

Analysing sweat to determine internal training load during an incremental exercise

Thomas, Miguel; Bossche, Andre; Groen, Pim; Bastemeijer, Jeroen; Steijlen, Annemarijn; French, Paddy

Publication date

2019

Document Version

Final published version

Published in

Smart Systems Integration 2019 - International Conference and Exhibition on Integration Issues of Miniaturized Systems, SSI 2019

Citation (APA)

Thomas, M., Bossche, A., Groen, P., Bastemeijer, J., Steijlen, A., & French, P. (2019). Analysing sweat to determine internal training load during an incremental exercise. In T. Otto (Ed.), *Smart Systems Integration 2019 - International Conference and Exhibition on Integration Issues of Miniaturized Systems, SSI 2019* (pp. 193-199). (Smart Systems Integration 2019 - International Conference and Exhibition on Integration Issues of Miniaturized Systems, SSI 2019). VDE.

Important note

To cite this publication, please use the final published version (if applicable).
Please check the document version above.

Copyright

Other than for strictly personal use, it is not permitted to download, forward or distribute the text or part of it, without the consent of the author(s) and/or copyright holder(s), unless the work is under an open content license such as Creative Commons.

Takedown policy

Please contact us and provide details if you believe this document breaches copyrights.
We will remove access to the work immediately and investigate your claim.

Green Open Access added to TU Delft Institutional Repository

'You share, we take care!' - Taverne project

<https://www.openaccess.nl/en/you-share-we-take-care>

Otherwise as indicated in the copyright section: the publisher is the copyright holder of this work and the author uses the Dutch legislation to make this work public.

Analysing sweat to determine internal training load during an incremental exercise

Miguel Thomas*, Andre Bossche*, Pim Groen+, Jeroen Bastemeijer*, Annemarijn Steijlen*, Paddy French*#

*EI-EWI, TU Delft, Mekelweg 4, 2628CD, Delft, The Netherlands

+Aerospace Structures & Materials, L&R, TU Delft, Kluyverweg 1, 2629 HS Delft, The Netherlands.

Corresponding Author +31-15-2784729, p.j.french@tudelft.nl

Abstract

Sweating is a normal reaction of the body to exercise. Although much of sweat is water, there are many other components. These components can be an indication of the condition of the athlete. Increase of elements and salts in the tissue will also work their way through to the sweat. Measurement directly in tissue can be an excellent indicator, but a non-invasive approach is simpler to use and safer. Concentrations in sweat can also be an indication that the athlete is in danger of collapse. This paper looks into the components in sweat and how this change with exercise. The aim is to develop a simple, wearable system able to warn the athlete of the impending danger and prevent a potential accident.

1 Introduction

Currently in the field of sport, many athletes, coaches and support staff are taking an increasingly scientific approach in order to get the edge on their competitor. This can be done by improving the equipment they use such as increase aerodynamics of a bicycle or improving running economy by designing better running shoes. Alternatively, improved preparation through the training itself and monitoring during training to validate whether the training is effective in performance increase. One method of doing this is by monitoring with wearable devices, which in 2018, is a B\$5.8 industry [1]. However, most wearable devices fail to provide insight into internal load parameters such as, hydration status, energy consumption and muscle fatigue. Measurement of human perspiration could enable such insight, because it contains physiologically and metabolically rich information that can be retrieved non-invasively [2]. This work looks into methods to determine fatigue through real-time sweat analysis.

2 Fatigue definition

The term fatigue can be described as the load measurable by assessing internal response factors within the biological system, which may be physiological, psychological or other [3]. This progressive phenomenon developed over time, resulting from a continuous physical or mental effort, being characterized from the muscular point of view by the inability to maintain strength, depending on the muscle under analysis and the patient's own morphology [4]. This occurs due an oxygen shortage, glucose will be metabolized anaerobically in the muscle, which produces lactic acid.

3 Sweat

The main component of sweat is water. However, within the water are a number of components. The volume of water lost in sweat daily is highly variable, ranging from 100 to 8,000 mL/day, depending on conditions and level of activity.

3.1 Sweat glands

Sweating can be classified in two groups: the thermal sweat, through eccrine glands, and the mental or emotional sweating, though apocrine glands [5]. Eccrine glands cover almost the entire body, with the exception of the palms and soles. They have a tubular structure with a deep sub-dermal coiled secretory section which is connected to a duct which passes through the skin. The primary function of eccrine sweat glands is thermoregulation [6]. Apocrine glands are the largest and occur in the axillae, areola of nipple and genital areas and they produce a viscous sweat containing lipids, cholesterol and steroids [6]. Since we want to determine internal training load parameters, sweat from the eccrine glands must be analysed. These sweat glands are shown in figure 1.

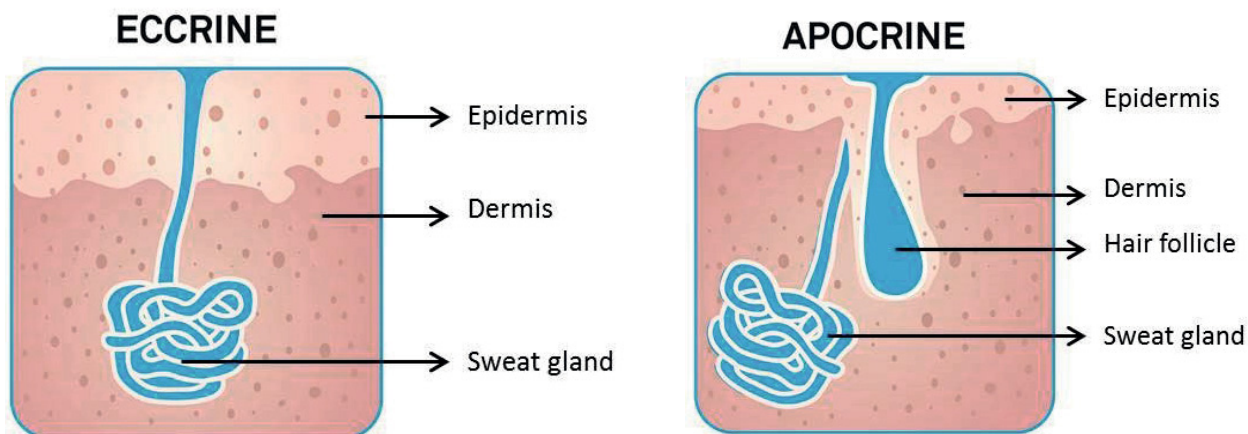


Figure 1. (left) Eccrine sweat glands, (right) apocrine sweat glands.

3.2 Sweat composition

The sweat contains manifold constituents, but all of them are so small in amount that the total solid component makes only 0.3% to 0.8% of sweat. The sweat may therefore be regarded as the most dilute human secretion. These constituents can be grouped in inorganic constituent, nitrogen compounds and sugars and its metabolites. Out of these constituents, lactic acid and ammonia are brought into light for determining state of muscle fatigue. The constituents of sweat are shown in the appendix.

Though lactic acid is a very well-known constituent to relate to fatigue, an overwhelming amount of research concludes that there is little correlation between lactic acid concentration in plasma and in sweat [2] [5] [7]. This is due to the lactic acid coming from different sources; lactate in plasma comes from the fatigued muscles whereas the lactic acid in sweat comes from the sweat glands. In contrast, sweat ammonia does show to correlate with ammonia in plasma, because ammonia diffuses from the plasma into the sweat glands [2] [7]. In sweat there are other electrolytes that may indicate internal training load. Changes in Na^+ and Cl^- concentrations in sweat can indicate sweat rate [2] dehydration, overhydration and electrolyte loss [7].

4 Measurement of ammonia in sweat

The clearest indication of muscle fatigue is in the tissue itself. However, measuring in sweat using a plaster, or in clothing is a much safer and more convenient method. Figure 2 shows measurements of ammonia and lactic acid in tissue and sweat during and after exercise measured by Alvear-Ordenes et al. [7]. The exercise in this case was rugby training. This shows with both parameters a clear peak during training. In sweat the change is not clear for lactic acid, but remains clear in the ammonia concentration. In this experiment, it is

researched how the ammonia concentration changes real-time during the exercise, Although the change is clear with ammonia in figure 2, the concentrations are low, leading to challenges to measure real time during training.

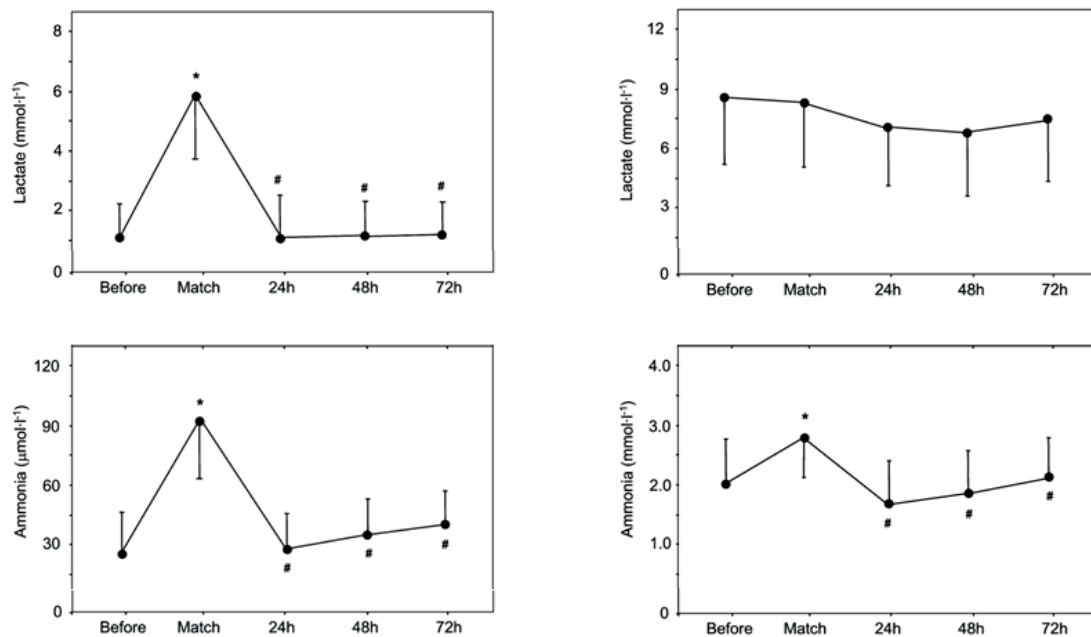
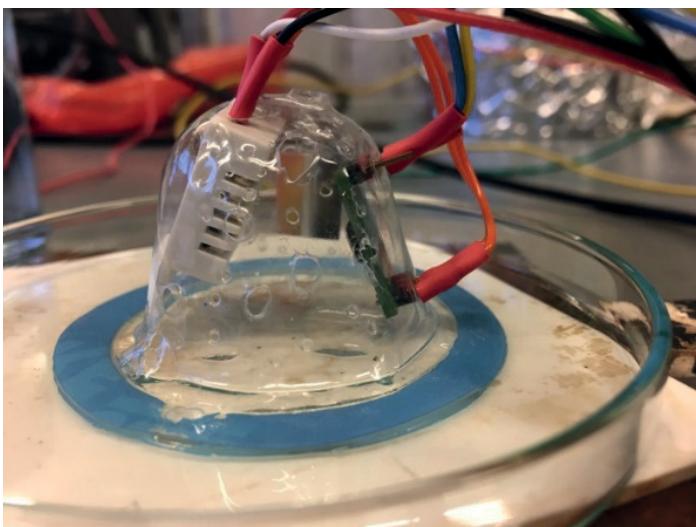


Figure 2. Ammonia and lactate concentrations in blood (left) and in sweat (right). Samples were collected before rugby training, during the training, 24 hr, 48 hr and 72 hr after training [7].

4.1 Measuring method

Traditionally, measuring method in real-time sweat measurements were done through AgCl electrodes. The novel approach that this research has taken was by using a MOS sensor which measures gas ammonia concentrations. Compared to MOS sensor, common methods require a higher sweat quantity in order to start measurements. Because of the lower sweat requirement, it may also be possible to place this sensor on a body section where less sweating occurs (i.e. limbs). Most importantly, there is an abounding amount of commercially available gas ammonia sensors.



For this concept, the MiCS 5914 ammonia sensor by SGX Sensortech™ was used alongside with the DHT22 to monitor humidity and temperature, as shown in figure 3.

Figure 3. Sensor concept which includes the ammonia sensor temperature and humidity sensor.

6 Experiment method

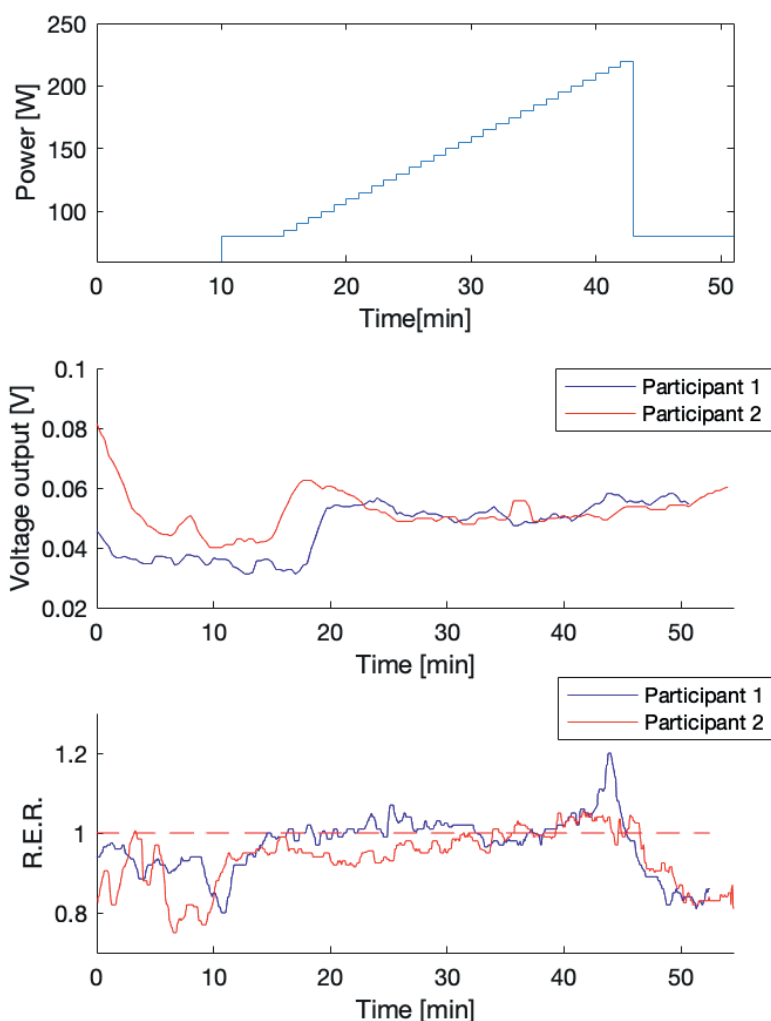
One male (26) and one female (25) participated in this experiment. The test was using cycling ergometer (LODE Excalibur™)

Prior to starting the experimental trial, the participants were advised to be well-rested before conducting the experiment. The skin surface where the ammonia sensor concept is placed is cleaned with distilled water to remove possible contaminants. The ammonia sensor was placed in close proximity to the muscle belly of the rectus femoris. Before the experimental trial, the ammonia sensor is placed and turned on 10 minutes prior to starting the experiment in order to warm up the embedded heater. Then the participant would initiate a 5-minute warm up at 80 Watt. Followed by incremental cycling exercise which increases by 5 Watt every minute. Once the participants reached their state of fatigue, they would perform a 10-minute cooldown at 80 Watt.

The ammonia was measured directly on the subject. During the experiment, the participants breathe through a mask connected to a turbine flowmeter (COSMED K5™) for continuous measurement respiratory exchange ratio (RER), in order to indicate when the participants become anaerobic.

7 Results

The output signal of the ammonia measurements show gradual increase in the end of the trial when the participants became anaerobic according to the RER system. This is



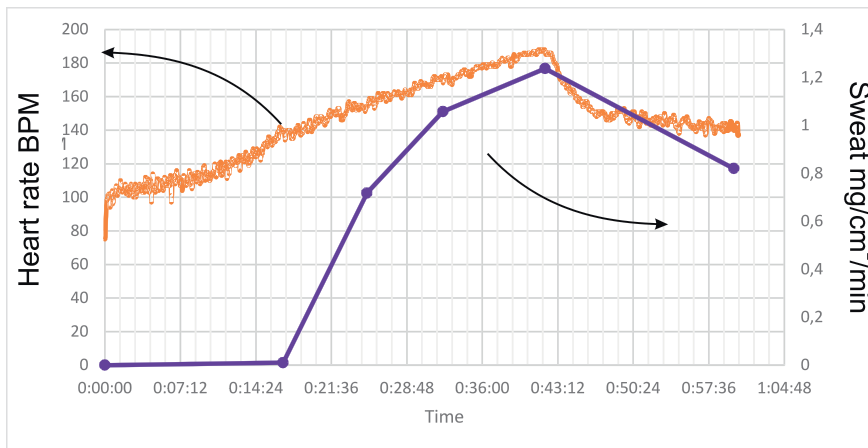
approximately initiated at the 35th minute. There is also an increase in the R.E.R signal output (bottom graph). This is possibly due to a change in humidity, once the participants start overheating which initiates perspiration. Temperature was completely negligible since for both participants, the maximum temperature difference (ΔT) of 1°C.

Unfortunately, no decrease in ammonia concentration was measured once the participants started their cool-down exercise as what have been expected similar to the RER measurement.

Figure 4. Power output (above), which was asked to the participants to generate during experiment, ammonia signal output (middle) and RER (below) output.

8 Electrolytes in Sweat

Another incremental exercise experiment was executed with two male participants (26 and 30 years old), to see how potassium, sodium ammonium and chloride concentrations change during this exercise. Sweat was collected five times during the exercise with a Macroduct sweat collector. Analysis was then performed on sweat rate and salts in the lab with an Ion Chromatograph (Metrohm, 818 anion system, 883 cation system). This time heart rate was measured with a Polar H10 heart rate monitor. Figure 5 shows the increase in sweat and heart rate with increased resistance. It also clearly shows the drop in both



when the resistance is returned to a low level, which is around the 42nd minute

Figure 5 Increased heart rate and sweat rate during the exercise.

Participant 2 showed a similar increase in heart rate, but only in the last phase an increase in sweat rate. This also shows the need for more tests to illuminate individual variations. Figure 6 shows the concentration of Na⁺ in sweat. This shows a clearer link to heart rate and sweat rate. Subject 2 displayed a similar pattern.

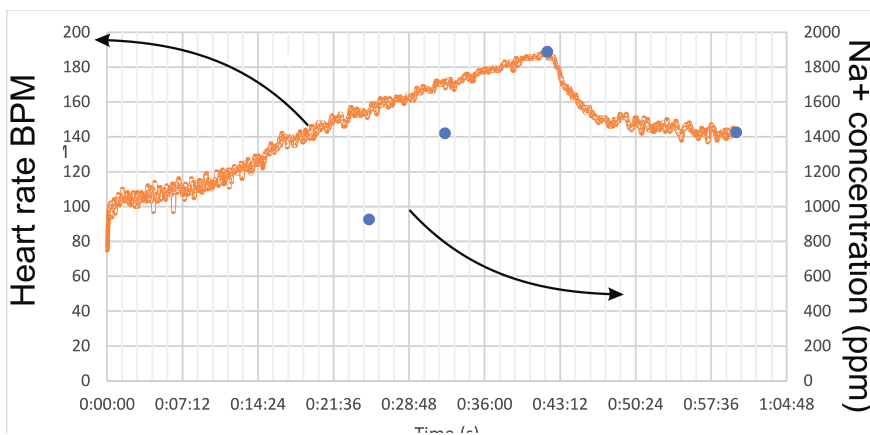


Figure 6. Na⁺ concentration and heart rate during incremental exercise

The K⁺ concentration appears from initial results to reduce with increased work, as shown in Figure 7. Subject No. 2 showed an increase in K concentration after exercise. This will require further measurements, also with more subjects to establish the pattern. At this stage we were unfortunately not able to detect ammonium yet. Since sample volumes are small (sometimes less than 10 microl) and concentrations are very low. This will be investigated further.

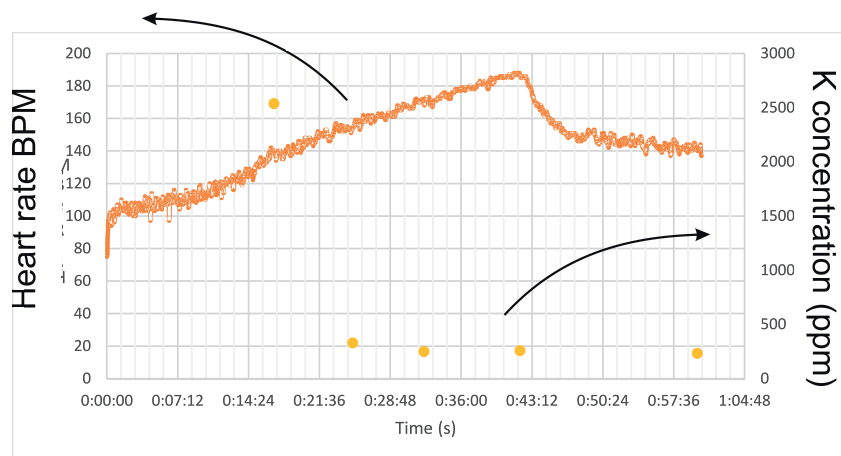


Figure 7 Heart rate and K concentration during exercise.

8 Conclusions

This research shows the first experiments on how NH_4^+ , Na^+ , K^+ and Cl^- change during an incremental exercise. Ammonia concentrations were measured with a gas sensor and electrolytes were measured in the Ion Chromatograph. Further research is needed to draw conclusions from a physiological point of view and find relations with internal training load. The measurements show that there is a need for a better sweat collection system, to perform more reliable measurements. Also, the exercise protocol needs to be improved to test the relation between lactate in blood and ammonia in sweat during exercise.

9 Acknowledgements

The authors wish to thank the Dutch Science foundation NWO for funding this work.

9 References

- [1] Statista. (n.d.). *Global wearable technology market 2012-2018* | *Statistic*. Retrieved 10 8, 2018.
- [2] Sonner, Z., Wilder, E., Heikenfeld, J., Kasting, G., Beyette, F., Swaile, D., ... & Naik, R. (2015). The microfluidics of the eccrine sweat gland, including biomarker partitioning, transport, and biosensing implications. *Biomicrofluidics*, 9(3), 031301.
- [3] Halson, S. L. (2014). Monitoring Training Load to Understand Fatigue in Athletes. *Sports Medicine (Auckland, N.z.)*, 44(Suppl 2), 139-147. doi:10.1007/s40279-014-0253-z
- [4] Barry, B. K., & Enoka, R. M. (2007). The neurobiology of muscle fatigue: 15 years later. *Integrative and comparative biology*, 47(4), 465-473.
- [5] Kuno, Y. (1934). *Physiology of human perspiration*. J. And A. Churchill: London.
- [6] Morris, D., Coyle, S., Wu, Y., Lau, K. T., Wallace, G., & Diamond, D. (2009). Bio-sensing textile based patch with integrated optical detection system for sweat monitoring. *Sensors and Actuators B: Chemical*, 139(1), 231-236.
- [7] Alvear-Ordenes, I., García-López, D., De Paz, J. A., & González-Gallego, J. (2005). Sweat lactate, ammonia, and urea in rugby players. *International journal of sports medicine*, 26(08), 632-637.
- [8] Morgan, R. M., Patterson, M. J., & Nimmo, M. A. (2004). Acute effects of dehydration on sweat composition in men during prolonged exercise in the heat. *Acta Physiol Scand*, 182(1), 37-43. doi:10.1111/j.1365-201X.2004.01305.x
- [9] Y. Kondoh, M. Kawase, and S. Ohmori, D-lactate concentrations in blood, urine and sweat before and after exercise, *European journal of applied physiology and occupational physiology* **65**, 88 (1992).
- [10] W. Gao, S. Emaminejad, H. Y. Y. Nyein, S. Challa, K. Chen, A. Peck, H. M. Fahad, H. Ota, H. Shiraki, D. Kiriya, et al., Fully integrated wearable sensor arrays for multiplexed in situ perspiration analysis, *Nature* **529**, 509 (2016).
- [11] I. Alvear-Ordenes, D. García-López, J. De Paz, and J. González-Gallego, Sweat lactate, ammonia, and urea in rugby players, *International journal of sports medicine* **26**, 632 (2005).

- [12] Z. Sonner, E. Wilder, J. Heikenfeld, G. Kasting, F. Beyette, D. Swaile, F. Sherman, J. Joyce, J. Hagen, N. Kelley-Loughnane, et al., The microfluidics of the eccrine sweat gland, including biomarker partitioning, transport, and biosensing implications, *Biomicrofluidics* **9**, 031301 (2015).
- [13] R. M. HARDEN, Calcium excretion in thermal sweat in thyrotoxicosis, *Journal of Endocrinology* **28**, 153 (1964).
- [14] Y. Kuno, *Physiology of human perspiration* (J. And A. Churchill: London, 1934).
- [15] T. Guinovart, A. J. Bandodkar, J. R. Windmiller, F. J. Andrade, and J. Wang, A potentiometric tattoo sensor for monitoring ammonium in sweat, *Analyst* **138**, 7031 (2013).

Appendix

Chemical	Molecular weight	Concentration [mM]	Concentration [ppm]	Trend when exercising
Pyruvate	88.06	42.9 - 67.6*	0.38 - 0.60	Decrease [9]
Glucose	180.156	0.001 - 1	0.18 - 180.15	Decrease [10]
Lactate	90.08	5 - 60	450.40 - 5404.80	Decrease [11] [12] [9]
Sodium	22.9898	10 - 100	229.90 - 2298.98	Increase [12] [10]
Chloride	35.453	10 - 100	354.53 - 3545.30	Increase [12] [10]
Potassium	39.0983	4 - 24	156.39 - 938.36	Decrease [12] [10]
Calcium	18.039	0.35 - 1.125	14 - 45	? [13]
Magnesium	24.305	8.23 - 1366*	0.2 - 33.2	? [14]
Phosphorus	30.97	0 - 1.5	0 - 48	? [14]
Sulfate	96.06	0.42 - 1.77	40 - 170	? [14]
Iodine	126.9	0.055*	0.007	? [14]
Copper	63.546	0.94*	0.06	? [14]
Manganese	54.94	1.092*	0.06	? [14]
Iron	55.845	1.074 - 35.81*	0.06 - 2	? [14]
Ammonium	18.039	0.5 - 8	9.02 - 144.31	Increase [12]
Ammonia	17.031	1.8 - 4.2	30.66 - 71.53	Increase [12] [11] [15]
Urea	46.07	2 - 6	120.12 - 360.36	Increase [11]
Amino acids	X	X	11 - 102	? [14]
Uric acids	X	X	0 - 12	? [14]
Creatine	131.13	15.3 - 144.9*	2 - 19	? [14]
Ethanol	17.031	2.5 - 22.5	115.18 - 1036.58	

Table A.1 Constituents of sweat in μM