The virtual cyclist

Role of nutrition in the cyclist's performance

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General context

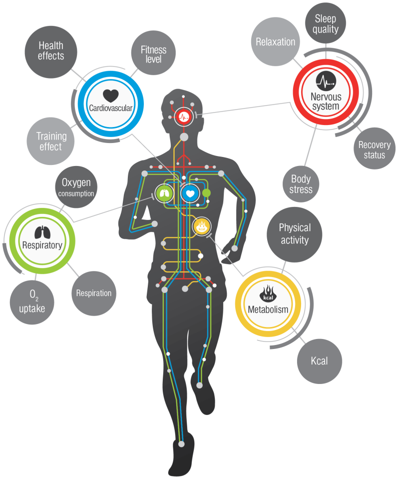
- subject proposed by the Cemosis laboratory, in collaboration with the Groupama-FDJ cycling team
- continuity of the project but main focus was on the nutritional aspect of the Pulse software and on cycling nutrition

Companies Presentation

- beginning of the 1997
- won more than 500 victories in 24 years
- in 2020 it was the 9th world team and the 1st French team [3]

- created in January 2013
- hosted by the IRMA
- works on modeling simulation, in data science or high performance computing [12]

Pulse Physiology Engine [1]



- C++ based
- comprehensive human physiology simulator that drives medical education, research, and training technologies

Objective 1

- Reconstitute information on cyclists' nutrition : understanding the value of supervised nutrition to prepare for a race, and knowing the recommended amounts to achieve the best performance (before, during and after effort)
- Studying the nutritional aspect of Pulse models : to understand what the functions of these systems are and what principles are used to construct them

Objective 2

- Simulate scenarios different from the classic scenario, by changing the energy drink consumption or changing the amount of food before the race
- Compare Pulse output data and observe the effects of a change in nutrient consumption on the cyclist's vital data.

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High-performance cyclist

Parameters	Values
Age (year)	27
Weight (kg)	83
Height (cm)	193
BodyFatFraction (Scalar between 0 and 1)	0.08
HeartRateBaseline (1/min)	45
RespirationRateBaseline (1/min)	8
DiastolicArterialPressureBaseline (mmHg)	60
SystolicArterialPressureBaseline (mmHg)	100

Table: Description of a high-performance cyclist (Source : Olivier Mazenot)

MAE (Mean Absolute Error) and MSE (Mean Square Error) errors

MAE is defined as: $$\frac{1}{n}\sum_{i}^{n}\left|y_i - y_{i_{Pulse}}\right|$$

MSE is defined as follows: $$\frac{1}{n}\sum_{i}^{n}\left(y_i - y_{i_{Pulse}}\right)^2$$

Parameters	**Values**
AirVelocity (m/s)	2.5
AmbientTemperature (degC)	10.1
AtmosphericPressure (mmHg)	692.0
ClothingResistance (clo)	0.513
Emissivity (Scalar between 0 and 1)	0.95
MeanRadiantTemperature (degC)	10.1
RelativeHumidity (Scalar between 0 and 1)	0.45
RespirationAmbientTemperature (degC)	10.1
Nitrogen (Scalar between 0 and 1)	0.7901
Oxygen (Scalar between 0 and 1)	0.2095
CarbonDioxide (Scalar between 0 and 1)	4.0E-4

Table: Environment parameters associated to activity nr. 6

Heart rate baseline : 45

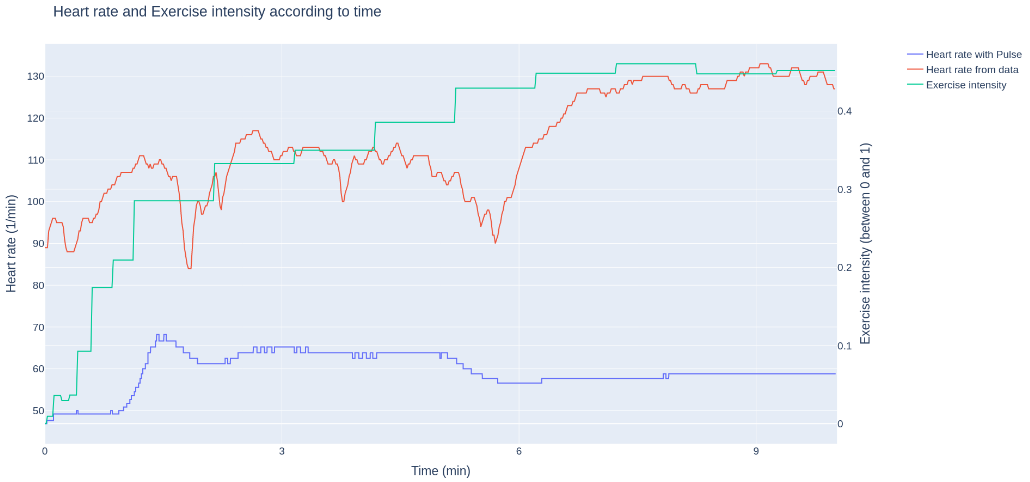

Figure: Heart rate and Exercise intensity for activity nr. 6

Heart rate baseline : 85

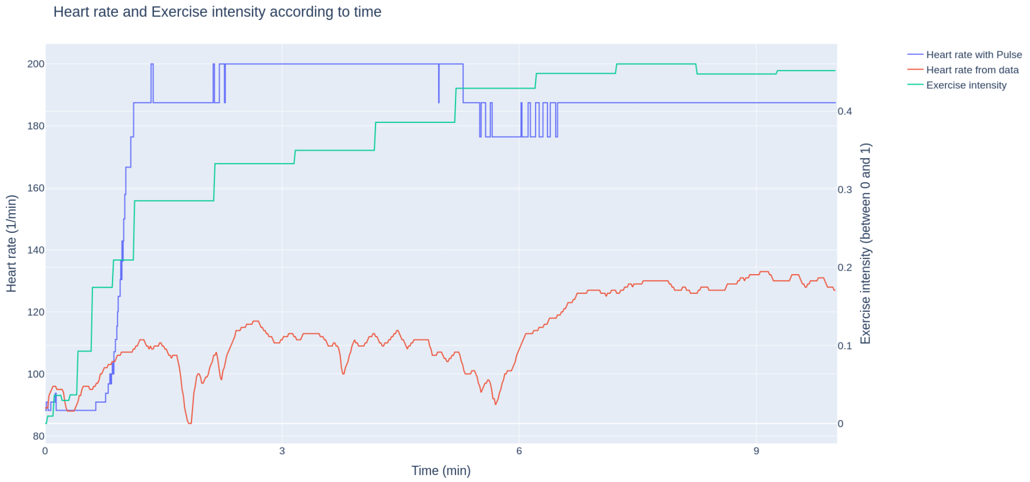

Figure: Heart rate and Exercise intensity for activity nr. 6

Heart rate baseline : 61

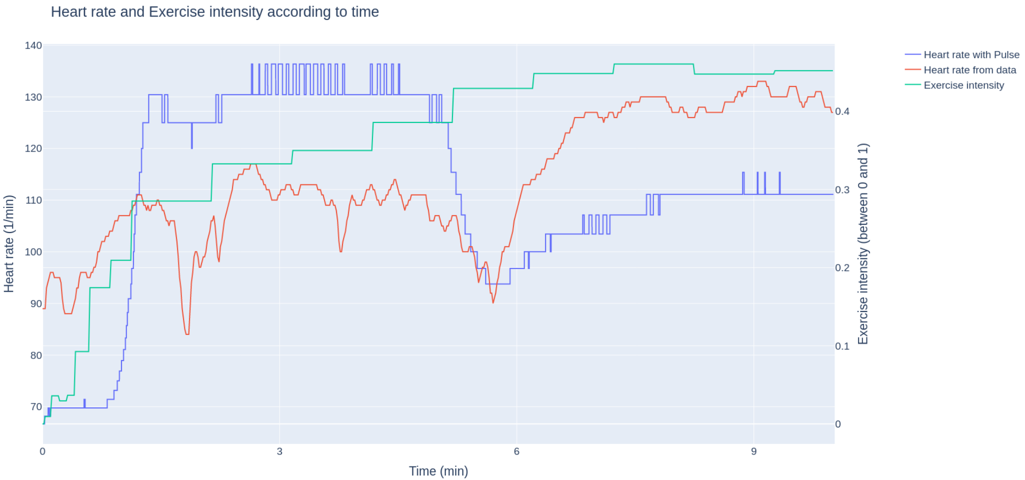

Figure: Heart rate and Exercise intensity for activity nr. 6

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Nutrient	Role in body
Carbohydrate	Maintains energy reserves (particularly glycogenic)
Protein	Maintains tissue structures (including muscles)
Fat	Aid to the energy input
Calcium	Helps for proper muscular function
Magnesium	Helps to anticipate magnesium losses included in sweat
Sodium	Helps to compensate for sodium losses included in sweat
Potassium	Helps for proper neuromuscular function
Citrate	Helps to limit the muscle acidity
Vitamins B1 + B2	Vitamin intake for energy metabolism
Vitamins C + E	Antioxidant properties

Table: Nutrients and function in human body (Source : Nicolas Aubineau [7])

Befort the effort [7]

Nutrients	Quantities
Energie (kcal)	775 - 1300
Glucides (g)	120 - 201
Protides (g)	20 - 31
Lipides (g)	20 - 39
Calcium (mg)	475 - 521
Sodium (mg)	880 - 1604

Table: Nutritional benefits of the cyclist breakfast (Source: Nicolas Aubineau [7])

During the effort [5] [6] [4]

- continuous intake of carbohydrates during exercise : 60 to 90 g per hour
- 400 - 500 mg sodium (1.2 - 1.5 g sodium chloride) per hour of exercise
- between 0.5 L and 1 L of water per hour (2 to 3 sips every 7 to 10 minutes)
- more than 4-5 hours of effort : protein intake to delay the onset of nervous fatigue

After the effort [8]

- Carbohydrate intake after exercise is particularly important.
- 10 to 30 g of proteins after an effort, especially long and/or intense
- consumption must be preferred immediately at the end of the race
- recovery drinks allow to optimize the processes of regeneration of muscle and joint tissues

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Models selection and linkages between them

- focus on the energy, tissue, endocrine and gastrointestinal systems
- nutritional aspect of energy system depends on renal (endocrine) and gastrointestinal systems
- tissue system interacts with energy and drug system
- interaction : post-process step updates the data at every step of time

Energy system [2]

- simulate metabolism by the consumption of nutrients in the tissues
- calculations obtained using the principles of advection and diffusion of transport methods
- “famine” event is not yet activated in Pulse models

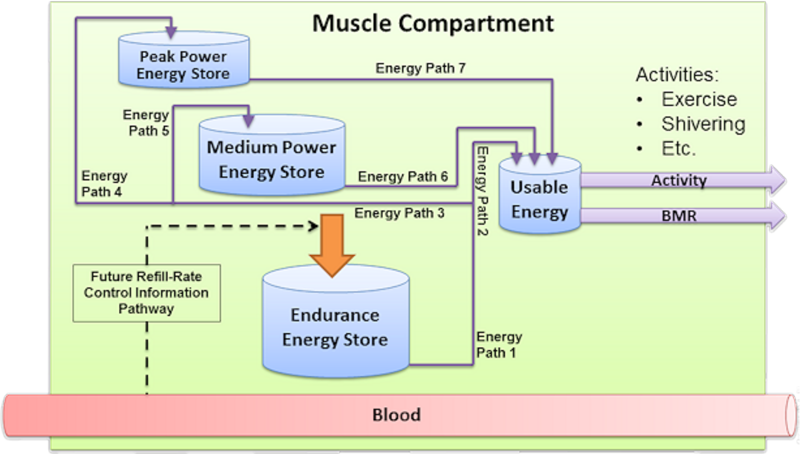

Figure: Energy storage (Source : Pulse [2])

Tissue system [9]

- controlling the transport of substances (nutrients, gases, ions) between tissues and blood
- gradient modes of transport : instant diffusion, simple diffusion, facilitated diffusion
- active transport requires energy (currently inactive)

Endocrine system [10]

- release hormones to maintain homeostasis and regulate body functions
- currently contains two hormones: epinephrine and insulin
- not currently model the physiological effects of epinephrine deficiency
- response to insulin currently depends only on blood glucose concentration

Gastrointestinal system [11]

- currently reproduces the behaviour of the stomach and small intestine
- stomach initialized with configurable amounts of each macronutrient, sodium, calcium and water
- *ConsumeMeal* condition is used to specify a meal ingested before a simulation (currently inactive)
- *ConsumeNutrients* action allows the patient to consume nutrients, with a configurable digestion rate for proteins, fats, carbohydrates

Gastrointestinal system [11]

Macronutrient	Resultant Substance	Technique
Fat	Tristearin	emulsified by the small intestine and then quickly broken down by pancreatic enzymes to absorb them
Protein	Urea	currently decomposed into urea to simulate amino acid deamination in the liver
Calcium	Calcium	regulated by parathyroid hormone
Sodium	Sodium	quickly absorbed thanks to active transport (not yet active in the model)
Water	Water	absorbed through the osmotic gradient between intestinal chyma and blood OR absorbed through active transport via the intestinal wall

Table: How macronutrients are converted into substances (Source : Pulse [11])

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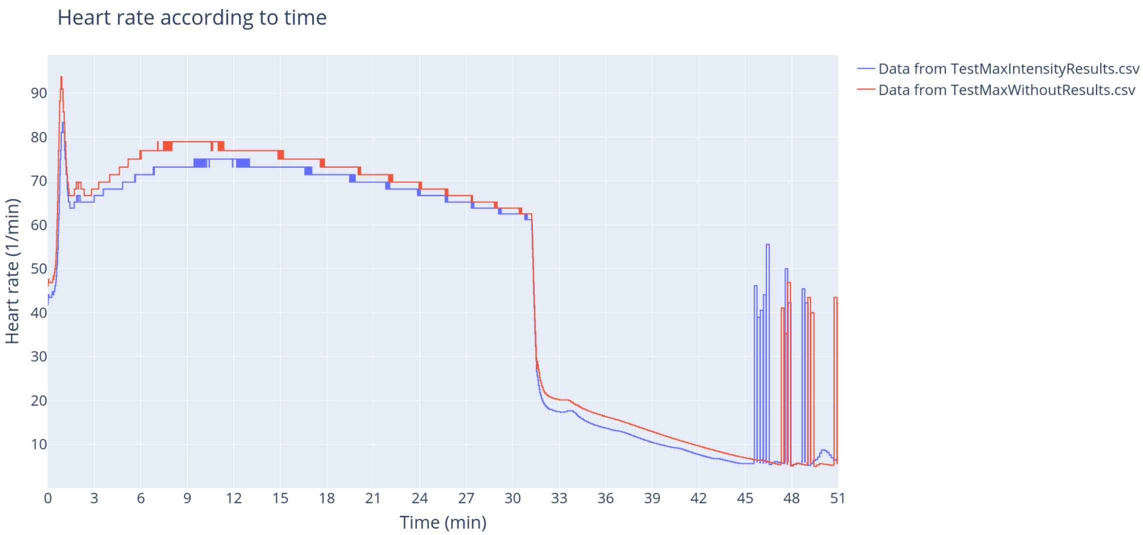
Example of a cyclist meal [7]

Cyclist breakfast

- 200g of bread (a baguette)
- 40g sweet butter (four individual trays)
- 60g of honey or jam (two small individual pots)
- 250mL of black coffee (a large bowl)
- 300mL of pure orange juice (two glasses or two oranges)
- 250g of plain yogurt (two units)

Maximum capacity : with nutrients vs without nutrients



Nutrients consumption during the simulation

```
"PatientAction": {
    "ConsumeNutrients": {
      "Nutrition": {
        "Carbohydrate" : { "ScalarMass":  { "Value": 15.0,  "Unit": "g" }},
        "CarbohydrateDigestionRate":{ "ScalarMassPerTime":{ "Value": 1.083,
            "Unit":"g/min" } },
        "Sodium" :         { "ScalarMass":   { "Value": 1500, "Unit": "mg" }},
        "Water" :          { "ScalarVolume": { "Value": 0.2,   "Unit": "L" }}
        }
    }
}

```

Listing 1: ConsumeNutrients field in a scenario file

Medium capacity : with nutrients vs without nutrients

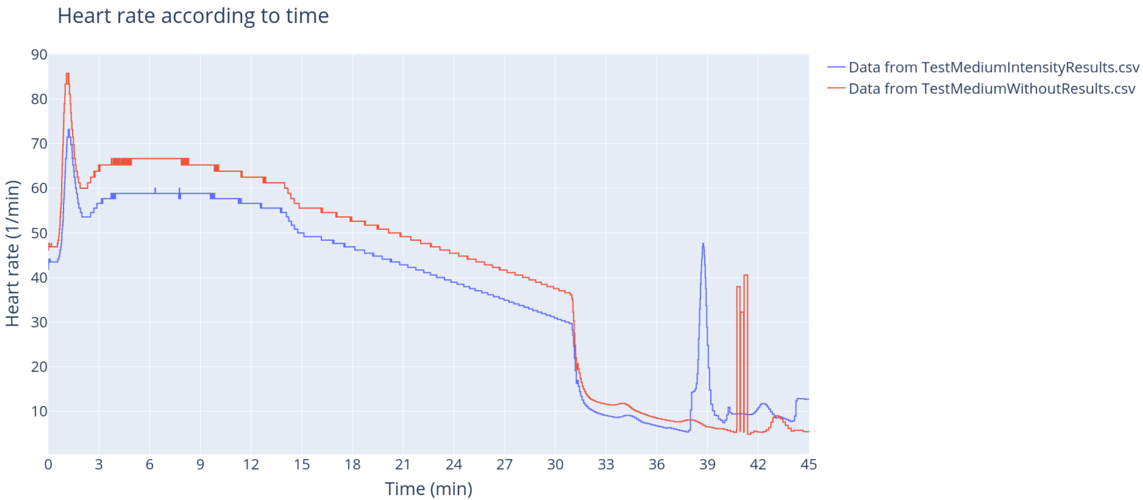


Figure: Output data with Pulse model

Medium capacity : with nutrients vs without nutrients

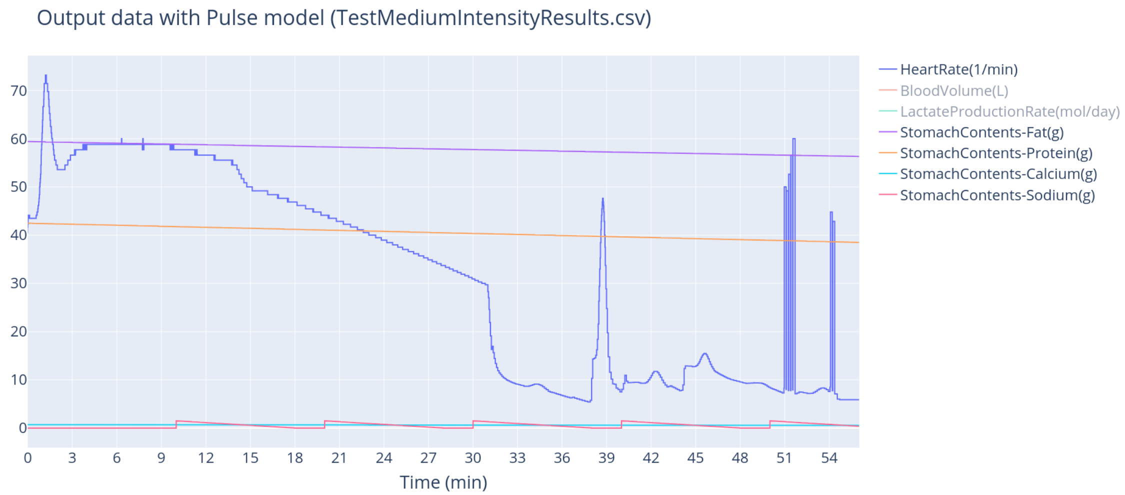


Figure: Output data with Pulse model

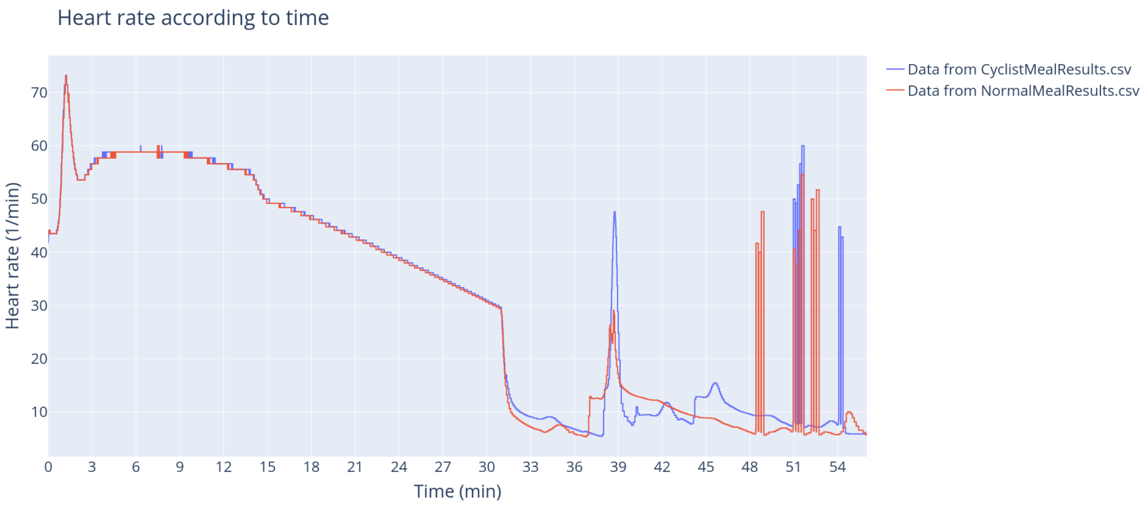


Figure: Output data with Pulse model

Medium capacity : cyclist meal vs normal meal

Output data	MAE	MSE
Epinephrine-BloodConcentration(ug/L)	0.0023102219490854546	1.6664624246495683e-05
Albumin-BloodConcentration(g/dL)	0.0005975941478628871	5.975941478628878e-05
Chloride-BloodConcentration(g/L)	0.000989533769426274	2.5285913086954713e-06
Globulin-BloodConcentration(g/dL)	5.4759623110941854e-05	5.475962311094191e-06
Insulin-BloodConcentration(ug/L)	0.009279494306784835	0.00033580996029927316
Sodium-BloodConcentration(g/dL)	0.0	0.0

Table: Errors between CyclistMealResults.csv and NormalMealResults.csv

Medium capacity : cyclist meal vs normal meal

Output data	MAE	MSE
Acetoacetate-BloodConcentration(mg/L)	0.06866456754778075	0.019270220431291552
Creatinine-BloodConcentration(mg/L)	0.08793562173004696	0.009866731743320218
Hemoglobin-BloodConcentration(g/dL)	0.0045278470539917934	6.452409721023524e-05
Potassium-BloodConcentration(mg/L)	0.04535239603111773	0.0052214657722594905
Glucose-BloodConcentration(mg/dL)	0.33163618182575705	0.35801936824060854
Calcium-BloodConcentration(mg/L)	0.029042837500818784	0.002904283750081916
Lactate-BloodConcentration(mg/L)	0.12459480854964369	0.06651008588927834

Table: Errors between CyclistMealResults.csv and NormalMealResults.csv

Medium capacity : only water vs cyclist meal

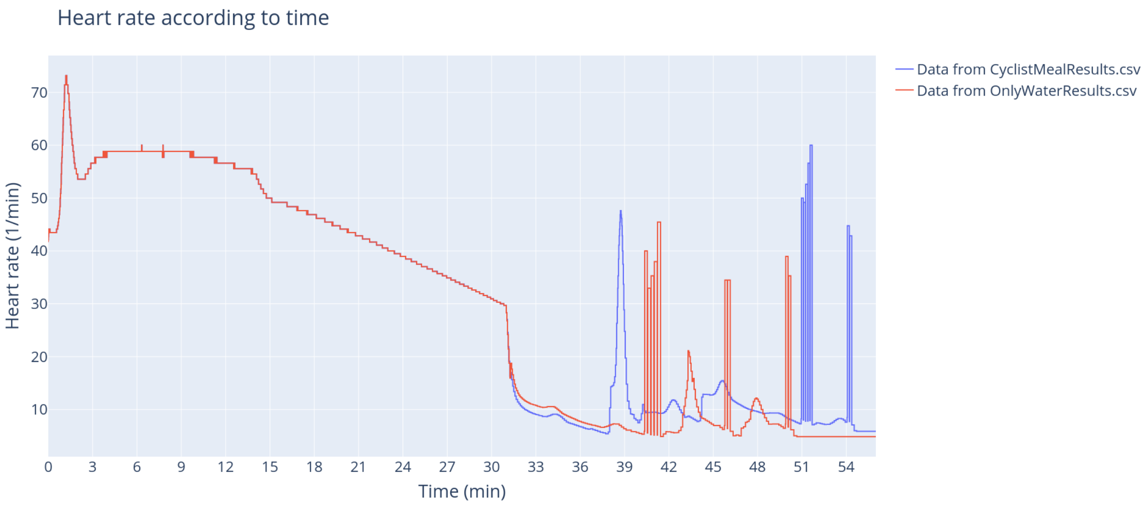


Figure: Output data with Pulse model

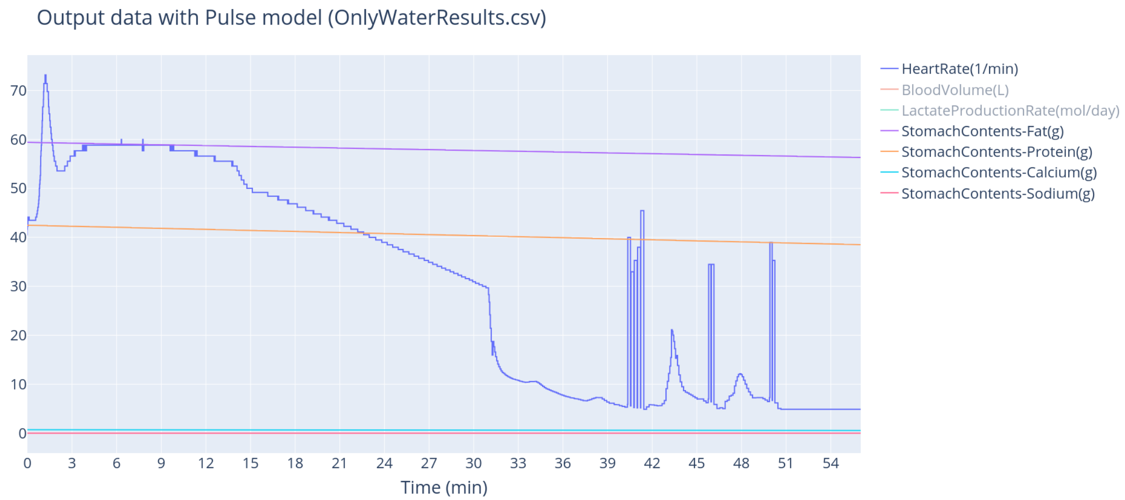


Figure: Output data with Pulse model

Medium capacity : nutrients without water vs cyclist meal

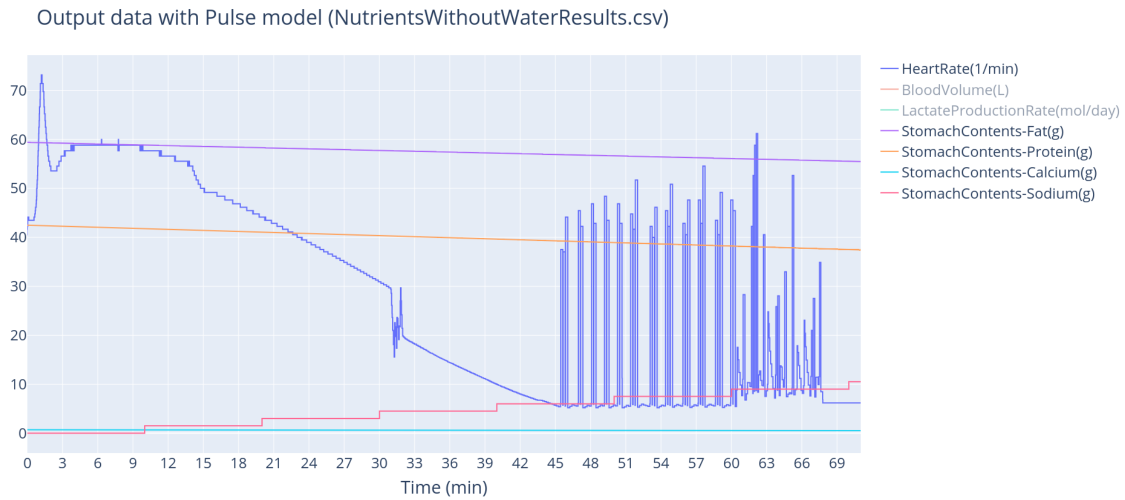


Figure: Output data with Pulse model

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Conclusion

- link between the stomach and the blood is not yet modeled
- blood sodium concentration was still the same in the different cases studied
- energy reserves do not take nutrients as parameters to regenerate

$\Rightarrow$ currently impossible to model correctly the vital data of a cyclist during a race

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