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## Research Article

# The effect of altitude on decision making in male rugby union players

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Running Title: hypoxia and cognitive function

## Abstract

The body is typically forced to undergo several physiological adaptations when exposed to hypoxia, which can impact physical and cognitive performance. The purpose of this investigation was to study the effects of altitude on cognitive function, specifically decision-making, in male athletes. Seven male rugby union players, at senior club level or above, performed a 15-minute cycling protocol (70-80% HRmax, with 3 × 6-s maximal sprints performed at 5, 10, and 15 min) in normoxia (FIO2 = 0.21%) and hypoxia (FIO2 = 0.15%) in a randomised order. Throughout both trials, a Stroop test was conducted immediately after each sprint to assess decision-making ability. Additionally, heart rate (HR) and rating of perceived exertion (RPE), along with average and peak power output were recorded. Stroop test time (13.3 ± 1.6 vs. 11.8 ± 1.6 s) and oxygen saturation ($S_PO_2$; 87 ± 2 vs. 97 ± 1%) were impaired in hypoxia compared to normoxia ($P = 0.029$ and $P < 0.01$ respectively). All other outcome measures showed no difference between trials. These data confirm that player decision making is negatively affected by altitude, likely due to reduced cerebral oxygenation driving the cognitive impairment. Our findings infer that while rugby union players may be capable of maintaining physiological stability over short durations at altitude, their cognitive ability may be inhibited, resulting in potentially handicapped decision-making during high pressure game situations.

**Keywords:** cognition, hypoxia, normoxia, performance.

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# Introduction

Hypoxia is widely defined as a severe reduction in oxygen within blood vessels and tissues, limiting physiological ability to maintain homeostasis (Span and Bussink, 2015). An increase in altitude elicits a drop in barometric pressure, subsequently reducing the partial pressure of ambient oxygen (PaO2). Consequently, individuals at high altitude experience a constrained oxygen supply, most notable when exercising (Su et al., 2024), presenting the well-researched challenge of adapting to this altered environment. The body is typically forced to undergo several physiological adaptations when exposed to hypoxia, which can impact physical and cognitive performance (Bailey et al., 2017).

Oxygen deficiency experienced in a hypoxic environment has been shown to elicit reductions in cerebral oxygenation (Komiyama et al., 2015, Morrison et al., 2019) and as a result, cognition. Cerebral oxygenation is reliant on pulmonary and ventilatory systems (Koike et al., 2004), which are required to adequately meet increased neuronal metabolism in the brain (Secher et al., 2008). Hypoxia encourages the excitation of specific neurons (typically located in the caudal hypothalamus and rostral ventrolateral medulla), which subsequently increase respiratory activity, heart rate, and blood pressure to account for the decline in physiological function (Goodall et al., 2014a). Consequently, reduced levels of oxygen mean the demand for this supply to the brain is intensified often beyond the capabilities of the body, leading to cerebral oxygenation reduction and overall cognitive impairment (Wang et al., 2022). Cognitive function has been widely researched from a mountaineering perspective with a focus on the effects of acute hypobaric hypoxia, and some altitude-related diseases that may occur as a result (Richalet et al., 2024). McMorris et al. (2019), reported that the level of haemoglobin saturated with oxygen (SPO2) was the main predictor for the reduction in cognitive ability. A wide range of assessments have been employed previously to evaluate cognitive performance such as decision making, reaction time, and task efficacy. Langenecker et al. (2007) identify the Go/No-Go Test as an effective method of identifying an individual's inhibitory control and reaction time by forcing a response to a stimulus. Similarly, the Trail Making Test (Reitan and Tarshes, 1959) assesses processing speed and cognitive flexibility, with participants aiming to connect sequences of number or words as quickly as possible. More commonly used are simple and choice reaction time tests, often employed in sport to assess concussion severity or recovery status (Tommerdahl et al., 2020), or in a more clinical setting to assess diseases such as multiple sclerosis (Cabib et al., 2015).

While these methods of assessment are all justifiable in sport-specific studies, they do not critically assess or specifically target decision-making ability. The Stroop Colour and Word Test (Stroop, 1935), however, remains arguably the most effective method for this specific cognitive investigation as it attempts to inhibit cognitive interference to complete an automated task (Scarpina and Tagini, 2017). By doing this, it measures selective attentional focus and cognitive flexibility, which are all key elements in high-pressure sporting decisions (Keeler et al., 2014). Furthermore, the Stroop test has been extensively used to detect changes in cognitive performance within sporting environments, with previous work using it in fatigue, stress, and environmental contexts (Post et al., 2023), providing credibility for use within rugby.

The effect of acute hypoxia on cognitive function has also been evidenced by increased error rates, where such a slowed performance is described as a cognitive symptom revealing a potential subconscious strategy to minimise mistakes (Hornbein, 2001). Despite its relevance, this work focuses on the ascent of Mount Everest, and while it looks at 'moderate hypoxia', typically 2,000-4,500 m (the lower bound similar to the interests of the current study), it does not directly compare to the effects hypoxia may have on rugby performance, in particular player decision making. It does, however, conclude that these levels of altitude can impair brain function when in a state of hypoxia, fuelling the present research question that assesses the extent to which this happens in a sport-specific scenario. León-Carrion et al. (2008) investigated the effect of reduced cerebral oxygenation and Stroop test performance, concluding that impaired performance could be due to an insufficient oxygen supply. However, such evidence relating to rugby union players is limited.

Regarding exercise, acute hypoxia exposure is seen to have effects on multiple performance measures, with the general trend that performance is hindered due to the combination of decreased supply of oxygen and increased fatigue (Amann et al., 2007, Goodall et al., 2012, Goodall et al., 2010, Romer et al., 2007) which is reversible with acclimatisation (Amann et al., 2013, Goodall et al., 2014b). Metrics such as power output, maximal oxygen consumption, and peak speed are all negatively affected by hypoxia (Scott et al., 2017, Simpson et al., 2015). In a rugby union setting, this places increased strain on the demands of players who are aiming to perform at optimal physical and mental levels. This has become an increasingly relevant factor in the UK since the introduction of South African teams in the United Rugby Championship (URC) since 2017, meaning Irish, Welsh, and Scottish teams having to travel away to moderate altitude (1,800 m, Ellis Park, Johannesburg). The high intensity nature of rugby union suggests that the working muscles demand a large supply of oxygen, particularly when the body is using aerobic processes to provide energy (Duthie et al., 2003). Subsequently, a high demand of oxygen in the working muscles would likely be matched by a high neural demand for cognitive processes (Keeler et al., 2024), leading to the assumption that performance in hypoxia would be impaired. Importantly, tactical awareness is widely regarded as a crucial attribute in rugby union (Parrant and Martin, 2010), and a combination of this along with optimal execution of technical skills (e.g., tackling & kicking), provide greater overall team success (Till et al., 2017). As a result, cognitive processing speed and situational awareness are highlighted as the key drivers of decision making (Richards et al., 2016), particularly in open-play settings where approximately half of an 80-minute game is said to be played (George et al., 2015). Finally, the constantly changing game-specific circumstances can be vital for a team's strategy and overall outcome (Ashford et al., 2021), which environmental changes have the capacity to influence.

Accordingly, the purpose of this study was to assess whether cognitive function in rugby players was impacted by exercise in hypoxia. It was hypothesised that altitude would negatively affect player decision making and physiological performance.

# Methods

*Participants*

Seven healthy male rugby union players (Mean ± SD age, 21.4 ± 0.53 years; stature, 184.6 ± 4.3 cm; body mass, 96 ± 13 kg) were recruited from the Northumbria University Men's Rugby Union team. Prior to any experimental procedures, participants provided written informed consent and confirmed their eligibility via the inclusion/exclusion criteria, meaning they were fit and free from injury with no known adverse reaction to altitude, regularly exercising, with previous competitive playing experience of at least 2 years. Participants were instructed to avoid vigorous exercise and adhere to a non-alcoholic, consistent diet, for 24 hours prior to experimental visits. All research activities were approved by the local institutional ethics committee and conformed to the latest revision of the Declaration of Helsinki.

*Experimental Design*

The study was a repeated measures design, with participants completing an exercise protocol in two different conditions (normoxia, fraction of inspired oxygen [FIO2] = 0.21 vs. hypoxia, FIO2 = 0.15) in an environmental chamber (TIS Service Hampshire, UK). Humidity and ambient temperature remained constant across experimental visits at 50% and 17°C, respectively. The outcome measures were peak and average power (W), heart rate (HR), rating of perceived exertion (RPE; Borg, 1982), and SpO2. Participants completed three sessions (familiarisation, hypoxic, and normoxia) with the order of experimental visits randomised. Participants were blinded to the environmental condition, limiting the pre-meditation of condition on performance and improving overall validity. The experimental trials were repeated with a minimum of one-weeks rest in between to mitigate fatigue effects and limit learning of the cognitive task used to assess decision making.

*Procedures*

*Familiarisation*

During the familiarisation, participants were thoroughly habituated with the methods used to understand the physiological and psychological demands of the trial. This involved completion of a 10 minute cycle on a stationary ergometer (Watt Bike, Nottingham, UK), whereby load was gradually increased to elicit a steady state HR of 70-80% maximum (calculated as 220 minus participant age; Mayo Clinic) along with the performance of a 6 s maximal sprint. Participants were also introduced to the Stroop test (MacLeod, 1991), selected to assess cognitive function. This involved presenting a sheet of A4 paper full of words written in different colours, to the colour they spelt out to participants. The test consisted of naming the colour of the word, rather than the word that was written.

*Experimental Trials*

The sessions began in the environmental chamber with a 5-minute, self-paced warm up, prior to completing a 15 minute constant load bout of cycling at an intensity that elicited (70-80% HRMAX). The intensity was set to whichever Watt Bike gear elicited the required HR, as determined in the familiarisation. Due to the anticipated increase in HR during hypoxia (Goodall et al., 2010), the respective Watt Bike gear was lowered by 1, for the hypoxia trial. During the 15 minute cycle, time was controlled by standardised software (Golden Cheetah) and participants were instructed to maintain a cadence of 75 RPM. At minutes 5, 10, and 15, participants completed a 6 s, maximum intensity sprint, simulating a common duration and intensity of maximum efforts in rugby union (Duthie et al., 2003). A five second countdown was given before each sprint to prepare participants and, to permit a consistent increase in resistance when sprinting, the Watt Bike gear was increased by three for each 6 s period allowing for a greater force to be put through pedals during the maximal efforts; average and peak power values were identified post-testing, using automated software (Golden Cheetah). Upon completion of the 6 s sprint, the Watt Bike gear was returned to the pre-sprint level and participants completed the Stroop test, where the time taken to obtain ten correct answers was recorded; the researcher pointed to random words to be recalled by the participant. A Pulse Oximeter (Biosync B-50DL, Contec Medical Systems, China) was placed on the left index finger to measure $SpO_2$, this parameter along with HR and RPE was measured following each sprint.

*Statistical Analysis*

Data are presented as means ± standard deviation (SD). Data were recorded for each measure after each sprint (5 minutes apart) apart from average power. Data were analysed using SPSS (v29, IBM, Chicago, USA); two-way (2 [condition] × 3 [time]) repeated analyses of variance (ANOVA) were conducted to assess differences in outcome variables with any post-hoc differences assessed using the Tukey comparison. Average power in each condition was assessed using a paired t-test. The level of statistical significance was set at 0.05 and all data are available on request. Figures were drawn using GraphPad (GraphPad software Inc, California, USA).

# Results

Hypoxia had a profound effect on physiological function as demonstrated by lower $S_PO_2$ values throughout exercise (87 ± 2 vs. 97 ± 1%, mean difference [MD] = −10%; $F1,6 = 197.4$, $P < 0.001$). The condition effect was not accompanied by time ($F_{2,12} = 3.3$, $P = 0.121$) or interaction ($F_{2,12} = 0.3$, $P = 0.784$) effects demonstrating a consistent difference throughout the protocol in each condition (Figure 1A). By design, HR was similar between conditions (167 ± 16 vs. 171 ± 11 bpm; $F_{1,6} = 0.2$, $P = 0.645$) and increased comparably throughout exercise (time, $F_{2,12} = 5.8$, $P = 0.017$; interaction, $F_{2,12} = 0.4$, $P = 0.373$; Figure 1B). Likewise, average power between conditions was similar (155 ± 29 vs. 140 ± 22 W; $P = 0.142$), as too was the peak power elicited in the 6 s sprints (1,059 ± 184 vs. 968 ± 93 W; $F_{1,6} = 2.1$, $P = 0.195$) with a trend for a reduction over time ($F_{2,12} = 3.5$, $P = 0.063$; interaction, $F2,12 = 0.9$, $P = 0.437$; Figure 1C).

Perceived exertion was similar during each condition (6.6 ± 1.2 vs. 6.4 ± 1.1; $F1,6 = 0.3$, $P = 0.631$) and increased similarly over time ($F_{2,12} = 118$, $P < 0.001$; interaction, $F_{2,12} = 0.4$, $P = 0.561$; Figure 2A). Decision making took longer in hypoxia (13.3 ± 1.6 vs. 11.8 ± 1.6 s, MD = 1.5 s; $F_{1,6} = 8.1$, $P = 0.029$) with pronounced differences at 15 min (13.8 ± 1.7 vs. 11.6 ± 0.7 s, $P = 0.017$). The condition effect was not accompanied by time ($F_{2,12} = 2.4$, $P = 0.137$) or interaction ($F_{2,12} = 0.8$, $P = 0.469$) effects, demonstrating a stable response throughout the protocol in each condition (Figure 2B).

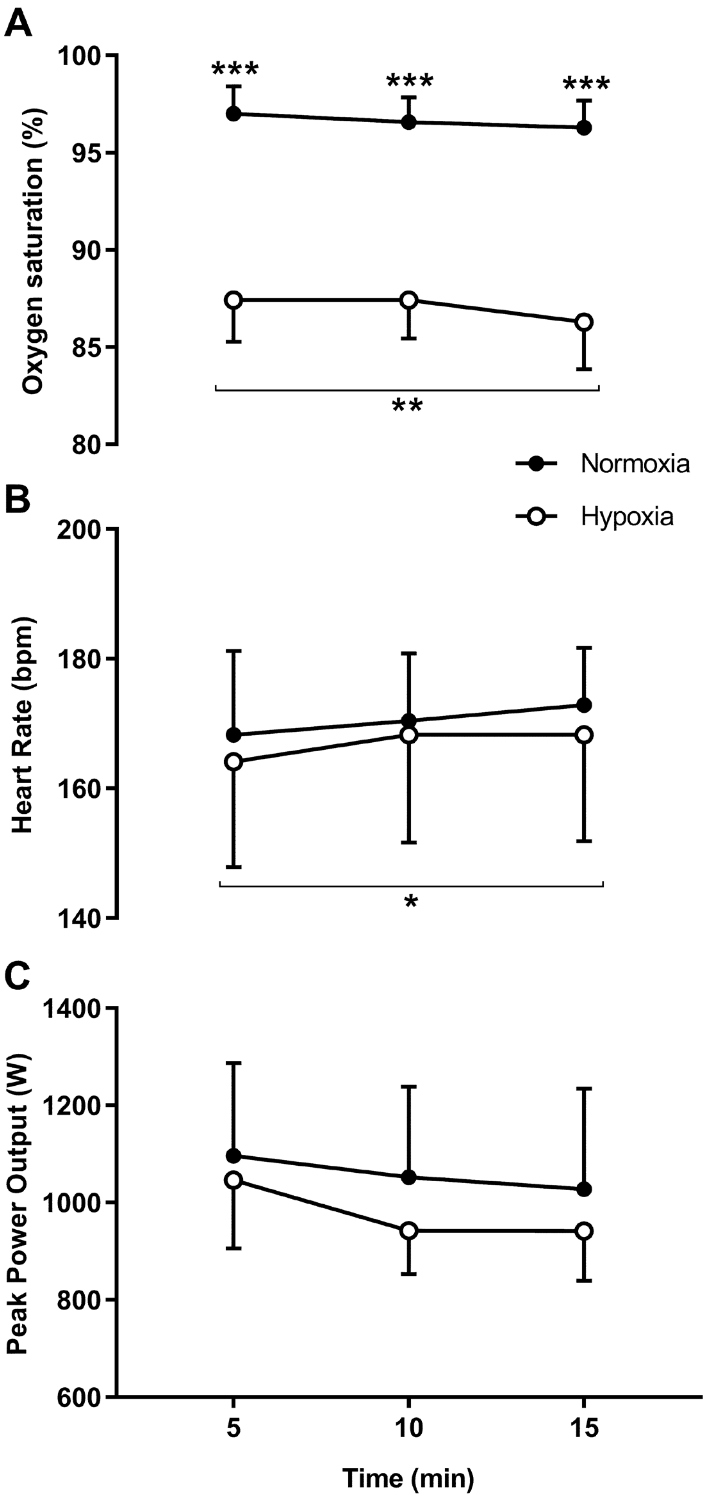


**Figure 1.** Oxygen saturation (A), heart rate (B), and peak power output (C) throughout the 15 min cycling trial performed in normoxia and hypoxia. Data are for 7 participants. * = P < 0.05 time effect; ** = P < 0.05 condition effect; *** P < 0.05 vs. hypoxia at that time point.

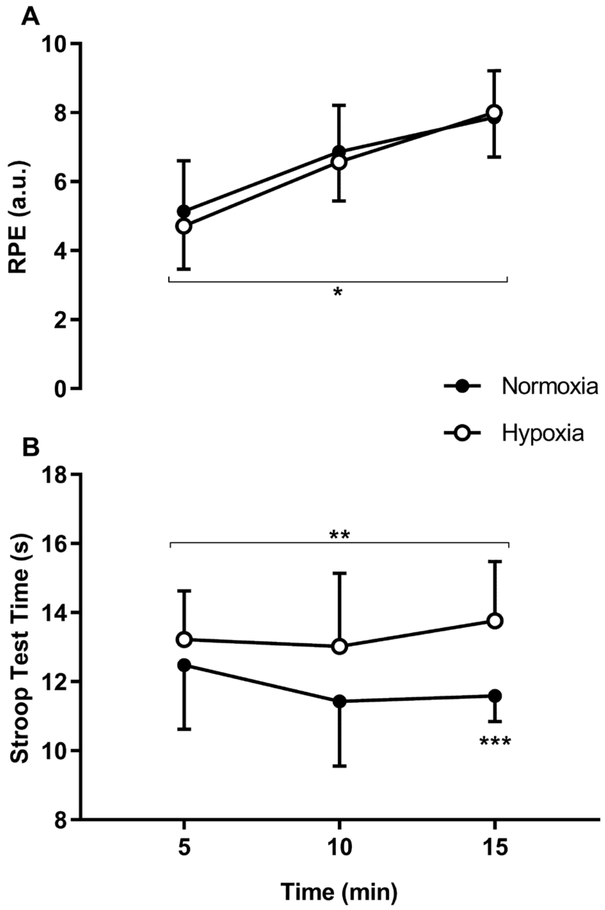


**Figure 2.** Rating of perceived exertion (A) and the time take to record 10 correct Stroop test scores (B) throughout the 15 min cycling trial performed in normoxia and hypoxia. Data are for 7 participants. * = P < 0.05 time effect; ** = P < 0.05 condition effect; *** P < 0.05 vs. hypoxia at that time point.

## Discussion

The purpose of this investigation was to evaluate the effect of altitude on cognitive function among men's rugby union players. The main finding was a reduced cognitive performance in hypoxia, characterised by longer times to complete the Stroop test. The difference in physiological function was stark, with large differences in arterial oxygen saturation, however, no differences were apparent in any other outcome measure (HR, RPE, and PPO). These data confirm that player decision making is negatively affected by altitude, likely due to reduced cerebral oxygenation driving the cognitive impairment.

The decrement in Stroop test performance in hypoxia strongly aligns with previous research suggesting that executive function is impaired by hypoxia, most notably cognitive tasks which require attentional focus and rapid decision making (Keeler et al., 2024). As previously stated, cerebral oxygenation is the most likely cause of the observed decline in cognitive performance, with decreased levels inhibiting prefrontal cortex activity as a result of increased oxygen strain in hypoxia (Bailey et al., 2017). Our study identified that the most notable decrease in Stroop test performance came after the third sprint (15 minutes; Figure 2B), suggesting that fatigue and hypoxia combine to exaggerate cognitive impairment over time. Previous work from Ando et al. (2020) supports this explanation, emphasising the progressive decline in cognitive performance that occurs with prolonged exposure to hypoxia and physiological strain. Additionally, the increased cognitive processing time was also likely due to the effect of hypoxia on motor activity (Davranche et al., 2016). When referring to rugby union, our data suggest that decision making would be more severely hindered as playing time ensues, potentially impacting individual and team performance towards the latter stages of a game. Moreover, this highlights the advantage that native highlanders may have over visiting players, with adaptations to altitude contributing to a more sustained level of cognitive and overall rugby performance.

As expected, $S_PO_2$ was consistently lower in hypoxia (Figure 1A) but despite this compromised oxygen supply, there were no changes in heart rate, power, or RPE between conditions during this study (see Figures 1 & 2). Although this contradicts previous work implying that hypoxia induces greater cardiovascular strain and elevates levels of perceived effort (Goodall et al., 2014a). Despite this difference, the controlled nature of exercise intensity in this study (70-80% HRmax) is the likely reason for no change in cardiovascular and physical performance parameters. By standardising the workload to target a specific heart rate is the reason for similar findings across both conditions. While RPE wasn't a fixed variable in the current study, previous work suggests that in a hot hypoxic environment, increases in RPE are driven by elevations in HR and core temperature (Levine and Buono, 2019). Thus, it can be concluded that the lack of change in RPE in the present study is explained by HR and ambient temperature being fixed variables, causing RPE values to remain consistent over both trials. It does, however, suggest that if the protocol were to be repeated at a higher intensity and for a longer duration, RPE would likely be elevated in hypoxia.

The lack of change in PPO (Figure 1C) contradicts previous work that has reported hypoxia to negatively affect maximal work (Simpson et al., 2015). This previous work used an alternative methodology (3-minute ‘all out’ tests) meaning their participants were sprinting for longer, compared to the 18 seconds of ‘all out’ effort in the present investigation. It is likely that the short-duration, maximal efforts, were predominately fuelled by anaerobic sources of energy production, masking any effects of a reduced oxygen availability. These data are confirmed by Girard et al. (2017) who report that the initial sprints in a repeated sprint activity, are almost always unchanged despite differing environmental conditions, due to the predominant use of anaerobic processes for energy production. The oxygen deficit in hypoxia is therefore somewhat irrelevant at the beginning, but would likely become a detrimental factor as the duration of these efforts lengthen and aerobic process begin to be primary provider of energy (Girard et al., 2017). It would therefore have been likely that a longer protocol, involving more sprints, would have shown differences over time; an avenue that future research should look to investigate in this population.

The similar average power in each condition is likely due to the heart rate-based intensity approach of the cycling protocol. While this once again contrasts with previous work (Amann et al., 2008), it suggests that when exercise intensity is controlled, athletes can maintain consistent performance levels. The short duration of sprints, as well as the short length of the whole protocol itself, gives potential reason to why no changes were evident between the conditions. Hypoxia has been found to have an intensified effect on repeated sprinting when phosphocreatine is unable to be fully resynthesized due to insufficient recovery periods (Faiss et al., 2013). In this case, participants may not have been fully exerted from just three sprints, with the 5-minute intervening period allowing for recovery. While athletes were able to maintain similar PO levels over the 15 minutes, this would likely differ if exercise duration was increased. By simulating a rugby-specific fatigue protocol, it is likely that a decline in performance would occur (Coutts et al., 2003). Research from Girard et al. (2017) emphasises the increased effect of hypoxia in longer, endurance-based exercise, suggesting that if the protocol were to be repeated for a longer duration (i.e. 60 minutes of a rugby match), differences would be more pronounced between the conditions, with the effects of hypoxia causing reduced power output towards the latter stages of a match.

The findings from this study offer important inferences both cognitive and physiological processes within men's rugby union. With particular importance because of the increase in matches played in high-altitude locations (e.g. Johannesburg, South Africa), this research fills voids in literature which have yet to analyse the hypoxic effects from a cognitive perspective in a rugby union setting. The impairment of cognitive function emphasises the potential for an increase in the amount of unforced, decision-related errors which are likely to occur in hypoxic environments. As previously stressed, accurate decision making is vital in elite rugby union (Ashford et al., 2021), with errors in this domain, or a lack of, capable of deciding the outcome of a match. Therefore, decrements in reaction time during the course of a match played at altitude, may hinder players' ability to read game-specific scenarios such as defensive setups or passing plays. Recommendations from this work could be given to coaches to consider implementing cognitive training in hypoxia, in preparation for matches played at altitude. This could eliminate submaximal cognitive performance, as well as develop physiological systems that would likely be challenged over the course of 80 minutes. Published work shows that pre-exposure to a hypoxic environment elicits improvement in cognitive performance (Lin et al., 2024) via increased cerebral oxygenation and neurovascular coupling (Mateo-March et al., 2022), giving positive evidence to suggest that time spent training at altitude, or simulated altitude, would be beneficial to rugby union athletes in preparation for away matches.

*Limitations*

Despite the changes seen in cognitive function, a limitation of this study was a relatively small sample size ($n$ = 7). Just over half of a standard team number were recruited and future studies should acknowledge player positions, as cognitive function and task complexity are known to differ between forwards and backs (Ashford et al., 2021). Additionally, despite the Stroop test being a reputable method of cognitive assessment, particularly for decision making, a rugby-specific protocol for this outcome measure would have been more appropriate and could have simulated in-game decisions to greater effect. This would have allowed for a greater understanding of the way hypoxia influences the decisions that occur in a game scenario. It is also worth noting that despite spacing out trials in different conditions by at least one week, a learning effect may have been a factor in participants' ability to complete the Stroop test. By becoming somewhat accustomed to the process of working out answers, both between sprints and between trials, there must be consideration given to this parameter.

*Conclusion*

The novel finding of this work was a reduced cognitive performance in hypoxia, characterised by longer times to complete the Stroop test. The difference in physiological function was stark, with large differences in arterial oxygen saturation, however, no differences were apparent in any other outcome measure (HR, RPE, and PPO). These data confirm that player decision making is negatively affected by altitude, likely due to reduced cerebral oxygenation driving the cognitive impairment. Our findings infer that while rugby union players may be capable of maintaining physiological stability over short durations at altitude, their cognitive ability may be inhibited, resulting in potentially handicapped decision-making during high pressure game situations.

# References

Amann, M., Goodall, S., Twomey, R., Subudhi, A. W., Lovering, A. T. & Roach, R. C. (2013). AltitudeOmics: on the consequences of high-altitude acclimatization for the development of fatigue during locomotor exercise in humans. *J Appl Physiol*, 115, 634-42.

Amann, M., Hopkins, W. G. & Marcora, S. M. (2008). Similar sensitivity of time to exhaustion and time-trial time to changes in endurance. *Med Sci Sports Exerc*, 40, 574-8.

Amann, M., Peglow, D. F., Jacques, A. J. & Dempsey, J. A. (2007). Inspiratory muscle work in acute hypoxia influences locomotor muscle fatigue and exercise performance of healthy humans. *Am J Physiol Regul Integr Comp Physiol*, 293, R2036-45.

Ando, S., Komiyama, T., Sudo, M., Higaki, Y., Ishida, K., Costello, J. T. & Katayama, K. (2020). The interactive effects of acute exercise and hypoxia on cognitive performance: A narrative review. *Scand J Med Sci Sports*, 30, 384-398.

Ashford, M., Abraham, A. & Poolton, J. (2021). What Cognitive Mechanism, When, Where, and Why? Exploring the Decision Making of University and Professional Rugby Union Players During Competitive Matches. *Front Psychol*, 12, 609127.

Bailey, D. M., Willie, C. K., Hoiland, R. L., Bain, A. R., Macleod, D. B., Santoro, M. A., Demasi, D. K., Andrijanic, A., Mijacika, T., Barak, O. F., Dujic, Z. & Ainslie, P. N. (2017). Surviving Without Oxygen: How Low Can the Human Brain Go? *High Alt Med Biol*, 18, 73-79.

Borg, G. A. (1982). Psychophysical bases of perceived exertion. *Med Sci Sports Exerc*, 14, 377-81.

Cabib, C., Llufriu, S., Casanova-Molla, J., Saiz, A. & Valls-Sole, J. (2015). Defective sensorimotor integration in preparation for reaction time tasks in patients with multiple sclerosis. *J Neurophysiol*, 113, 1462-9.

Coutts, A., Reaburn, P. & Abt, G. (2003). Heart rate, blood lactate concentration and estimated energy expenditure in a semi-professional rugby league team during a match: a case study. *J Sports Sci*, 21, 97-103.

Davranche, K., Casini, L., Arnal, P. J., Rupp, T., Perrey, S. & Verges, S. (2016). Cognitive functions and cerebral oxygenation changes during acute and prolonged hypoxic exposure. *Physiol Behav,* 164, 189-97.

Duthie, G., Pyne, D. & Hooper, S. (2003). Applied physiology and game analysis of rugby union. *Sports Med*, 33, 973-91.

Faiss, R., Leger, B., Vesin, J. M., Fournier, P. E., Eggel, Y., Deriaz, O. & Millet, G. P. (2013). Significant molecular and systemic adaptations after repeated sprint training in hypoxia. *PLoS One*, 8, e56522.

George, T. M., Olsen, P. D., Kimber, N. E., Shearman, J. P., Hamilton, J. G. & Hamlin, M. J. (2015). The Effect of Altitude and Travel on Rugby Union Performance: Analysis of the 2012 Super Rugby Competition. *J Strength Cond Res*, 29, 3360-6.

Girard, O., Brochierie, F. & Millet, G. P. (2017). Effects of Altitude/Hypoxia on Single- and Multiple-Sprint Performance: A Comprehensive Review. *Sports Med*, 47, 1931-1949.

Goodall, S., Gonzalez-Alonso, J., Ali, L., Ross, E. Z. & Romer, L. M. (2012). Supraspinal fatigue after normoxic and hypoxic exercise in humans. *J Physiol*, 590, 2767-82.

Goodall, S., Ross, E. Z. & Romer, L. M. (2010). Effect of graded hypoxia on supraspinal contributions to fatigue with unilateral knee-extensor contractions. *J Appl Physiol*, 109, 1842-51.

Goodall, S., Twomey, R. & Amann, M. (2014a). Acute and chronic hypoxia: implications for cerebral function and exercise tolerance. *Fatigue*, 2, 73-92.

Goodall, S., Twomey, R., Amann, M., Ross, E. Z., Lovering, A. T., Romer, L. M., Subudhi, A. W. & Roach, R. C. (2014b). AltitudeOmics: exercise-induced supraspinal fatigue is attenuated in healthy humans after acclimatization to high altitude. *Acta Physiol*, 210, 875-88.

Hornbein, T. F. (2001). The high-altitude brain. *J Exp Biol*, 204, 3129-32.

Keeler, J. F., Pretsell, D. O. & Robbins, T. W. (2014). Functional implications of dopamine D1 vs. D2 receptors: A 'prepare and select' model of the striatal direct vs. indirect pathways. *Neurosci*, 282, 156-75.

Keeler, J. M., Listman, J. B., Hite, M. J., Heeger, D. J., Tourula, E., Port, N. L. & Schlader, Z. J. (2024). Arterial oxygen desaturation during moderate hypoxia hinders sensorimotor performance. *PLoS One*, 19, e0297486.

Koike, A., Itoh, H., Oohara, R., Hoshimoto, M., Tajima, A., Aizawa, T. & Fu, L. T. (2004). Cerebral oxygenation during exercise in cardiac patients. *Chest*, 125, 182-90.

Komiyama, T., Sudo, M., Higaki, Y., Kiyonaga, A., Tanaka, H. & Ando, S. (2015). Does moderate hypoxia alter working memory and executive function during prolonged exercise? *Physiol Behav*, 139, 290-6.

Langenecker, S. A., Zubieta, J. K., Young, E. A., Akil, H. & Nielson, K. A. (2007). A task to manipulate attentional load, set-shifting, and inhibitory control: convergent validity and test-retest reliability of the Parametric Go/No-Go Test. *J Clin Exp Neuropsychol*, 29, 842-53.

León-Carrion, J., Damas-Lopez, J., Martin-Rodriguez, J. F., Dominguez-Roldan, J. M., Murillo-Cabezas, F., Barroso, Y. M. J. M. & Dominguez-Morales, M. R. (2008). The hemodynamics of cognitive control: the level of concentration of oxygenated hemoglobin in the superior prefrontal cortex varies as a function of performance in a modified Stroop task. *Behav Brain Res*, 193, 248-56.

Levine, A. & Buono, M. J. (2019). Rating of perceived exertion increases synergistically during prolonged exercise in a combined heat and hypoxic environment. *J Therm Biol*, 84, 99-102.

Lin, Y., Yan, J., Guo, X., Lin, H., Ruan, C., Dai, Y., Wang, S., Cao, Y., Xiang, Q., Yang, M., Liu, W. & Chen, L. (2024). Effects of Exercise Training Under Hypoxia Versus Normoxia on Cognitive Function in Clinical and Non-Clinical Populations: A Systematic Review and Meta-analysis. *Arch Phys Med Rehabil*, 105, 975-987.

Macleod, C. M. (1991). Half a century of research on the Stroop effect: an integrative review. *Psychol Bull*, 109, 163-203.

Mateo-March, M., Muriel, X., Valenzuela, P. L., Gandia-Soriano, A., Zabla, M., Barrancho-Gil, D., Pallares, J. G. & Lucia, A. (2022). Altitude and Endurance Performance in Altitude Natives versus Lowlanders: Insights from Professional Cycling. *Med Sci Sports Exerc*, 54, 1218-1224.

McMorris, T., Hale, B. J., Barwood, M., Costello, J. & Corbett, J. (2019). Corrigendum to "Effect of acute hypoxia on cognition: A systematic review and meta-regression analysis" *Neurosci Biobehav Rev* 74 (2017) 225-232. *Neurosci Biobehav Rev*, 98, 333.

Morrison, J. D., Quinn, K., Macdonald, L. A., Billaut, F. & Minahan, C. (2019). Repeated Treadmill Sprints Impair Cognitive Performance in Amateur Team-Sport Athletes When Performed in Normobaric Hypoxia. *J Sports Sci Med*, 18, 369-375.

Parrant, D. & Martin, A. (2010). Developing decision-making in rugby. *Waikato J Edu*, 15, 69-87.

Post, T. E., Heijn, L. G., Jordan, J. & Van Gerven, J. M. A. (2023). Sensitivity of cognitive function tests to acute hypoxia in healthy subjects: a systematic literature review. *Front Physiol*, 14, 1244279.

Reitan, R. M. & Tarshes, E. L. (1959). Differential effects of lateralized brain lesions on the trail making test. *J Nerv Ment Dis*, 129, 257-62.

Richalet, J. P., Hermand, E. & Lhuissier, F. J. (2024). Cardiovascular physiology and pathophysiology at high altitude. *Nat Rev Cardiol*, 21, 75-88.

Richards, P., Collins, D. & Mascarenhas, D. (2016). Developing team decision-making: a holistic framework integrating both on-field and off-field pedagogical coaching processes. *Sports Coach Rev*, 6, 57-75.

Romer, L. M., Haverkamp, H. C., Amann, M., Lovering, A. T., Pegelow, D. F. & Dempsey, J. A. (2007). Effect of acute severe hypoxia on peripheral fatigue and endurance capacity in healthy humans. *Am J Physiol Regul Integr Comp Physiol*, 292, R598-606.

Scarpina, F. & Tagini, S. (2017). The Stroop Color and Word Test. *Front Psychol*, 8, 557.

Scott, B. R., Slattery, K. M., Sculley, D. V., Lockhart, C. & Dascombe, B. J. (2017). Acute Physiological Responses to Moderate-Load Resistance Exercise in Hypoxia. *J Strength Cond Res*, 31, 1973-1981.

Secher, N. H., Seifert, T. & Van Lieshout, J. J. (2008). Cerebral blood flow and metabolism during exercise: implications for fatigue. *J Appl Physiol*, 104, 306-14.

Simpson, L. P., Jones, A. M., Skiba, P. F., Vanhatalo, A. & Wilkerson, D. (2015). Influence of hypoxia on the power-duration relationship during high-intensity exercise. *Int J Sports Med*, 36, 113-9.

Span, P. N. & Bussink, J. (2015). Biology of hypoxia. *Semin Nucl Med*, 45, 101-9.

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. PhD, George Peabody College for Teachers.

Su, R., Jia, S., Zhang, N., Wang, Y., Li, H., Zhang, D., Ma, H. & Su, Y. (2024). The effects of long-term high-altitude exposure on cognition: A meta-analysis. *Neurosci Biobehav Rev*, 161, 105682.

Till, K., Scantlebury, S. & Jones, B. (2017). Anthropometric and Physical Qualities of Elite Male Youth Rugby League Players. *Sports Med*, 47, 2171-2186.

Tommerdahl, M., Francisco, E., Holden, J., Lensch, R., Tommerdahl, A., Kirsch, B., Dennis, R. & Favorov, O. (2020). An Accurate Measure of Reaction Time can Provide Objective Metrics of Concussion. *J Sci Med*, 2, 2.

Wang, X., Cui, L. & Ji, X. (2022). Cognitive impairment caused by hypoxia: from clinical evidences to molecular mechanisms. *Metab Brain Dis*, 37, 51-66.

## Data Availability

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to data restrictions, namely survey responses containing information that could compromise the anonymity and privacy of research participants.

## Conflicts of Interest

There are no relevant financial or non-financial competing interests to report.