

2016

Environmental Influences on Elite Sport Athletes Well Being: From Gold, Silver, and Bronze to Blue Green and Gold

Aoife Donnelly

Technological University Dublin, aoife.donnelly@tudublin.ie

Tadhg MacIntyre

University of Limerick

Nollaig O'Sullivan

University of Limerick

See next page for additional authors

Follow this and additional works at: <https://arrow.tudublin.ie/schfsehart>



Part of the [Community Psychology Commons](#), [Environmental Studies Commons](#), [Health Psychology Commons](#), and the [Urban Studies and Planning Commons](#)

Recommended Citation

Donnelly, A. et al. (2016). Environmental Influences on Elite Sport Athletes Well Being: From Gold, Silver, and Bronze to Blue Green and Gold. *Frontiers in Psychology*, 2016, 7(1167), p.1-8. doi: 10.3389/fpsyg.2016.01167

This Article is brought to you for free and open access by the School of Food Science and Environmental Health at ARROW@TU Dublin. It has been accepted for inclusion in Articles by an authorized administrator of ARROW@TU Dublin. For more information, please contact arrow.admin@tudublin.ie, aisling.coyne@tudublin.ie, vera.kilshaw@tudublin.ie.

Authors

Aoife Donnelly, Tadhg MacIntyre, Nollaig O'Sullivan, Giles Warrington, Andrew Harrison, Eric Igou, Marc Jones, Chris Gidlow, Noel Brick, Ian Lahart, and Andrew Lane



Environmental Influences on Elite Sport Athletes Well Being: From Gold, Silver, and Bronze to Blue Green and Gold

Aoife A. Donnelly^{1*}, Tadhg E. MacIntyre², Nollaig O'Sullivan², Giles Warrington², Andrew J. Harrison², Eric R. Igou³, Marc Jones⁴, Chris Gidlow⁴, Noel Brick⁵, Ian Lahart⁶, Ross Cloak⁶ and Andrew M. Lane⁶

¹ School of Food Science and Environmental Health, Dublin Institute of Technology, Dublin, Ireland, ² Health Research Institute – Department of Physical Education and Sport Sciences, University of Limerick, Limerick, Ireland, ³ Health Research Institute, Department of Psychology, University of Limerick, Limerick, Ireland, ⁴ Centre for Sport, Health and Exercise Research, Faculty of Health Sciences, Staffordshire University, Stoke-on-Trent, UK, ⁵ School of Psychology, Ulster University, Londonderry, UK, ⁶ Research Centre for Sport, Exercise and Performance, Institute of Sport, Faculty of Exercise, Health and Wellbeing, University of Wolverhampton, Walsall, UK

OPEN ACCESS

Edited by:

Adam Robert Nicholls,
University of Hull, UK

Reviewed by:

Laura Catherine Healy,
Newman University, UK
James Rumbold,
Sheffield Hallam University, UK

*Correspondence:

Aoife A. Donnelly
aoife.donnelly@dit.ie

Received: 02 May 2016

Accepted: 22 July 2016

Published: 04 August 2016

Citation:

Donnelly AA, MacIntyre TE, O'Sullivan N, Warrington G, Harrison AJ, Igou ER, Jones M, Gidlow C, Brick N, Lahart I, Cloak R and Lane AM (2016) Environmental Influences on Elite Sport Athletes Well Being: From Gold, Silver, and Bronze to Blue Green and Gold. *Front. Psychol.* 7:1167. doi: 10.3389/fpsyg.2016.01167

This paper considers the environmental impact on well-being and performance in elite athletes during Olympic competition. The benefits of exercising in natural environments are recognized, but less is known about the effects on performance and health in elite athletes. Although some Olympic events take place in natural environments, the majority occur in the host city, usually a large densely populated area where low exposure to natural environments is compounded by exposure to high levels of air, water, and noise pollution in the ambient environment. By combining methods and expertise from diverse but inter-related disciplines including environmental psychology, exercise physiology, biomechanics, environmental science, and epidemiology, a transdisciplinary approach will facilitate a greater understanding of the effects of the environment on Olympic athletes.

Keywords: well being, Olympic Games, mental health, elite athletes, air pollution, environmental health, physical activity

INTRODUCTION

Olympic Games, including Rio 2016, induce acute stressors on athletes comprising both competitive (Schinke et al., 2012; Nicholls and Levy, 2016) and organizational factors (Fletcher et al., 2012). Although many variables have been explored, including athlete resilience and adaptation (Fletcher and Sarkar, 2012) the environment in which sport occurs has not been subject to the same level of scrutiny. This is surprising, given that Olympic Games are typically hosted by a large densely populated city where low exposure to natural environments is compounded by exposure to high levels of air, water, and noise pollution in the ambient environment. This perspective article considers some of the environmental challenges and benefits for athletes.

Environmental Concerns at Past Olympics

Consideration of environmental challenges for athletes is not a new issue as in 1968, at the XIX Olympiad in Mexico, studies examined the effect of the high altitude (>2,250 m) running

performance (Jokl et al., 1969). Four decades later at the 2008 Beijing Olympics, this deleterious view of the environment still pervaded. The 2008 games were dominated by controversies over anthropogenic contributions to the environment and, in particular, air pollution. Beijing then ranked second among the World's most polluted cities according to Lippi et al. (2008).

In 2004, the Beijing Olympic organizing committee set a target that concentrations of pollutants should meet WHO guidelines for the Olympic Games period. A range of mitigating measures were employed during the competition period of the Summer Games including an “odd–even ban” which meant that private vehicles could only be used on either odd or even days. Post-Olympic Games studies have provided support for the mitigation measures as Schleicher et al. (2012) reported that air pollution in Beijing decreased significantly during the enforcement period.

The Greenness of Rio de Janeiro

The sport venues for Rio 2016 Olympics have been subject to scrutiny because of the risks to competitors from environmental hazards. For instance, the degraded water quality of 384 km² Guanabara Bay (Olympic Sailing venue) has led to heavy eutrophication and the emergence of pathogenic micro-organisms (Fistarol et al., 2015). Tackling pollution here is not “only of ecological, social-cultural and aesthetic relevance, but is also a public health issue” (Fistarol et al., 2015, p. 14). Degraded air quality is also an issue. For instance, Sousa et al. (2012a) measured air quality in Rio between 2000 and 2005 and found that PM₁₀ (particles < 10 μm diameter) concentrations were in excess of double the EU annual mean limit value of 40 μg/m³ on occasion. The authors attributed these high levels of PM₁₀ primarily to traffic emissions. Subsequently, Sousa et al. (2012b) showed that ambient air pollution levels in the city were linked to hospital admission rates in children and elderly populations for respiratory issues. These findings are supported by Gioda et al. (2016) reported that total suspended particle (TSP) levels exceeded the annual mean Brazilian limit value of 80 μg/m³ every year between 1968 and 2013. PM₁₀ levels were also found to be in breach of the annual mean Brazilian limit value of 50 μg/m³ and significantly above the WHO guidelines levels. While certain areas showed some reduction in PM₁₀, increases were also observed over the time period. For instance, PM₁₀ levels at the Cidade de Deus station where the Olympic park is situated, were found to average > 90 μg/m³ between 1998 and 2013.

Air pollution is interlinked with other environmental, social, and political and economic systems and is the primary environmental cause of premature death in the EU (European Commission, 2013). The most problematic pollutants have consistently been oxides of nitrogen (NO_x), PM₁₀, PM_{2.5}, and ozone (O₃), while polyaromatic hydrocarbons (PAHs) have been recently identified as pollutants of concern (European Environment Agency [EEA], 2013). A recent view stated that the previous causal link between PM_{2.5} and adverse health impact has been strengthened by recent evidence (WHO, 2013). Short and long-term exposure to PM_{2.5} were noted to result in adverse health impacts, even where exposure was below the current recommended WHO annual limit of 10 μg/m³. There is

significant evidence from toxicological and clinical studies that short duration exposure to combustion derived particles leads to immediate physiological changes (supported by epidemiological observations). Furthermore, this review also highlights emerging links between NO₂ exposure and mortality/morbidity (WHO, 2013) highlighting the need for continued measures to reduce air pollution.

Are We Going in the Right Direction?

The 2020 Olympic games will take place in Tokyo, a megacity which Gurjar et al. (2008) gave a multi-pollutant index (MPI) of −0.27 in their study of air pollution levels in megacities (negative MPI values tend toward a good air quality classification, while positive values tend toward poor air quality). For comparison, Rio was given an MPI of 0.11, Beijing 2.01 (and second worst) while the megacity with the most favorable MPI was Osaka-Kobe (−0.37). A follow on study (Gurjar et al., 2010) showed that the excess number of deaths in megacities was closely linked to TSP levels. Tokyo has a low excess mortality rate (EMR; <500/yr). Beijing in contrast, has an EMR of 11,500/yr, while Rio has an EMR of 2,000/yr. London also has its own air quality issues which have been very topical in recent times as EU limit values are frequently breached in several of regions. Stedman (2004) highlighted the importance of considering air quality levels and climate as a whole and estimated that during a heat-wave in the UK when temperatures peaked at 38.5°C, there were between 423 and 769 excess deaths in England and Wales due to elevated levels of ozone and PM₁₀. One would question therefore, in what environment an elite athlete would prefer to perform and whether they can be sure that they are not putting themselves at a higher risk than the rest of the population by exerting themselves to their maximum ability in their drive for sporting success. Tokyo has the highest population of any city in the world at almost 43 million inhabitants and has a population density of 4,400 people per km² yet maintains a favorable MPI compared to other megacities. Sustaining such population density levels and retaining some degree of greenness/natural environment is a challenge faced by many cities but doing so may result in significant effects on well-being and elite athletic performance.

BENEFITS OF EXPOSURE TO THE GREEN AND BLUE ENVIRONMENTS

There is consistent evidence of a positive relationship between natural environment exposure and health (e.g., Attention Restoration Theory; Kaplan and Kaplan, 1989; Stress Reduction Theory; Ulrich et al., 1991). Specifically, there is potential for natural environments to reduce stress, aid recovery from stressful events, improve cognitive function and provide beneficial changes in cardiovascular indicators of stress (Bowler et al., 2010; Hartig et al., 2014). The concept of green exercise is of particular relevance to Olympic athletes, as exercising in natural versus built environments has been linked with additional benefits for performance and indicators of well-being.

Early studies have reported enhanced performance and satisfaction in cross-country versus track running (Pennebaker and Lightner, 1980), and lower perceived 'effort' in trained athletes running on an outdoor track (Ceci and Hassman, 1991) or university campus (Harte and Eifert, 1995), compared with treadmill running. A systematic review also found that physical activity in natural environments was associated with decreased feelings of tension, confusion, anger, and depression, while exhibiting greater feelings of revitalisation (Thompson Coon et al., 2011). Similarly, positive effects on mood, for walking or running in natural environments were reported by Bowler et al. (2010). Outdoor experiences are also rated as more restorative (Hug et al., 2009) and more effective in improving mood and vitality (Ryan et al., 2010). In comparison, indoor activity was associated with increased frustration, anxiety, anger, and sadness (Teas et al., 2007). De Wolfe et al. (2011) investigated performance of 128 collegiate track and field athletes across four locations rated for greenness. They reported that greenness was a predictor of performance ($r^2 = 0.61$, $p < 0.001$) with more of the athletes' best performances occurring at the site with the highest greenness rating. In sum, there is consistent evidence that exercising in clean, natural environments is associated with positive changes in self-reported psychological state. Given the results of such studies, considering the relationships between athlete's performance and health in Olympic cities has particular relevance.

Pierson et al. (1986) noted that air pollution can be an important factor in the success of Olympic athletes, drawing reference to several studies that show that the combination of exercise with exposure to SO₂ or O₃ can cause a marked bronchoconstriction and reduced ventilatory flow. This follows from an early study by Wayne et al. (1967) that found a correlation between team athletic performance of high school cross-country track runners and oxidant exposure levels in the preceding hour. It can be challenging to disentangle confounding environmental effects on performance and El Helou et al. (2012) found that higher ozone levels were associated with poorer performance in six city marathons but noted that the effect may be due to associations between ozone levels and ambient temperature.

The negative effects of PM on human health are, however, now widely established and Rundell (2012) notes that the prevalence of exercise induced bronchoconstriction, asthma, and low resting lung function for athletes who train and compete in high PM environments is far in excess of that for both non-athletes and athletes who train in lower PM environments. Indeed (Kippelen et al., 2012) recommends that athletes who must train on or near roads (such as cyclists, endurance runners) do so early in the morning to benefit from the diurnal trough that typically occurs in pollutant concentrations.

One of the less commonly studied ways in which natural environments might benefit health and athletic performance is through mitigation of risk from environmental pollutants. Trees have been shown to reduce the level of air pollutants in urban areas (Rowe, 2011), with one study suggesting that trees remove 711,000 tons of air pollutants from the US per year (Nowak et al., 2006). In the absence of available space for substantial

tree planting in urban areas, roof spaces can provide a further opportunity to incorporate green vegetation into the urban environment. Yang et al. (2008) used a dry deposition model to show that a total of 1675 kg of air pollutants were removed by 19.8 hectares of green roofs in 1 year in Chicago. They suggest that the use of a green roofs is a good supplement to the use of urban trees. Such initiatives have the potential to improve environmental quality and boost population health, well-being and athletic performance.

We Are all in this Together

Air pollution control policies and technology have, in the past, included direct measures to reduce the concentration of air pollutants and also measures to reduce emissions rates and quantities. The direct control of air pollution concentrations in the urban environment has been the focus of some research in recent years. Passive controls have included road/noise barriers, green walls, changes in urban planning/geometry to control dispersion and settlement (McNabola, 2010), TiO₂ infused building materials, pedestrian ventilation systems, etc. (Mirzaei and Haghighat, 2010; Gallagher et al., 2015). Such controls tend to be quite localized in their effectiveness but it could certainly be suggested that the provision of greener routes for pedestrians and cyclists could benefit the environment as well as the psychological and physiological health of the population.

The control of emission rates can have large spatial implications for pollution concentration levels and examples include: the introduction of carbon-based vehicle tax systems which encourage the use of vehicles with smaller engine capacities and/or emissions intensities (Giblin and McNabola, 2009); the regulation of industrial point emissions through the licensing of emissions intensities (Styles et al., 2009); improvements in vehicle technology and alternative fuels (Manzie et al., 2007); congestion charging (Atkinson et al., 2009), low emissions zones (Boogaard et al., 2012), carbon taxation (Clancy et al., 2002), improvements in public transport incentives (González-Díaz and Montoro-Sánchez, 2011), and renewable fuel use (Granovskii et al., 2007). Bickerstaff and Walker (2001) concluded that community involvement approaches which encourage local people to identify the environmental issues that affect them and how they can be involved in designing and implementing policy and communication responses to the problems will lead to a greater sensitivity to local diversity.

Encouraging society at large to become more active and less polluting can, in the long term, lead to a cleaner, greener and happier society. De Hartog et al. (2010) concluded that the health benefits of a modal shift from driving to cycling were substantially larger than the risks and aside from quantifiable and measureable effects, societal benefits are even larger. Sustainable transport schemes such as the Irish Cycle to Work Scheme and the Dublin Bikes Rental Scheme (Dublin City Council, 2009) are good examples of incentives that have the capability to reduce traffic congestion and thus reduce emissions from the transport sector (Caulfield and Leahy, 2011) while at the same time increasing exercise capacity in the general population.

There is clearly a need for evidence-based research to promote the psychological health effects of a greener society and the

provision and use of green and blue spaces for physical activity (which can also equate to commuting). The Olympic Games provides a high profile opportunity to highlight the benefits that can be gained from utilizing and improving the natural environment in cities; not only for athletic performance, but for athlete health and that of the spectators, organizers, workers, and all those involved in the Olympic movement.

Avenues for Future Research

Future research needs to include relevant environmental monitoring to quantify the greenness of the competition landscape from an environmental health perspective. There exists great disparity in the natural influences which pervade various sports. Pool swimming for example may be considered to take place in an entirely artificial environment with little potential for green influences. In contrast marathon swimmers are subjected to the varying quality of the natural environment. Research needs to assess if and how, the quality of these environments can affect athlete health, well-being and ultimately performance. Such research will differentiate between sports that are ordinarily held in green/blue spaces (e.g., mountain bike venue, Deodoro Olympic Park) and those which take place in highly artificial or hybrid artificial/natural environments. Exploring the mental health benefits of natural environments, Pearson and Craig (2014) performed a review of the existing literature and call for future research to focus on substantiating the rather simplistic dichotomy of “nature” vs. “built” environments. Many studies have focused primarily on studying human interactions with only images of natural and urban environments but in this review the importance of considering the actual immersion of the nature intervention was noted. We suggest that the mental health benefits to athletes that can be gained from blue (Nichols, 2014) and green spaces (Kuo, 2015), an area of growing interest (Uphill et al., 2016), relates not only to the visual appearance of these spaces but also the environmental characteristics that we may not be able to see such as air quality, water quality, and biodiversity.

For athletes immersed in the Olympic environment, future research should explore the role of the environment in enhancing psychological well-being and whether exposure to green spaces facilitates athletes achieving peak performance and well-being during the competition period; and indeed, whether there a minimum environmental standard that must be present before positive benefits of the environment are observed. In exercisers, natural environments are proposed to reduce stress, help individuals recover quicker from stressful events, and improve cognitive function, all effects which would be expected to enhance performance. Yet research in elite populations is limited and could augment De Wolfe et al.'s (2011) college based study.

Individual preferences or nature relatedness may also be a mediator of the positive effects of exposure to natural environments (Nisbet et al., 2009). Although studies with athletic samples are lacking, tentative evidence has emerged for example from a physical activity study with sedentary individuals (Kinnafick and Thøgersen-Ntoumani, 2014). Implicit in this research would be a consideration of the urban density and pre-existing green spaces accessible to the population at large.

The environmental quality of these green spaces must also be proportional to their positive health effects, and it must always be remembered that just because an area is green, it does not automatically imply environmental cleanliness. Future studies must take account of dose–response effects, the actual versus the perceived environmental quality and accessibility. Our preliminary hypothesis is that a green space with an environmental quality superior to an otherwise comparable green space could result in better physical and psychological health, and potentially better athletic performance. We propose a model where physical and psychological well-being (and better performance) are linked to green and blue environments and suggest that current developments in the Olympic context are often in sharp contrast with this model.

CONCLUSION

The effects of environmental pollution must now be considered a global concern among the scientific community for its impacts on human health, the environment and climate change. Environmental quality can potentially positively affect physiological health, mental health, and well-being in the elite athlete population. In green exercise, the synergistic benefit of engaging in physical activities while at the same time being directly exposed to nature, is worthy of further exploration.

Athletes competing at the Tokyo 2020 Olympics can potentially benefit from a more comprehensive understanding of the impact of activity in green and blue natural spaces on health and well-being. Green and blue may well become a feature of the pathway to achievement; not just on the individual level for mental health, nor simply on a societal level by increasing pro-environmental behavior, and also by a continued greening of the Olympic movement. Perhaps the IOC should provide more weight to the environmental ethos of hosting cities when making their selections and by doing so promote athlete health and well-being as a priority in the path to success. We propose a reframing of the environment in the Olympic context, a perspective that goes beyond toxicity, and instead accounts for the positive effect of the environment on health, well-being, and athletic performance.

AUTHOR CONTRIBUTIONS

AD and TM led the development of the manuscript from inception to final version. All other authors contributed to draft revisions and the final manuscript.

FUNDING

This submission was funded in part by an Irish Research Council New Foundations Awards in 2015 to the project entitled: GO GREEN EX: Going Outdoors: Gathering Research Evidence on ENvironment and Exercise in collaboration with Mental Health Ireland. Open access cost is funded by a PESS research start-up award to TM.

REFERENCES

- Atkinson, R. W., Barratt, B., Armstrong, B., Anderson, H. R., Beevers, S. D., Mudway, I. S., et al. (2009). The impact of the congestion charging scheme on ambient air pollution concentrations in London. *Atmos. Environ.* 43, 5493–5500. doi: 10.1016/j.atmosenv.2009.07.023
- Bickerstaff, K., and Walker, G. (2001). Public understandings of air pollution: the 'localisation' of environmental risk. *Glob. Environ. Chang.* 11, 133–145. doi: 10.1016/S0959-3780(00)00063-7
- Boogaard, H., Janssen, N. A., Fischer, P. H., Kos, G. P., Weijers, E. P., Cassee, F. R., et al. (2012). Impact of low emission zones and local traffic policies on ambient air pollution concentrations. *Sci. Total Environ.* 435, 132–140. doi: 10.1016/j.scitotenv.2012.06.089
- Bowler, D. E., Buyung-Ali, L. M., Knight, T. M., and Pullin, A. S. (2010). A systematic review of evidence for the added benefits to health of exposure to natural environments. *BMC Public Health* 10:456. doi: 10.1186/1471-2458-10-456
- Caulfield, B., and Leahy, J. (2011). Learning to cycle again: examining the benefits of providing tax-free loans to purchase new bicycles. *Res. Transp. Bus. Manage.* 2, 42–47. doi: 10.1016/j.rtbm.2011.08.005
- Ceci, R., and Hassman, P. (1991). Self-monitored exercise at three different RPE intensities in treadmill vs field running. *Med. Sci. Sports Exerc.* 23, 732–738. doi: 10.1249/00005768-199106000-00013
- Clancy, L., Goodman, P., Sinclair, H., and Dockery, D. (2002). Effect of air-pollution control on death rates in Dublin, Ireland: an intervention study. *Lancet* 360, 1210–1214.
- De Hartog, J. J., Boogaard, H., Nijland, H., and Hoek, G. (2010). Do the health benefits of cycling outweigh the risks? *Environ. Health Perspect.* 118, 1109–1116. doi: 10.1289/ehp.0901747
- De Wolfe, J., Waliczek, T. M., and Zajicek, J. M. (2011). The relationship between levels of greenery and landscaping at track and field sites, anxiety, and sports performance of collegiate track and field athletes. *Horttechnology* 21, 329–325.
- Dubin City Council (2009). *Dublinbikes Strategic Planning Framework 2011 – 2016. Making Dublin More Accessible*. Dublin, OH: Dubin City Council.
- El Helou, N., Tafflet, M., Berthelot, G., Tolaini, J., Marc, A., Guillaume, M., et al. (2012). Impact of environmental parameters on marathon running performance. *PLoS ONE* 7:e37407. doi: 10.1371/journal.pone.0037407
- European Commission (2013). *Communication from the Commission to the European Parliament, the Council, The European Economic And Social Committee and the Committee of the Regions*. Brussels: European Commission.
- European Environment Agency [EEA] (2013). *Status of Black Carbon Monitoring in Ambient Air in Europe*. EEA Technical Report, 18. Copenhagen: European Environment Agency.
- Fistaro, G. O., Coutinho, F. H., Moreira, A. P. B., Venas, T., Cánovas, A., de Paula, S. E. M. Jr., et al. (2015). Environmental and sanitary conditions of Guanabara Bay, Rio de Janeiro. *Front. Microbiol.* 6:1232. doi: 10.3389/fmicb.2015.01232
- Fletcher, D., Hanton, S., Mellalieu, S. D., and Neil, R. (2012). A conceptual framework of organizational stressors in sport performers. *Scand. J. Med. Sci. Sports* 22, 545–557. doi: 10.1111/j.1600-0838.2010.01242.x
- Fletcher, D., and Sarkar, M. (2012). A grounded theory of psychological resilience in Olympic champions. *Psychol. Sport Exerc.* 13, 669–678. doi: 10.1016/j.psychsport.2012.04.007
- Gallagher, J., Baldauf, R., Fuller, C. H., Kumar, P., Gill, L. W., and McNabola, A. (2015). Passive methods for improving air quality in the built environment: a review of porous and solid barriers. *Atmos. Environ.* 120, 61–70. doi: 10.1016/j.atmosenv.2015.08.075
- Giblin, S., and McNabola, A. (2009). Modelling the impacts of a carbon emission-differentiated vehicle tax system on CO2 emissions intensity from new vehicle purchases in Ireland. *Energy Policy* 37, 1404–1411. doi: 10.1016/j.enpol.2008.11.047
- Gioda, A., Ventura, L. M. B., Ramos, M. B., and Silva, M. P. R. (2016). Half century monitoring air pollution in a Megacity: a case study of Rio de Janeiro. *Water Air Soil Pollut.* 227, 1–17. doi: 10.1007/s11270-016-2780-8
- González-Díaz, M., and Montoro-Sánchez, Á (2011). Some lessons from incentive theory: promoting quality in bus transport. *Transp. Policy* 18, 299–306. doi: 10.1016/j.tranpol.2010.09.001
- Granovskii, M., Dincer, I., and Rosen, M. A. (2007). Greenhouse gas emissions reduction by use of wind and solar energies for hydrogen and electricity production: economic factors. *Int. J. Hydrogen Energy* 32, 927–931. doi: 10.1016/j.ijhydene.2006.09.029
- Gurjar, B., Butler, T., Lawrence, M., and Lelieveld, J. (2008). Evaluation of emissions and air quality in megacities. *Atmos. Environ.* 42, 1593–1606. doi: 10.1016/j.atmosenv.2007.10.048
- Gurjar, B., Jain, A., Sharma, A., Agarwal, A., Gupta, P., Nagpure, A., et al. (2010). Human health risks in megacities due to air pollution. *Atmos. Environ.* 44, 4606–4613. doi: 10.1016/j.atmosenv.2010.08.011
- Harte, J. L., and Eifert, G. H. (1995). The effects of running, environment, and attentional focus on athletes' catecholamine and cortisol levels and mood. *Psychophysiology* 32, 49–54. doi: 10.1111/j.1469-8986.1995.tb03405.x
- Hartig, T., Sjøerp de Vries, R. M., and Frumkin, H. (2014). Nature and health. *Annu. Rev. Public Health* 35, 207–228. doi: 10.1146/annurev-publhealth-032013-182443
- Hug, S., Hartig, T., Hansmann, R., Seeland, K., and Hornung, R. (2009). Restorative qualities of indoor, and outdoor exercise settings as predictors of exercise frequency. *Health Place* 15, 971–980. doi: 10.1016/j.healthplace.2009.03.002
- Jokl, E., Jokl, P., and Seaton, D. C. (1969). Effect of altitude upon 1968 Olympic Games running performances. *Int. J. Biometeorol.* 13, 309–311. doi: 10.1007/BF01553038
- Kaplan, R., and Kaplan, S. (1989). *The Experience of Nature: A Psychological Perspective*. Cambridge: Cambridge University Press.
- Kinnafick, F.-E., and Thøgersen-Ntoumani, C. (2014). The effect of the physical environment and levels of activity on affective states. *J. Environ. Psychol.* 38, 241–251. doi: 10.1016/j.jenvp.2014.02.007
- Kippelen, P., Fitch, K. D., Anderson, S. D., Bougault, V., Boulet, L.-P., Rundell, K. W., et al. (2012). Respiratory health of elite athletes—preventing airway injury: a critical review. *Br. J. Sports Med.* 46, 471–476. doi: 10.1136/bjsports-2012-091056
- Kuo, M. (2015). How might contact with nature promote human health? Promising mechanisms and a possible central pathway. *Front. Psychol.* 6:1093. doi: 10.3389/fpsyg.2015.01093
- Lippi, G., Guidi, G. C., and Maffulli, N. (2008). Air pollution and sports performance in Beijing. *Int. J. Sports Med.* 29, 696–698. doi: 10.1055/s-2008-1038684
- Manzie, C., Watson, H., and Halgamuge, S. (2007). Fuel economy improvements for urban driving: Hybrid vs. intelligent vehicles. *Transp. Res. Part C Emerg. Technol.* 15, 1–16. doi: 10.1016/j.trc.2006.11.003
- McNabola, A. (2010). New Directions: passive control of personal air pollution exposure from traffic emissions in urban street canyons. *Atmos. Environ.* 44, 2940–2941. doi: 10.1016/j.atmosenv.2010.04.005
- Mirzaei, P. A., and Haghigat, F. (2010). A novel approach to enhance outdoor air quality: pedestrian ventilation system. *Build. Environ.* 45, 1582–1593. doi: 10.1016/j.buildenv.2010.01.001
- Nicholls, A. R., and Levy, A. R. (2016). The road to London 2012: the lived stressor, emotion, and coping experiences of gymnasts preparing for and competing at the world championships. *Int. J. Sport Exer. Psychol.* 14, 255–267. doi: 10.1080/1612197X.2015.1020664
- Nichols, W. J. (2014). *Blue Mind*. New York, NY: Little Brown and Co.
- Nisbet, E. K., Zelenski, J. M., and Murphy, S. A. (2009). The Nature Relatedness Scale: linking individuals' connection with nature to environmental concern and behavior. *Environ. Behav.* 41, 715–740. doi: 10.1177/0013916508318748
- Nowak, D. J., Crane, D. E., and Stevens, J. C. (2006). Air pollution removal by urban trees and shrubs in the United States. *Urban For. Urban Greening* 4, 115–123. doi: 10.1016/j.ufug.2006.01.007
- Pearson, D. G., and Craig, T. (2014). The great outdoors? Exploring the mental health benefits of natural environments. *Front. Psychol.* 5:1178. doi: 10.3389/fpsyg.2014.01178
- Pennebaker, J. W., and Lightner, J. M. (1980). Competition of internal and external information in an exercise setting. *J. Pers. Soc. Psychol.* 39, 165–174. doi: 10.1037/0022-3514.39.1.165
- Pierson, W. E., Covert, D. S., Koenig, J. Q., Namekata, T., and Kim, Y. S. (1986). Implications of air pollution effects on athletic performance. *Med. Sci. Sports Exerc.* 18, 322–327. doi: 10.1249/00005768-198606000-00012
- Rowe, D. B. (2011). Green roofs as a means of pollution abatement. *Environ. Pollut.* 159, 2100–2110. doi: 10.1016/j.envpol.2010.10.029

- Rundell, K. W. (2012). Effect of air pollution on athlete health and performance. *Br. J. Sports Med.* 46, 407–412. doi: 10.1136/bjsports-2011-090823
- Ryan, R. M., Weinstein, N., Bernstein, J., Brown, K. W., Mistretta, L., and Gagné, M. (2010). Vitalizing effects of being outdoors and in nature. *J. Environ. Psychol.* 30, 159–168. doi: 10.1016/j.jenvp.2009.10.009
- Schinke, R. J., Battocchio, R. C., Dube, T. V., Lidor, R., Tenenbaum, G., and Lane, A. M. (2012). Adaptation processes affecting performance in elite sport. *J. Clin. Sport Psychol.* 6, 180–195.
- Schleicher, N., Norra, S., Chen, Y., Chai, F., and Wang, S. (2012). Efficiency of mitigation measures to reduce particulate air pollution—A case study during the Olympic Summer Games 2008 in Beijing, China. *Sci. Total Environ.* 42, 146–158. doi: 10.1016/j.scitotenv.2012.04.004
- Sousa, S., Pires, J., Martins, E., Fortes, J., Alvim-Ferraz, M., and Martins, F. (2012a). Short-term effects of air pollution on respiratory morbidity at Rio de Janeiro—Part I: air pollution assessment. *Environ. Int.* 44, 18–25. doi: 10.1016/j.envint.2012.01.005
- Sousa, S., Pires, J., Martins, E., Fortes, J., Alvim-Ferraz, M., and Martins, F. (2012b). Short-term effects of air pollution on respiratory morbidity at Rio de Janeiro—Part II: health assessment. *Environ. Int.* 43, 1–5. doi: 10.1016/j.envint.2012.02.004
- Stedman, J. R. (2004). The predicted number of air pollution related deaths in the UK during the August 2003 heatwave. *Atmos. Environ.* 38, 1087–1090. doi: 10.1016/j.atmosenv.2003.11.011
- Styles, D., O'Brien, K., and Jones, M. B. (2009). A quantitative integrated assessment of pollution prevention achieved by Integrated Pollution Prevention Control licensing. *Environ. Int.* 35, 1177–1187. doi: 10.1016/j.envint.2009.07.013
- Teas, J., Hurley, T., Ghumare, S., and Ogoussan, K. (2007). Walking outside improves mood for healthy postmenopausal women. *Clin. Med. Insights Oncol.* 1, 35–43.
- Thompson Coon, J., Boddy, K., Stein, K., Whear, R., Barton, J., and Depledge, M. H. (2011). Does participating in physical activity in outdoor natural environments have a greater effect on physical and mental wellbeing than physical activity indoors? A systematic review. *Environ. Sci. Technol.* 45, 1761–1772. doi: 10.1021/es102947t
- Ulrich, R. S., Simons, R. F., Losito, B. D., Fiorito, E., Miles, M. A., and Zelson, M. (1991). Stress recovery during exposure to natural and urban environments. *J. Environ. Psychol.* 11, 231–248. doi: 10.1016/S0272-4944(05)80184-7
- Uphill, M., Sly, D., and Swain, J. (2016). From mental health to mental wealth in athletes. Looking back and moving forward. *Front. Psychol.* 7:935. doi: 10.3389/fpsyg.2016.00935
- Wayne, W. S., Wehrle, P. F., and Carroll, R. E. (1967). Oxidant air pollution and athletic performance. *JAMA* 99, 901–904. doi: 10.1001/jama.199.12.901
- WHO (2013). *Review of Evidence on Health Aspects of Air Pollution – REVIHAAP Project: Final Technical Report*. Copenhagen: WHO Regional Office for Europe.
- Yang, J., Yu, Q., and Gong, P. (2008). Quantifying air pollution removal by green roofs in Chicago. *Atmos. Environ.* 42, 7266–7273. doi: 10.1016/j.atmosenv.2008.07.003

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Copyright © 2016 Donnelly, MacIntyre, O'Sullivan, Warrington, Harrison, Igou, Jones, Gidlow, Brick, Lahart, Cloak and Lane. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) or licensor are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.