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Near-infrared spectroscopy wearable biosensor for monitoring exhaustion in sports climbing

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Abstract

Monitoring exhaustion using near-infrared spectroscopy (NIRS) wearable biosensors seems promising in sports climbing. However, there is a lack of research regarding climbing specific muscular exhaustion and muscle oxidative metabolism. The current study analyses how exhaustion affects muscle oxidative metabolism and deduces to what extent measurements using NIRS are suitable for an objective monitoring as well as feedback of exhaustion.

Keywords: fatigue, training, fingerboard, grip strength, bouldering

Introduction

The continuous monitoring of physiological signals using wearable devices or wearable biosensors plays an important role in modern sports practice. One promising application, which seems highly feasible for monitoring local forearm oxygenation in climbing, is the near-infrared spectroscopy (NIRS). This is a non-invasive technique for monitoring muscle oxygen saturation (SmO_2) in vivo (Hamaoka et al., 2011). It might be used as an indicator of training status in sports climbing (Fryer et al., 2016), relates to the overall climbing performance (e.g. oxidative capacity predicts red-point grade (Feldmann et al., 2022)) and possibly form the basis for an objective feedback system of exhaustion (see, e.g. Muramatsu and Kobayashi (2013) in muscular context of biceps brachii). Nevertheless, there is still a need for research regarding the use of NIRS in the context of climbing specific exhaustion, especially since most studies only analyse experienced climbers (Baláš et al., 2018; Feldmann et al., 2022). Therefore, the current study analyses how climbing specific exhaustion affects finger flexor muscle oxygenation of regularly and non-climbing subjects. The overall aim is to discuss whether the use of NIRS for measuring SmO_2 is suitable for an objective monitoring of acute exhaustion (caused during isometric muscle contraction) and cumulative exhaustion (result of multiple, intermittent isometric muscle contractions) in the context of the maximal climbing specific holding time (CSHT).

Methods

42 healthy subjects (gender: 22 female, 20 male, 0 divers; age: M = 22.45, SD = 3.13; height: M = 173.08, SD = 8.96; weight: M = 69.90, SD = 12.39; body fat: M = 20.04, SD = 8.24; 8 subjects with experiences in sports climbing) underwent an anthropometric analysis as well as maximal pull-up test before the experiments. After 15 minutes of rest, the CSHT was measured three times with about 90 seconds in between to assess the influence of exhaustion. For this purpose, subjects were advised to hold themselves as long as possible without touching the ground on a four centimetre deep crimp with rounded edges and structuring (see Fig. 1) of a MOON fingerboard

(Moon Climbing Limited, Seffield, England). Before the exercise, as well as during the 90 seconds in between the CSHT measurements, hand grip strength (HGS) was assessed according to the instructions of Mathiowetz et al. (1984) using the Jamar hydraulic hand dynamometer (JLW Instruments, Chicago, IL, USA).

In parallel, the muscle oxygen level was measured using the Moxy NIRS biosensor (Moxy Monitor, Huttchinson, Minnesota, USA). According to Philippe et al. (2012), the sensor was placed at the forearm of the handiness side using kinesio tape. The recording interval was set to two seconds and data was smoothed using a ten second moving average. For the statistical analysis the following parameters were extracted: initial SmO_2 before hanging, SmO_2 at the termination time (fall off event), the average slope of SmO_2 reduction, SmO_2 ten seconds after termination time (recovery). Statistical analysis was performed using IBM SPSS (version 16, SPSS Inc. Chicago, USA).

Fig. 1 Hand positioning on the fingerboard.

Results

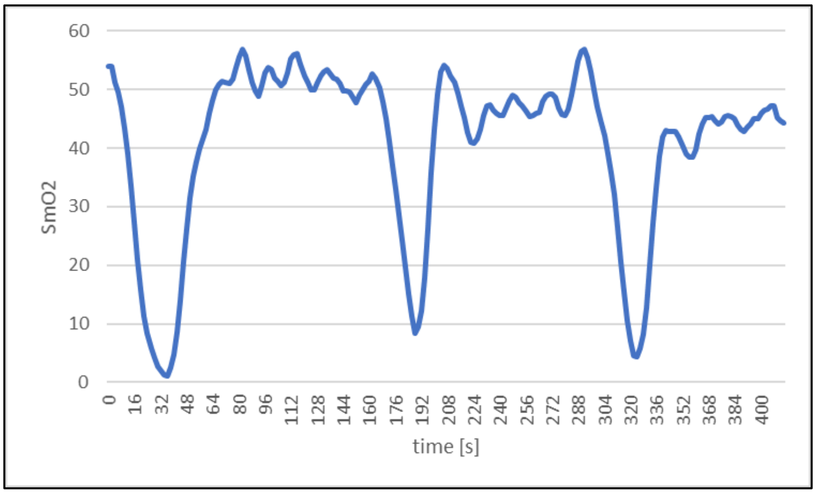


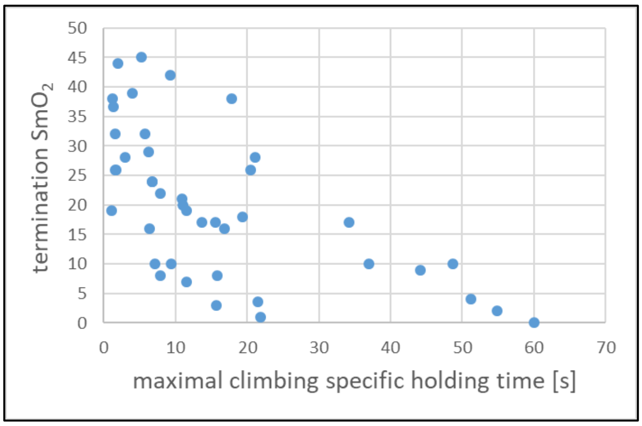
Fig. 2 Waveform SmO_2 data of an exemplary subject with an initial CSHT of 21.83 s. (second CSHT: 11.00 s; third CSHT: 13.79 s) during the test procedure.

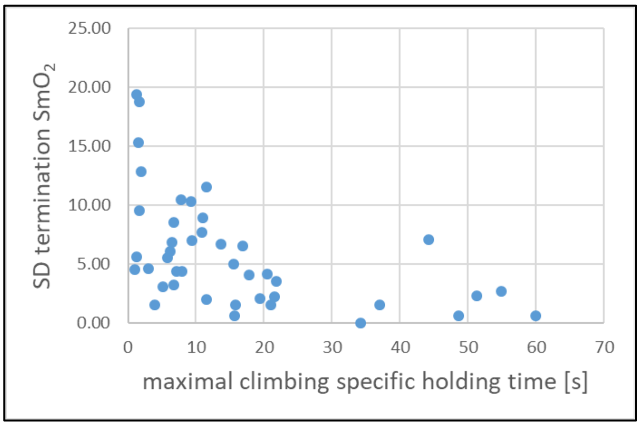
A significant reduction of CSHT ($F(1.29,60.72) = 12.43$, $p < .001$, $\eta_p^2 = .21$) as well as HGS ($F(1.60,75.32) = 50.84$, $p < .001$, $\eta_p^2 = .52$) along the different measurements could be found. Post-hoc analysis shows that all HGS measurements were different between each other ($p \leq .001$). For the CSHT the first and second as well as first and third measurements were different ($p < .05$).

Between the second and third measurement, no significant differences was found for the CSHT (p = .21).

Significant differences were present between pre, termination as well as recovery SmO_2 saturation level (F(1.47,60.05) = 284.33, p < .001, η_p^2 = .87). Exemplary waveform SmO_2 data of one subject is presented in Fig. 2. There were no differences in initial SmO_2 level, SmO_2 level at fall off, SmO_2 recovery (F(2,82) = 0.54, p = .58) and mean negative slope of the SmO_2 reduction between the different measuring times (F(1.46,65.79) = 1.46, p = .24).

Visually, subjects with relative longer holding times do not appear to have a higher basal O_2 saturation. However, they seem to be able to better and deeper drain their SmO_2 level and seem to show less variability in their SmO_2 level at the fall-off events (see Fig. 3).





(a) (b)

Fig. 3 (a) SmO_2 levels at the first termination event in dependence of the maximal holding time; (b) Standard deviation (SD) of the SmO_2 levels at termination events in dependence of the maximal holding time.

Discussion

The significant decreases in both CSHT and HGS shows that consecutive maximal isometric holding introduces cumulative exhaustion of the finger flexors. However, the current study indicates that SmO_2 level in the different regarded conditions (initial SmO_2 before hanging, SmO_2 at the termination time, average slope of SmO_2 reduction, SmO_2 ten seconds after termination time) does not change under the different measuring times. Therefore, monitoring cumulative exhaustion during intermittent isometric climbing specific muscle contractions using SmO_2 level does not seem useful. Contrary, Feldmann et al. (2022) showed using regularly climbing subjects that the climbing specific force production correlates negatively with the minimal attainable muscle oxygenation in the forearms in climbers in the context of HIT training. A possible explanation for the current studies results might be the consideration of subjects that are unexperienced in climbing.

Significant differences between pre, termination and recovery SmO_2 level indicates the potential usefulness of NIRS as an indicator for acute exhaustion. Visually, the individual SmO_2 profiles show that even with a relative short holding time, SmO_2 seems to be sensitive enough to map a load. Subjects with relatively long CSHT seem to show less variability in their SmO_2 level at fall off events. This is in accordance with the work of Baláš et al. (2018), which showed that NIRS provides a reliable measure of oxygenation during intermittent contractions to fall off in the forearm flexors of climbers. Therefore, SmO_2 level seems preferable for monitoring acute exhaustion for subjects with relative long CSHT. The fall off SmO_2 level seems to be highly individual and possibly dependent on the training status of the subjects. For monitoring acute exhaustion, it seems necessary to perform a fit on the individuals' drop-off SmO_2 level. Furthermore, it must be considered that the Moxy biosensor only covers a small area, while the finger flexors responsible for gripping take up a large volume of the forearm. Missing statistical correlations can therefore also be due to the isolated observation of a small muscle section.

Conflict of interest We declare no conflicts of interest.

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References

Baláš, J., Kodejška, J., Krupková, D., Hannsmann, J., & Fryer, S. (2018). Reliability of Near-Infrared Spectroscopy for Measuring Intermittent Handgrip Contractions in Sport Climbers. *Journal of strength and conditioning research*, *32*(2), 494–501. https://doi.org/10.1519/JSC.0000000000002341

Feldmann, A., Lehmann, R., Wittmann, F., Wolf, P., Baláš, J., & Erlacher, D. (2022). Acute Effect of High-Intensity Climbing on Performance and Muscle Oxygenation in Elite Climbers. *Journal of Science in Sport and Exercise*, *4*(2), 145–155. https://doi.org/10.1007/s42978-021-00139-9

Fryer, S., Stoner, L., Stone, K., Giles, D., Sveen, J., Garrido, I., & España-Romero, V. (2016). Forearm muscle oxidative capacity index predicts sport rock-climbing performance. *European Journal of Applied Physiology*, *116*(8), 1479–1484. https://doi.org/10.1007/s00421-016-3403-1

Hamaoka, T., McCully, K. K., Niwayama, M., & Chance, B. (2011). The use of muscle near-infrared spectroscopy in sport, health and medical sciences: recent developments. *Philosophical Transactions of the Royal Society*, *369*(1955), 4591–4604. https://doi.org/10.1098/rsta.2011.0298

Mathiowetz, V., Weber, K., Volland, G., & Kashman, N. (1984). Reliability and validity of grip and pinch strength evaluations. *The Journal of Hand Surgery*, *9*(2), 222–226. https://doi.org/10.1016/S0363-5023(84)80146-X

Muramatsu, Y., & Kobayashi, H. (2013). Assessment of local muscle fatigue by NIRS. In *2013 Seventh International Conference on Sensing Technology (ICST)* (S. 1-4). IEEE. https://doi.org/10.1109/ICSensT.2013.6727728

Philippe, M., Wegst, D., Müller, T., Raschner, C., & Burtscher, M. (2012). Climbing-specific finger flexor performance and forearm muscle oxygenation in elite male and female sport climbers. *European Journal of Applied Physiology*, *112*(8), 2839–2847. https://doi.org/10.1007/s00421-011-2260-1