native token of the ecosystem blockchain). Enrollments and transactions will have separate fee structures. Participants will initially need to purchase $FET for use in the ecosystem. If $HEALTH ever ends up on an exchange, it could be swapped for $FET to use the ecosystem. Fees will be the source of income for members of the Proof of Heart Rate team.

As the breadth and strength of the ecosystem increases, third parties may desire to interact with $HEALTH holders as partners or customers.

$HEALTH might be used to fuel smart contracts connecting people to healthcare services. A trustless referral system with cumulative cost-effectiveness and outcomes data can be carefully built. Decentralised digital IDs can be constructed for both individuals and healthcare service entities. These can be populated with evolving scores on a variety of measures.

CRYPTOGRAPHY AND FACIAL RECOGNITION

Smartphone face ID technology is a powerful and convenient method for securing a device. The security and privacy of this technology has been well developed by companies such as Apple. Several methods of face scanning are available and used individually or in combination by devices. These methods include a standard front facing camera to measure facial features or irises, front facing laser emitting devices to measure facial depth for enhanced geometric mapping. The owner's face is scanned upon enrollment to their device and the data is converted to a mathematical representation of the face and stored cryptographically in the trusted execution environment of the device. These environments are more secure than the rest of the computing and storage environments of the device. The next time the user attempts to unlock their device, their face is scanned again and the resulting data is compared with the stored data to verify the owner of the device.

The Proof of Heart Rate technology will not measure any identifying features of the face. Facial ID will be performed and secured by the operating system of the smartphone in use. Secure algorithms can be created that first utilise a smartphone FaceID via API call, and secondly, perform PPG measurement of facial blood vessel pulsations to measure heart rate. A second FaceID API call can then be performed to improve the security.

SECURITY AND PERFORMANCE

Without security, immutability of blockchain stored data, and excellent performance, this project would have no value. Great care will be taken to ensure trustworthiness of the tokenomics.

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