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On the usability of digital sleep interventions in sports

High sleep quality is essential to promote health as it—beyond other functions such as learning and memory consolidation—serves to recreate psychophysiological homeostasis which is of particular importance for human well-being (Grandner, 2017).

In the sports context, better sleep is associated with performance enhancement (Walsh et al., 2020). However, due to the high time pressure in athletes' daily training and competition routine, athletes are prone to suffer from sleep disturbances. Therefore, commercially accessible and easily manageable interventions helping athletes to improve their sleep quality, and consequently, their performance and health, are needed. As digitalization and the use of technology are increasing rapidly, digital features are one promising approach to assess sleep patterns, and to provide suitable (e.g., mindfulness-based, Mrazek et al., 2019) interventions (Bonnar, Bartel, Kakoschke, & Lang, 2018).

While numerous studies have been conducted on the importance of sleep in general and specifically in sports (Fullagar et al., 2015; Grandner, 2017), so far, the potentials (i.e., opportunities as well as constraints) of digital features in the context of sleep interventions for the optimization of sleep quality among athletes have neither been elaborated from a theoretical perspective nor have they been empirically tested. Thus, this article aims to give an overview on the usability of digital sleep interventions with a specific focus on the potentials of mindfulness-based sleep optimization.

Importance of sleep quality in the context of sports

In the sports performance setting, studies have shown that better recovery and sleep quality positively influence sports performance, motivation and concentration as well as the general physiological and psychological capability (Chandrasekaran, Fernandes, & Davis, 2020). Furthermore, high sleep quality positively affects the circadian rhythm, and the hormonal and immune system, while decreasing perceived exhaustion and pain perception (Walsh et al., 2020). In contrast, sleep disturbances negatively affect mood and cause a decline in fine motor skills, maximum strength, and aerobic performance (Fullagar et al., 2015). Further, stress as well as cognitive and physical exertion negatively influence the regeneration process, in particular the process of falling asleep itself. In this context, Kellmann et al. (2018) have demonstrated the risk of short-term performance losses up to long-term health consequences due to the negative combination of stressful factors, low resources, and bad sleep habits in terms of sleep quality and sleep duration. However, many professional athletes sleep less than the 7–9 h recommended by the American Academy of Sleep Medicine and the German Sleep Society leading to an accumulation of sleep problems in athletes (Kölling, Duffield, Erlacher, Venter, & Halson, 2019; Nedelec, Aloulou, Duforez, Meyer, & Dupont, 2018). Especially before competitions, high arousal and fearful thoughts seem to appear more often. For instance, Lastella, Lovell, and Sargent (2014) have shown a variance of 4–5% in mood and general well-being after bad night sleep. To carry out this important role of sleep quality, detailed and holistic sleep assessment and treatments are needed (Claudino et al., 2019; Halson, 2019). Hence, an increased awareness and tailored optimization of athletes' sleep behavior might foster sports performance (Bonnar et al., 2018).

Potentials of mindfulness in the context of sleep

Besides the fact that proceeding digitalization could be used for monitoring actual sleep behavior, digital systems can also be used for interventions aiming to optimize sleep quality, and as a consequence, to increase health and performance. One technique which is already empirically tested and can also be practiced digitally, is a mindfulness-based intervention (Collins, Cox, Wilcock, & Sethu-Jones, 2019). Recently, several studies have examined common (i.e., non-digital-based) meditation and mindfulness-based practices as a time- and cost-effective possibility to reduce cognitive activity and arousal (Hülsheger, Feinholdt, & Nübold, 2015). Especially before going to bed, mindfulness meditation could help to fall asleep and enhances sleep quality (Rusch et al., 2019). Likewise, in sports, mindfulness-based programs such as the Mindfulness–Acceptance–Commitment (MAC) approach (Gardner & Moore, 2004) or Mindful Sports Performance Enhancement (MSPE; Kaufman, Glass, & Arnkoff, 2009) are well established as they seem

to improve focus and concentration as well as to reduce negative emotions and deflection among athletes. In accordance to Jones, Kaur, Miller, and Spencer (2020), Li, Kee, and Lam (2018) recorded a significant decrease in presleep arousal after having applied 6-minute mindfulness-based videos to university athletes from various sports. Thus, mindfulness-based interventions support sleep quality. As high sleep quality is an essential prerequisite for performance, mindful techniques might be especially useful for athletes (Bühlmayer, Birrer, Röthlin, Faude, & Donath, 2017).

Digital sleep interventions

When conducting research on sleep, sleep quality and sleep quantity need to be differentiated. While research on sleep quantity, i.e., total sleep time and sleep onset latency, is already highly elaborated and can be assessed by actigraphy or polysomnography, research on parameters influencing sleep quality is rather rare as it can only be measured by subjective ratings of recovery or sleepiness (for a review of sleep assessment methods see Ibáñez, Silva, & Cauli, 2018). As a high total sleep duration does not necessarily result in high feelings of recovery and low sleepiness, rather the individual sleep quality than quantity seems crucial, and therefore, should be particularly addressed in sleep interventions.

Online and smartphone applications

At first, before starting any intervention, athletes need to be sensitive concerning their individual sleep behavior by assessing their actual sleep situation. According to Ibáñez et al. (2018), a combination of objective and subjective assessment is recommended. This step can be digitally supported. The most common and easily accessible digital gadgets are web-based platforms and smartphone applications (Crivello, Barsocchi, Girolami, & Palumbo, 2019). Based on a medical assessment like sleep diaries and sleep questionnaires, they monitor the health status with only a few clicks and the results can be shared with health providers

such as the doctor or coach. These diaries or questionnaires retrospectively gather subjective information about athletes' sleep habits and well-being. Dependent on the respective software, athletes receive information about their sleep hygiene and by now recommendations to optimize recovery or sleep (Fietze, 2016). Besides the subjective rating of sleep quality some smartphone apps can even track sleep time, snore or body movements by placing the phone on the mattress during sleep. After this digital baseline assessment of athletes' sleep patterns, tailored interventions according to individual requirements (e.g., extend total sleep duration, reduce time to fall asleep by reducing presleep arousal or rumination) can be set. For this purpose, numerous, often free-of-charge apps are available for Android and iOS providing guided meditations, audiobooks or similar methods in order to support falling asleep or to establish an individual sleep routine. Widely-used apps are, for example, Pillow, Sleep Better, Headspace, Calm or Sleep (for a review of mobile phone interventions for sleep quality see Shin, Kim, & Grigsby-Toussaint, 2017). In this context, Huberty et al. (2021) have shown that a mindful meditation mobile app could foster mindfulness and sleep quality.

Wearables

As the use of smart technology in sports is increasing constantly, wearable devices such as smartwatches and fitness trackers are other promising technological approaches for sleep assessment and treatment (Vlahoyiannis, Sakkas, Manconi, Aphamis, & Giannaki, 2020). For instance, Seshadri, Drummond, Craker, Rowbottom, and Voos (2017) have demonstrated that wearable sensors allow more detailed insight into athletes' (physiological and psychological) demands than traditional monitoring methods. However, as the smart devices' validity is barely given, they are less a standardized medical tool than rather a supportive gadget (for review of sleep assessment devices see Ibáñez, Silva, Navarro, & Cauli, 2019). Examples for available features are Sleep Plus and

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Abstract

High sleep quality is highly related to better health and peak performance. Nowadays, multiple applications and platforms are available to track activity, to monitor heart rate, or to evaluate sleep quality. While activity tracking and heart rate monitoring are widely used, little is known about the potentials of digital tools to optimize sleep quality. Especially among athletes, who often suffer from reduced sleep quality because of full schedules and high competition performance pressure, interventions to maximize performance by optimizing recovery and sleep quality seem to be promising. In the present paper, we give an overview on existing research focusing on the potentials of digital interventions to enhance sleep quality among athletes. In particular, mindfulness-based digital interventions seem to be promising as they evidently foster high sleep quality and related health and performance patterns. Further, athletes can time- and cost-effectively integrate them into their daily routines. Future research is needed to empirically test the usability of digital features and suitable interventions to optimize sleep.

Keywords
Sports performance · Technology · Wearables · Virtual reality · Mindfulness

Serene for Polar® (Polar Electro GmbH Deutschland, Büttelborn, Germany) wearables, or Sleep Score and Relax for Fitbit® (Fitbit Germany GmbH, Frankfurt am Main, Germany) wearables, whereas Garmin® (Garmin Deutschland GmbH, Garching, Germany) provides sleep tracking and breathing exercises only via its Garmin connect app.

Virtual reality

Recently, studies have shown that the positive effects of mindfulness-based interventions can also be evoked by virtual mindfulness-based interventions (Kitson, Prpa, & Riecke, 2018). Virtual reality (VR) may facilitate getting

used to mindfulness practices because of its user-friendly, immersive surface (Seabrook et al., 2020). Moreover, in exploratory studies from Navarro-Harro et al. (2017) and Chandrasiri, Collett, Fassbender, and de Foe (2020), even a single mindful VR session was more efficient in terms of reducing negative thoughts and emotions compared to the traditional Mindfulness-Based Stress Reduction (MBSR) technique. Thus, virtual mindfulness-based interventions seem to be a promising approach to optimize health and recovery even though the feasibility and effects of these interventions needs to be empirically tested. Suitable VR-meditation apps (e.g., VR Relax Meditation & Sleep, Provata VR) are available for free or low-cost in smartphone and VR-glasses appstores.

Conclusion and future directions

Sleep is essential in terms of recovery, health, and peak performance by influencing physical, psychological, and cognitive functioning, whereas mindfulness-based techniques have been shown to improve sleep quality. The present paper provides an overview on the usability of digital mindfulness-based interventions to foster high sleep quality and associated health and performance aspects. We demonstrated that digital features could be used as both an assessment and an intervention tool. Regarding mindfulness-based interventions, apps and VR meditations seem particularly promising. However, future research is needed to gain deeper insight into the reliability and validity of digital sleep assessment and interventions.

In sum, the application of digital tools with the aim to optimize athletes' sleep habits without interfering in their daily lives seems to be a promising approach whose efficacy needs to be tested more precisely.

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Declarations

References

Bonnar, D., Bartel, K., Kakoschke, N., & Lang, C. (2018). Sleep interventions designed to improve athletic performance and recovery: a systematic review of current approaches. *Sports medicine*, 48(3), 683–703. https://doi.org/10.1007/s40279-017-0832-x.

Bühlmayer, L., Birrer, D., Röthlin, P., Faude, O., & Donath, L. (2017). Effects of mindfulness practice on performance-relevant parameters and performance outcomes in sports: a meta-analytical review. *Sports Medicine*, 47(11), 2309–2321. https://doi.org/10.1007/s40279-017-0752-9.

Chandrasekaran, B., Fernandes, S., & Davis, F. (2020). Science of sleep and sports performance—a scoping review. *Science & Sports*, 35(1), 3–11. https://doi.org/10.1016/j.scispo.2019.03.006.

Chandrasiri, A., Collett, J., Fassbender, E., & de Foe, A. (2020). A virtual reality approach to mindfulness skills training. *Virtual Reality*, 24(1), 143–149. https://doi.org/10.1007/s10055-019-00380-2.

Claudino, J. G., Gabbet, T. J., de Sá Souza, H., Simim, M., Fowler, P., de Alcantara Borba, D., Melo, M., Bottino, A., Loturco, I., D'Almeida, V., Amadio, C. A., Cerca Serrão, J., & Nassis, P. G. (2019). Which parameters to use for sleep quality monitoring in team sport athletes? A systematic review and meta-analysis. *BMJ open sport & exercise medicine*, 5(1), e475. https://doi.org/10.1136/bmjsem-2018-000475.

Collins, E., Cox, A., Wilcock, C., & Sethu-Jones, G. (2019). Digital games and mindfulness apps: comparison of effects on post work recovery. *JMIR mental health*, 6(7), e12853. https://doi.org/10.2196/12853.

Crivello, A., Barsocchi, P., Girolami, M., & Palumbo, F. (2019). The meaning of sleep quality: a survey of available technologies. *IEEE Access*, 7, 167374–167390. https://doi.org/10.1109/ACCESS.2019.2953835.

Fietze, I. (2016). Sleep applications to assess sleep quality. *Sleep medicine clinics*, 11(4), 461468. https://doi.org/10.1016/j.jsmc.2016.08.008.

Fullagar, H. H. K., Skorski, S., Duffield, R., Hammes, D., Coutts, A. J., & Meyer, T. (2015). Sleep and athletic performance: the effects of sleep loss on exercise performance, and physiological and cognitive responses to exercise. *Sports medicine*, 45(2), 161–186. https://doi.org/10.1007/s40279-014-0260-0.

Gardner, F. L., & Moore, Z. E. (2004). A mindfulness-acceptance-commitment-based approach to athletic performance enhancement: theoretical considerations. *Behavior Therapy*, 35(4), 707–723. https://doi.org/10.1016/S0005-7894(04)80016-9.

Grandner, M. A. (2017). Sleep, health, and society. *Sleep medicine clinics*, 12(1), 1–22. https://doi.org/10.1016/j.jsmc.2016.10.012.

Halson, S. L. (2019). Sleep monitoring in athletes: motivation, methods, miscalculations and why it matters. *Sports medicine*, 49(10), 1487–1497. https://doi.org/10.1007/s40279-019-01119-4.

Huberty, J. L., Green, J., Puzia, M. E., Larkey, L., Laird, B., Vranceanu, A.-M., Vlisides-Henry, R., & Irwin, M. R. (2021). Testing a mindfulness meditation mobile app for the treatment of sleep-related symptoms in adults with sleep disturbance: a randomized controlled trial. *PloS One*, 16(1), e244717. https://doi.org/10.1371/journal.pone.0244717.

Hülsheger, U. R., Feinholdt, A., & Nübold, A. (2015). A low-dose mindfulness intervention and recovery from work: effects on psychological detachment, sleep quality, and sleep duration. *Journal of Occupational and Organizational Psychology*, 88(3), 464–489. https://doi.org/10.1111/joop.12115.

Ibáñez, V., Silva, J., & Cauli, O. (2018). A survey on sleep assessment methods. *PeerJ*, 6, e4849. https://doi.org/10.7717/peerj.4849.

Ibáñez, V., Silva, J., Navarro, E., & Cauli, O. (2019). Sleep assessment devices: Types, market analysis, and a critical view on accuracy and validation. *Expert Review of Medical Devices*, 16(12), 1041–1052. https://doi.org/10.1080/17434440.2019.1693890.

Jones, B. J., Kaur, S., Miller, M., & Spencer, R. M. C. (2020). Mindfulness-based stress reduction benefits psychological well-being, sleep quality, and athletic performance in female collegiate rowers. *Frontiers in Psychology*, 11, 572980. https://doi.org/10.3389/fpsyg.2020.572980.

Kaufman, K. A., Glass, C. R., & Arnkoff, D. B. (2009). Evaluation of mindful sport performance enhancement (MSPE): a new approach to promote flow in athletes. *Journal of Clinical Sport Psychology*, *3*(4), 334–356. https://doi.org/10.1123/jcsp.3.4.334.

Kellmann, M., Bertollo, M., Bosquet, L., Brink, M., Coutts, A. J., Duffield, R., Erlacher, D., Halson, S. L., Hecksteden, A., Heidari, J., Kallus, K. W., Meeusen, R., Mujika, I., Robazza, C., Skorski, S., Venter, R., & Beckmann, J. (2018). Recovery and performance in sport: consensus statement. *International journal of sports physiology and performance*, *13*(2), 240–245. https://doi.org/10.1123/ijspp.2017-0759.

Kitson, A., Prpa, M., & Riecke, B. E. (2018). Immersive interactive technologies for positive change: a scoping review and design considerations. *Frontiers in Psychology*, *9*, 1354. https://doi.org/10.3389/fpsyg.2018.01354.

Kölling, S., Duffield, R., Erlacher, D., Venter, R., & Halson, S. L. (2019). Sleep-related issues for recovery and performance in athletes. *International journal of sports physiology and performance*, *14*(2), 144–148. https://doi.org/10.1123/ijspp.2017-0746.

Lastella, M., Lovell, G. P., & Sargent, C. (2014). Athletes' precompetitive sleep behaviour and its relationship with subsequent precompetitive mood and performance. *European journal of sport science*, *14*(Suppl 1), 123–130. https://doi.org/10.1080/17461391.2012.660505.

Li, C., Kee, Y. H., & Lam, L. S. (2018). Effect of brief mindfulness induction on university athletes' sleep quality following night training. *Frontiers in psychology*, *9*, 508. https://doi.org/10.3389/fpsyg.2018.00508.

Mrazek, A. J., Mrazek, M. D., Cherolini, C. M., Cloughesy, J. N., Cynman, D. J., Gougis, L. J., Landry, A. P., Reese, J. V., & Schooler, J. W. (2019). The future of mindfulness training is digital, and the future is now. *Current Opinion in Psychology*, *28*, 81–86. https://doi.org/10.1016/j.copsyc.2018.11.012.

Navarro-Haro, M. V., López-Del-Hoyo, Y., Campos, D., Linehan, M. M., Hoffman, H. G., García-Palacios, A., Modrego-Alarcón, M., Borao, L., & García-Campayo, J. (2017). Meditation experts try virtual reality mindfulness: a pilot study evaluation of the feasibility and acceptability of virtual reality to facilitate mindfulness practice in people attending a mindfulness conference. *PloS one*, *12*(11), e187777. https://doi.org/10.1371/journal.pone.0187777.

Nedelec, M., Aloulou, A., Duforez, F., Meyer, T., & Dupont, G. (2018). The variability of sleep among elite athletes. *Sports medicine—open*, *4*(1), 34. https://doi.org/10.1186/s40798-018-0151-2.

Rusch, H. L., Rosario, M., Levison, L. M., Olivera, A., Livingston, W. S., Wu, T., & Gill, J. M. (2019). The effect of mindfulness meditation on sleep quality: A systematic review and meta-analysis of randomized controlled trials. *Annals of the New York Academy of Sciences*, *1445*(1), 5–16. https://doi.org/10.1111/nyas.13996.

Seabrook, E., Kelly, R., Foley, F., Theiler, S., Thomas, N., Wadley, G., & Nedeljkovic, M. (2020). Understanding how virtual reality can support mindfulness practice: mixed methods study. *Journal of medical Internet research*, *22*(3), e16106. https://doi.org/10.2196/16106.

Seshadri, D. R., Drummond, C., Craker, J., Rowbottom, J. R., & Voos, J. E. (2017). Wearable devices for sports: new integrated technologies allow coaches, physicians, and trainers to better understand the physical demands of athletes in real time. *IEEE Pulse*, *8*(1), 38–43. https://doi.org/10.1109/MPUL.2016.2627240.

Shin, J. C., Kim, J., & Grigsby-Toussaint, D. (2017). Mobile phone interventions for sleep disorders and sleep quality: systematic review. *JMIR MHealth and UHealth*, *5*(9), e131. https://doi.org/10.2196/mhealth.7244.

Vlahoyiannis, A., Sakkas, G. K., Manconi, M., Aphamis, G., & Giannaki, C. D. (2020). A critical review on sleep assessment methodologies in athletic populations: factors to be considered. *Sleep medicine*, *74*, 211–223. https://doi.org/10.1016/j.sleep.2020.07.029.

Walsh, N. P., Halson, S. L., Sargent, C., Roach, G. D., Nédélec, M., Gupta, L., Leeder, J., Fullagar, H. H., Coutts, A. J., Edwards, B. J., Pullinger, S. A., Robertson, C. M., Burniston, J. G., Lastella, M., Le Meur, Y., Hausswirth, C., Bender, A. M., Grandner, M. A., & Samuels, C. H. (2020). Sleep and the athlete: narrative review and 2021 expert consensus recommendations. *British journal of sports medicine*. https://doi.org/10.1136/bjsports-2020-102025.