Chapter 4
Underwater Near-Infrared Spectroscopy: Muscle Oxygen Changes in the Upper and Lower Extremities in Club Level Swimmers and Triathletes

B. Jones and C.E. Cooper

Abstract To date, measurements of oxygen status during swim exercise have focused upon systemic aerobic capacity. The development of a portable, waterproof NIRS device makes possible a local measurement of muscle hemodynamics and oxygenation that could provide a novel insight into the physiological changes that occur during swim exercise. The purpose of this study was to observe changes in muscle oxygenation in the vastus lateralis (VL) and latissimus dorsi (LD) of club level swimmers and triathletes. Ten subjects, five club level swimmers and five club level triathletes (three men and seven women) were used for assessment. Swim group; mean ± SD = age 21.2 ± 1.6 years; height 170.6 ± 7.5 cm; weight 62.8 ± 6.9 kg; vastus lateralis skin fold 13.8 ± 5.6 mm; latissimus dorsi skin fold 12.6 ± 3.7. Triathlete group; mean ± SD = age 44.0 ± 10.5 years; height 171.6 ± 7.0 cm; weight 68.6 ± 12.7 kg; vastus lateralis skin fold 11.8 ± 3.5 mm; latissimus dorsi skin fold 11.2 ± 3.1. All subjects completed a maximal 200 m freestyle swim, with the PortaMon, a portable NIR device, attached to the subject's dominant side musculature. ΔTSI % between the vastus lateralis and latissimus dorsi were analysed using either paired (2-tailed) *t*-tests or Wilcoxon signed rank test. The level of significance for analysis was set at $p < 0.05$. No significant difference ($p = 0.686$) was found in ΔTSI (%) between the VL and LD in club level swimmers. A significant difference ($p = 0.043$) was found in ΔTSI (%) between the VL and LD in club level triathletes. Club level swimmers completed the 200 m freestyle swim significantly faster ($p = 0.04$) than club level triathletes. Club level swimmers use both the upper and lower muscles to a similar extent during a maximal 200 m swim. Club level triathletes predominately use the upper body for propulsion during the same exercise. The data produced by NIRS in this study are the first of their kind and provide insight into muscle oxygenation changes during swim exercise which can indicate the contribution of one muscle compared to another. This also enables a greater understanding of the differences in

B. Jones (✉) • C.E. Cooper
School of Biological Sciences, Centre for Sports and Exercise Science, University of Essex, Colchester CO4 3SQ, UK
e-mail: bjonesa@essex.ac.uk

C.E. Elwell et al. (eds.), *Oxygen Transport to Tissue XXXVII*, Advances in Experimental Medicine and Biology 876, DOI 10.1007/978-1-4939-3023-4_4

swimming techniques seen between different cohorts of swimmers and potentially within individual swimmers.

Keywords Underwater • NIRS • Swimming • Muscle oxygenation

1 Introduction

It has been shown that individual swimmers vary considerably with regard to swim technique and style [1]. It has also been reported that swim athletes display specific training adaptations in comparison to land based athletes and triathletes [2]. Specifically, it has been reported that triathletes and swimmers vary in swim velocity and propulsion efficiency [3]. It is therefore of interest to understand the different physiological responses that may occur within different swim athletes. Roels et al. demonstrated that during an incremental swim test, competition swimmers produced significantly higher heart rate maximum, maximal oxygen consumption (VO_2max) and maximal swim velocities in comparison with competition triathletes. Current physiological assessment during swim exercise has predominately focused upon global measurements such as heart rate [4], blood lactate [5] and VO_2max [6]. Systemic measurements of oxygen status have been made possible through the development of specialized snorkels such as the Aqua Trainer Valve Cosmed technologies©, which now allows for breath-by-breath analysis within the pool [7]. It has been suggested that a local measurement of muscle oxygenation during swim exercise would contribute to a multi-modality approach that is perhaps warranted, to enable a more detailed evaluation of swim athletes [8].

Near-infrared spectroscopy (NIRS) has been used successfully in the non-invasive observation of changes in local muscle oxygenation and hemodynamic responses in tissue within a variety of dynamic land based sports including; short track speed skating [9], downhill skiing [10] and sprint running [11] and recently the NIR technique has been utilised with swim athletes [12], albeit during incremental cycle exercise. To the best of our knowledge the concurrent observation of the muscle oxygenation in both the vastus lateralis (VL) and latissimus dorsi (LD) muscles, using NIRS, during underwater swimming has not been carried out. The development of a portable waterproof NIRS device, utilising an optically clear, waterproof, silicone covering, has enabled the provision of a local measurement of muscle oxygenation that could provide novel insight into the physiological changes that occur during swim exercise. Therefore, the aims of the study were: to advance the assessment and utility of an underwater near-infrared spectroscopy device and to monitor the differences (if any) in muscle oxygenation changes within two different cohorts of swim athletes in the upper and lower extremities.

2 Methods

Club level swimmers and triathletes from Essex based (United Kingdom) swim clubs were asked on a voluntary basis to take part in a 200 m maximal swim effort in their club training pool. Ten subjects, five club level swimmers and five club level triathletes, (three men and seven women) volunteered for assessment. Swim group; mean ± SD = age 21.2 ± 1.6 years; height 170.6 ± 7.5 cm; weight 62.8 ± 6.9 kg; vastus lateralis skin fold 13.8 ± 5.6 mm; latissimus dorsi skinfold 12.6 ± 3.7. Triathlete group; mean ± SD = age 44.0 ± 10.5 years; height 171.6 ± 7.0 cm; weight 68.6 ± 12.7 kg; vastus lateralis skin fold 11.8 ± 3.5 mm; latissimus dorsi skinfold 11.2 ± 3.1. All subjects were experienced swim athletes who had been involved in swim training for 11.1 ± 3.4 years. Subjects were asked not to perform any strenuous activity 24 h prior to the observational assessment. The study received ethical approval and all subjects provided informed consent.

Each subject was asked to perform a maximal 200 m freestyle swim (8 × 25 m) in a short course swimming pool. Subjects were made to complete a 400 m warm up comprised of 300 m (freestyle) at a self-selected pace and 100 m (freestyle) consisting of 15 m hard and 35 m easy × 2. Following warm up, subjects passively stood in the shallow end of the swimming pool (waist immersion), with their arms by their sides and their body weight evenly distributed over each leg, for a 2-min period to establish a baseline NIR reading. Subjects then started freestyle swimming without diving from the pool edge and were able to perform regular ('tumble turn') turning motions at the end of the lane. Upon completion subjects passively stood for 3 min at the shallow end of the pool, following the same procedure as for the baseline NIR attainment.

The portable NIRS apparatus (PortaMon, Artinis, Medical Systems, BV, the Netherlands) used in this study was a dual wavelength continuous system, which simultaneously uses the modified Beer-Lambert law and spatially resolved spectroscopy (SRS) methods. Changes in tissue oxyhemoglobin (O_2Hb), deoxyhemoglobin (HHb) and total hemoglobin (tHb) were measured using the difference in absorption characteristics of wavelength at 750 and 850 nm. The tissue hemoglobin saturation index (TSI) (expressed in % and calculated as $[O_2Hb]/([O_2Hb] + [HHb]) \times 100$), was calculated using the SRS method [13]. During testing, the PortaMon stored the data within the device's internal memory capacity. These data were subsequently downloaded onto a personal computer for analysis through an online software program. Data acquisition was sampled at a rate of 10 Hz for analogue-to-digital conversion and subsequent analysis. Baseline and minimum TSI (%) values were calculated as the 30-s average prior to the start of the exercise and the 3-s average surrounding the lowest value during the 200 m swim effort. The ΔTSI was therefore calculated as the baseline value minus the minimum

value e.g. TSI Baseline − TSI Min = ΔTSI. The NIRS devices were positioned on the belly of the vastus lateralis muscle, midway between the greater trochanter of the femur and the lateral femoral epicondyle and for the latissimus dorsi muscle, at the midpoint between the mid-axilla and the spinal column. To ensure the optodes and detector did not move relative to the subject's skin, the device was fixed into position using sports waterproof adhesive tape and secured using the subject's own specialist swim apparel.

Descriptive statistics are presented as a mean ± SD unless otherwise stated. Each variable was examined with Kolmogorov-Smirnov normality test. ΔTSI %, between muscle groups and time to swim completion (s) were analysed using either paired (2-tailed) *t*-tests or Wilcoxon signed rank test when the sample normality test failed as per Bravo and colleagues [14]. The level of significance for analyses was set at $p < 0.05$. All analyses were performed using Graphpad Prism 6 (Graphpad Software, San Diego, CA).

3 Results

Figures 4.1a–e and 4.2a–e show the individual tissue saturation index (TSI %) trends for the vastus lateralis and latissimus dorsi muscle for the club level swimmers and club level triathletes groups, respectively. Club level swimmers completed the 200 m freestyle swim significantly faster ($p = 0.04$) than the triathlete group. Swim group time; 172.4 ± 14.6 (s), triathlete group time; 232.6 ± 39.6 (s).

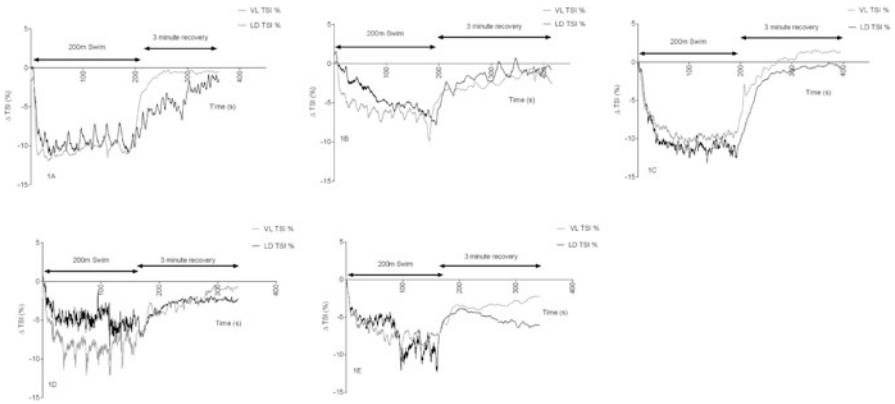

Fig. 4.1 Individual (subject's (**a**–**e**)) swim group ΔTSI (%) for the vastus lateralis and latissimus dorsi muscles. Group average data show there was no significant difference ($p = 0.686$) between the extent of desaturation in the upper and lower extremity; VL ΔTSI % = −9.44 ± 1.50, LD ΔTSI %= −9.00 ± 3.27

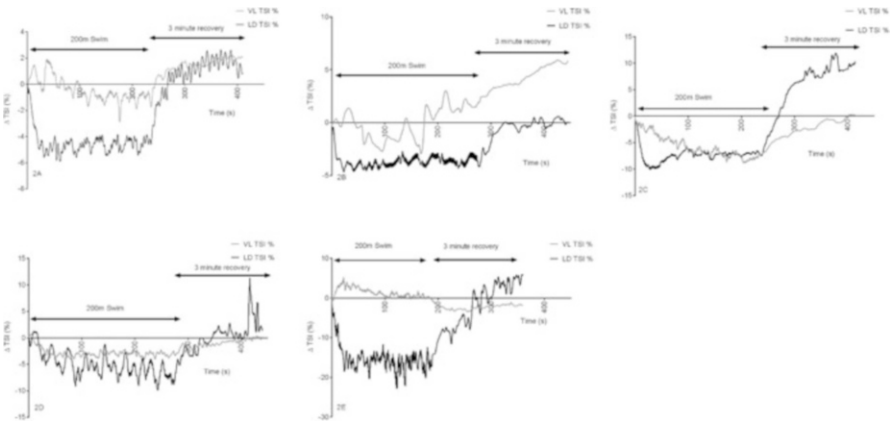

Fig. 4.2 Individual (subject's (**a**–**e**)) triathlete group ΔTSI (%) for the vastus lateralis and latissimus dorsi muscles. Group average data show there was a significant difference ($p = 0.043$) between the extent of desaturation in the upper and lower extremity; VL ΔTSI % = −3.27 ± 2.74, LD ΔTSI % = −8.79 ± 5.24

4 Conclusions

This pioneering study has demonstrated how, for the first time, a waterproofed NIR device was able to report on muscle oxygen changes at the local level in both the upper and lower body in club level swimmers and triathletes. Furthermore, the data reported in this study show that, during a maximal 200 m swim, club level swimmers displayed no significant difference in ΔTSI (%) in the upper and lower body ($p = 0.686$), whereas the club level triathletes experienced a significantly greater drop in TSI (%) in the upper body compared with the lower ($p = 0.043$). These data suggest that club level swimmers use both the upper and lower body muscles to a similar extent during a maximal 200 m swim effort. Club level triathletes, however, predominantly use the upper body for propulsion during the same exercise. A significant difference in swim time ($p = 0.04$) was seen, with the club level swimmers completing the 200 m swim distance faster than the triathlete group. As previously mentioned, notable differences in swim velocity and propulsion [3] and marked systemic differences [2] have previously been observed between these swim groups. The most likely explanation for the difference in swim time would be related to the contribution of the lower body (legs) to the swim exercise. It has been shown that when the leg kicking action is added to the arm action, a 10 % increment in swim speed can be seen during swim sprint efforts [15]. However, even when told to swim as fast as possible, triathletes used only the upper body, presumably due to the need to spare the leg muscles for the later cycling and running stages of their event. It must be stated that all subjects were asked to swim maximally and 'normally' during the swim task; the differences in swim style were, however, very apparent within this particular level (club) of triathlete and the NIRS data reflected these biomechanical differences. In

conclusion, the waterproofed NIR device was able to report upon muscle oxygenation changes in the upper and lower extremities in club level swimmers and triathletes. The ΔTSI % changes indicated that club level swimmers use both the upper and lower muscles to a similar extent during a maximal 200 m swim, whereas there was minimal desaturation in the lower body muscles of the triathletes.

Acknowledgments We like to especially thank all the athletes and swim coaches for their time and effort during this study.

References

1. Aspenes ST, Karlsen T (2012) Exercise-training intervention studies in competitive swimming. Sports Med 42:527–543
2. Roels B, Gimenes AC, Nascimmento RB et al (2005) Specificity of Vo2max and the ventilatory threshold in free swimming and cycle ergometry: comparison between triathletes and swimmers. Br J Sports Med 39:965–968
3. Toussaint HM (1990) Differences in propelling efficiency between competitive and triathlon swimmers. Med Sci Sports Exerc 22:409–415
4. Costa MJ, Bragada JA, Marinho DA et al (2012) Longitudinal interventions in elite swimming: a systematic review based on energetics, biomechanics, and performance. J Strength Cond Res 26:2006–2016
5. Pyne DB, Lee H, Swanwick KM (2001) Monitoring the lactate threshold in world-ranked swimmers. Med Sci Sports Exerc 33:291–297
6. Libicz S, Roels B, Millet GP (2005) Responses to intermittent swimming sets at velocity associated with max. Can J Appl Physiol 30:543–553
7. Reis V, Marinho D, Policarpo F et al (2010) Examining the accumulated oxygen deficit method in front crawl swimming. Int J Sports Med 31:421–427
8. Reis JF, Alves FB, Bruno PM et al (2012) Effects of aerobic fitness on oxygen uptake kinetics in heavy intensity swimming. Eur J Appl Physiol 112:1689–1697
9. Hesford CM, Laing SJ, Cardinale M et al (2012) Asymmetry of quadriceps muscle oxygenation during elite short-track speed skating. Med Sci Sports Exerc 44:501–508
10. Szmedra L, Nioka S, Chance B et al (2001) Hemoglobin/myoglobin oxygen desaturation during Alpine skiing. Med Sci Sports Exerc 33:232
11. Buchheit M, Ufland P, Haydar B et al (2011) Reproducibility and sensitivity of muscle reoxygenation and oxygen uptake recovery kinetics following running exercise in the field. Clin Physiol Funct Imaging 31:337–346
12. Wang B, Tian Q, Zhang Z et al (2012) Comparisons of local and systemic aerobic fitness parameters between finswimmers with different athlete grade levels. Eur J Appl Physiol 112:567–578
13. Suzuki S, Takasaki S, Ozaki T et al (1999) Tissue oxygenation monitor using NIR spatially resolved spectroscopy. Proc SPIE 3597:582–592
14. Bravo DM, Gimenes AC, Nascimento RB et al (2012) Skeletal muscle reoxygenation after high-intensity exercise in mitochondrial myopathy. Eur J Appl Physiol 112:1763–1771
15. Fulton SK, Pyne DB, Burkett B (2009) Quantifying freestyle kick-count and kick-rate patterns in Paralympic swimming. J Sport Sci 27:1455–1461