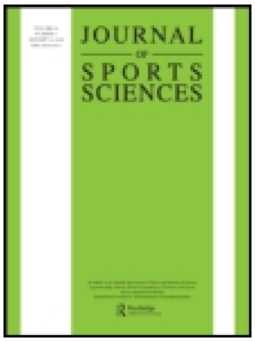

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Sand training: a review of current research and practical applications

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Abstract

Sand surfaces can offer a higher energy cost (EC) and lower impact training stimulus compared with firmer and more traditional team sport training venues such as grass. This review aims to summarise the existing research on sand training, with a specific focus on its application as a team sports training venue. Compared with grass, significant physiological and biomechanical differences are associated with sand exercise. However, evidence also exists to suggest that training adaptations unique to sand can positively influence firm-ground performance. Furthermore, the lower impact forces experienced on sand can limit muscle damage, muscle soreness, and decrements in performance capacity relative to exercise intensity. Therefore, using a sand training surface in team sports may allow greater training adaptations to be achieved, while reducing performance decrements and injuries that may arise from heavy training. Nevertheless, further research should investigate the effect of sand surfaces over a greater range of training types and performance outcomes, to increase the application of sand training for team sports.

Keywords: *team sports, energy cost, low impact, recovery*

Introduction

In highly competitive modern team sports such as soccer, rugby and hockey, there is an increasing demand for scientific research into practical and cost effective methods of athlete preparation. One such avenue that has been scarcely explored in team sports is the use of alternate training surfaces, such as sand. The widespread accessibility of various natural (beach) and artificial (indoor and outdoor) sand surfaces makes sand training a viable option for coaches and sport science practitioners working with team sports.

Compared with firmer and more traditional team sport training surfaces, such as grass, there are distinct physiological and biomechanical differences associated with sand exercise (Lejeune, Willems, & Heglund, 1998; Pinnington & Dawson, 2001a, 2001b; Pinnington, Lloyd, Besier, & Dawson, 2005; Zamparo, Perini, Orizio, Sacher, & Ferretti, 1992). These include significant alterations in kinematics and muscle activation patterns when running on sand (Pinnington et al., 2005), contributing to significantly greater energy expenditures than at similar running speeds on grass (Lejeune et al., 1998; Pinnington & Dawson, 2001a; Pinnington et al., 2005; Zamparo et al., 1992). Furthermore, the high shock absorptive qualities of sand can decrease the impact forces experienced during high intensity activity, potentially leading to reduced muscle damage and soreness, in addition to lesser decrements in performance capacity (Impellizzeri et al., 2008; Miyama & Nosaka, 2004). With these differences in mind, there is also recent evidence to support the use of sand in an applied sport setting (Binnie, Dawson, Pinnington, Landers, & Peeling, 2013a, 2013b). These studies showed that for a given training session, the use of sand versus firm training ground surfaces can allow for a greater relative training intensity, without causing any additional detriment to next day (24 h post exercise) athletic performance. Therefore, sand has the potential to not only offer a unique training stimulus for team sport athletes, but this training surface might also be considered as a viable option for recovery and rehabilitation sessions.

Despite such suggestions, there is currently a lack of evidence investigating the long-term effects of

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training on sand, and the implications for firm ground performance gains. Additionally, team sports involve a combination of endurance, power, speed and skill, so potentially requiring an equally specific training stimulus to develop all of these elements. As such, a greater understanding of sand training is necessary to fully gauge the extent of its application to team sports. Therefore, the aim of this review was to examine the existing research on sand training, with a specific focus on its potential use as an alternate training venue for team sport athletes.

Energy cost (EC) of sand running

Investigations into the physiology of locomotion on sand surfaces date back almost half a century, with early studies focusing on this terrain in military situations (Soule & Goldman, 1972; Strydom et al., 1966). The effect of marching at 5 km · h^{-1} on either soft desert sand or a firm dirt-road in full military kit (23 kg) for a 1 h period was investigated by Strydom et al. (1966). Marching on soft sand led to significant increases in heart rate (HR; >22 bpm), oxygen uptake (VO$_2$; >0.872 L · min^{-1}), and rectal temperature (T_{re}; >0.5°C) when compared with firm ground, clearly demonstrating that there is a higher level of physiological strain experienced during exercise on sand versus firm surfaces. However, only recently has there been more sophisticated research exploring the specific mechanisms that may produce this higher exertion level on sand. These studies have quantified the EC contributions (aerobic and anaerobic) during short bouts of steady-state exercise on sand (i.e. 10 min) (Lejeune et al., 1998; Pinnington & Dawson, 2001a, 2001b; Pinnington et al., 2005; Zamparo et al., 1992), with results generally showing significantly greater net aerobic EC (~ >1.5 times), anaerobic EC (~ >2.5 times), and total EC (~ >1.2 to 1.5 times) are incurred when running at similar speeds on sand compared with grass (Lejeune et al., 1998; Pinnington & Dawson, 2001a; Zamparo et al., 1992). Importantly, a large anaerobic contribution to the workload is demonstrated on sand, which is associated with a significantly greater (2–3 times) blood lactate (BLa) accumulation (Pinnington & Dawson, 2001a, 2001b). A higher lactate training stimulus experienced on sand may underpin an ability to improve anaerobic performance to a greater degree than firm ground training, since the accumulation of H+ during exercise is suggested as an important stimulus for improving muscle buffer capacity (Edge, Bishop, & Goodman, 2006).

The higher EC of locomotion on sand has been attributed to many factors, including reduced recovery of elastic energy (Zamparo et al., 1992), decreases in muscle-tendon efficiency and increases in work lost to the environment (Lejeune et al., 1998). However, Pinnington et al. (2005), who explored the kinematics and muscle activation patterns associated with soft sand running have provided the most conclusive evidence to date, by identifying a significantly greater contribution of the lower leg muscles to the exercise bout when compared with firm ground running. This was largely attributed to an increased need for stabilisation around the hip, knee and ankle joints during the stance phase of running. Therefore, running on sand likely involves the recruitment of additional musculature and neural patterns that are not required on firm surfaces (Pinnington & Dawson, 2001a). Furthermore, it is possible that the entrainment of these recruitment strategies can explain why a reduced EC differential exists between sand and firm surfaces in habituated (i.e. surf iron men) versus non-habituated sand runners (Pinnington & Dawson, 2001b).

Despite the unanimous findings of a significantly greater EC on sand versus firm surfaces, the magnitude of the EC difference will potentially vary based on the sand characteristics. It has been suggested that surface characteristics, such as granulation, moisture content and/or the depth and consistency of the substratum on sand can all contribute to the degree of stiffness recorded, and affect the resulting EC (Pinnington & Dawson, 2001a). Specifically, softer and drier sand may be associated with higher EC values during exercise, since there is a greater degree of energy absorbed by the training surface. Therefore, variations in the type of sand used, and the environmental conditions of the sand training location can have a significant influence on the subsequent training stimulus gained. For example, at the same measured running speeds (8–11 km · h^{-1}) Zamparo et al. (1992) reported a total EC difference of ~1.2 times greater on sand versus grass, less than the ~1.5 times reported by Pinnington and Dawson (2001a). Here, it is possible that the EC differences reported between these investigations may have been a result of the sand characteristics, with Zamparo et al. (1992) likely having encountered somewhat firmer sand in Northern Italy compared with the soft sand of Western Australia experienced by Pinnington and Dawson (2001a).

To account for these variations in surface conditions, recent studies have used a Clegg impact soil tester (Dr Baden Clegg Pty Ltd, WA, AUS) to quantify the degree of surface stiffness (peak impact deceleration forces) on both sand and grass training surfaces (Binnie et al., 2013a, 2013b; Pinnington & Dawson, 2001a, 2001b). The peak deceleration forces of soft, dry beach sand have been reported as 223.4 ± 44.1 N, compared with 898.7 ± 139.2 N on grass (Pinnington & Dawson, 2001a, 2001b).

Interestingly, the peak deceleration forces measured for wet beach sand (850.6 ± 2.4 N) (Pinnington & Dawson, 2001a) are very similar to grass values, highlighting variations that may also exist in different areas of sand on the beach (i.e. water's edge versus sand dunes). Regardless, it is evident that these measurements are essential for future research investigating exercise surface types, in order to accurately quantify the effects of surface variations on subsequent physiological responses.

Along with surface conditions, it is also apparent that the type of exercise performed on sand can also influence the resultant training stimulus. Specifically, there is a trend for EC values observed between sand and grass training surfaces to become more similar as running speed increases (Lejeune et al., 1998; Pinnington & Dawson, 2001a, 2001b; Pinnington et al., 2005). The EC difference between sand and grass surfaces have been reported as between 1.8 and 2.7 times for walking (3–7 km · h^{-1}), compared with 1.2–1.6 times when running (8–11 km · h^{-1}) (Lejeune et al., 1998; Pinnington & Dawson, 2001a, 2001b; Zamparo et al., 1992). A greater EC difference at slower movement speeds is likely associated with an increased stance time (*Ts*) on sand, leading to a relatively greater amount of active muscle mass required during the support phase. Pinnington et al. (2005) reported that running on sand versus grass resulted in a significantly greater *Ts* at 8 km · h^{-1}, but not at 11 km · h^{-1}. Currently, there is no evidence reporting the EC of running on sand at >11 km · h^{-1}, since this speed was found to be the maximum attainable steady-state speed on sand, even in habituated sand runners (Lejeune et al., 1998; Pinnington & Dawson, 2001b). Further research should therefore investigate the specific kinematics and energetics associated with running on sand at running speeds >11 km · h^{-1}, to better determine the effective range of running speeds at which sand training can provide additional performance benefits over firm ground training surfaces.

Following on from these steady-state running studies, recent research by Binnie et al. (2013a, 2013b) investigated the effect of sand surfaces in a more applied sport setting, consisting of variable running speeds over a longer training duration (60 min). Specifically, these studies compared the use of sand and grass surfaces during two common types of team sport conditioning sessions. For a standardised interval running session, the use of sand versus grass resulted in a significantly higher average heart rate (sand: 172 bpm; grass: 163 bpm) and blood lactate accumulation (sand: 10.1 mmol · L^{-1}, grass: 6.5 mmol · L^{-1}) over the duration of the training session (Binnie et al., 2013a). Similar results were also shown for a sport-specific conditioning session (sand: 162 bpm; grass: 156 bpm), consisting of high intensity sprint and agility drills, as well as small-sided game training (Binnie et al., 2013b). In both of these studies, the work intervals were matched for time and completed at a perceived maximal intensity, suggesting that higher training intensities can be achieved on sand versus grass surfaces for a given training session. Furthermore, although EC was not directly measured here, the heart rate and blood lactate differences between the two training surfaces were still significantly different, even at the higher running speeds reached (24 km · h^{-1}) during the various running drills.

Training adaptations

With these EC differences in mind, it is evident that sand training has the potential to offer a higher EC training stimulus compared with firmer and more traditional team sport training surfaces such as grass; and as such, using sand (versus grass) surfaces may allow for superior physiological adaptations to be gained over a given training period. Conversely, it could be argued that the significantly different physiological and biomechanical characteristics of exercising on sand might ultimately limit the training specificity needed for firm-ground performance. The high shock absorptive qualities of sand can also limit maximal movement speed in sprint training (Barrett, Neal, & Roberts, 1997) and jumping performance (Bishop, 2003; Castellano & Casamichana, 2010; Giatsis, Kollias, Panoutsakopoulos, & Papaiakovou, 2004). Ultimately, the long-term effect of sand training in an applied sport setting such as team sports is largely unknown. However, some evidence does suggest that training on sand can lead to improvements in firm ground athletic performance (Gortsila, Theos, Smirnioti, & Maridaki, 2011; Impellizzeri et al., 2008; Yiğit & Tuncel, 1998).

The first training study to use a sand surface was conducted by Yiğit and Tuncel (1998), in which 51 male students (15–21 years) completed a 6-week endurance running programme on either road or sand, in comparison to a control group who did no training at all. In both running groups, participants completed 3 × 30 min sessions per week at a fixed intensity of 75% of predicted HR reserve. Despite an intensity-matched training approach, there were still some significant differences observed between groups. Specifically, a significant increase in calf circumference over the training period occurred in the sand group only ($P < 0.05$), which may be indicative of a greater overload stimulus in that particular muscle group associated with sand running. In support, Pinnington et al. (2005) identified a significantly greater peak activation of the gastrocnemii when running on sand versus grass, primarily during the propulsive phase of running, where there is plantar flexion of the foot into a shifting (sand) surface. In addition to these apparent muscular adaptations, Yiğit and Tuncel (1998) also observed a significant improvement in predicted VO_{2max} (via a 12-min Cooper run/walk test) over the 6-weeks, again only in the sand running group. Since the training was matched for intensity between running groups, the superior improvement in VO_{2max} in the sand running group was attributed to superior adaptations in muscular size and strength. However, these findings are limited by the simplicity of the measures taken, and a more comprehensive analysis of the muscular adaptations and aerobic changes for sand versus grass training surfaces is still required.

Subsequently, research by Gortsila et al. (2011) and Impellizzeri et al. (2008) investigated the effect of sand versus grass training surfaces on performance based-outcomes in more applied sport settings. Impellizzeri et al. (2008) had 37 amateur soccer players complete three sessions of plyometric training per week for 4-weeks, either on an artificial sand surface or a grass field. Both sand and grass training interventions resulted in similar improvements in firm-ground 10 and 20 m sprint performance. However, differences in the relative jumping improvements were observed between the two groups; such that the grass training resulted in significantly greater improvements in counter-movement jump (CMJ) performance (>5.5 cm) compared with the sand group (>2.4 cm). Conversely however, there was also a trend for a greater improvement in squat jump (SJ) performance in the sand training group (>3.4 cm versus >1.8 cm; $P = 0.08$). Overall, these findings suggest that there are different training-induced effects of plyometric training on sand versus grass surfaces. Specifically, the SJ is thought to be a greater measure of pure concentric strength, due to the absence of pre-stretch actions (McGuigan et al., 2006). Therefore, this may indicate that during plyometric training on sand, there is a greater reliance on concentric muscle action, perhaps to compensate for the degradation of elastic energy during exercise (Giatsis et al., 2004; Impellizzeri et al., 2008). In support of this, the lower CMJ heights on sand have been attributed to a lower reuse of elastic energy and foot slippage (Giatsis et al., 2004; Lejeune et al., 1998; Miyama & Nosaka, 2004). Conversely, as CMJ performance is potentiated by the stretch reflex, and involves the stretch shortening cycle (SSC) (Impellizzeri et al., 2008; Kubo, Kawakami, & Fukunaga, 1999), a greater improvement in CMJ following grass training may indicate that sand surfaces are less effective for inducing the neuromuscular adaptations needed for improvement in activities requiring the SSC. The lower stiffness ratings on sand can likely reduce the mechanical load placed on the musculoskeletal system during exercise, thereby limiting the resultant training effects on the efficiency of the muscle–tendon complex (Impellizzeri et al., 2008). However, there was no difference observed between the training groups for sprint improvements, yet sprinting involves a faster (and repeated) SSC action when compared with jumping (Schmidtbleicher, 1992). These findings suggest that sand may only compromise the neuromuscular training stimulus during slower (and one-off) SSC exercises such as jumping, since there is a more prolonged pre-stretch action involved. This may be due to a greater difference in foot contact time between sand and grass surfaces during jumping versus sprinting, resulting in the degradation of more elastic energy. Overall, these factors must be taken into consideration when designing a training programme on sand, since there may be different training-induced effects relating to the efficiency of the SSC (Impellizzeri et al., 2008).

In addition to the findings of Impellizzeri et al. (2008), Gortsila et al. (2011) also demonstrated a transfer of training effects between sand and grass surfaces. Here, 10 weeks of agility training (three times per week) on a sand surface resulted in significant improvements in agility tests (*T*-Test and Illinois test) conducted on both sand and firm surfaces, suggesting that the physiological and biomechanical adaptations unique to sand training can also have a positive effect on firm-ground agility performance. In contrast, surface-specificity appears necessary in order to entrain the specific muscle recruitment strategies required during exercise on sand (Pinnington & Dawson, 2001b), and to date, no research has shown an improved performance on sand following firm-ground training alone. Therefore, there may be a one-way transfer of training effects between sand and grass surfaces. This has important implications for sand-based sports such as beach volleyball or beach soccer, and may also further the value of sand as an alternate training venue for firm ground sports.

With consideration of the training studies to date, there is still a need for further research to determine the full range of benefits associated with sand training in team sport. Specifically, the primary characteristic associated with exercise on a sand surface is higher EC of movement (Lejeune et al., 1998; Pinnington & Dawson, 2001a; Pinnington et al., 2005; Zamparo et al., 1992), and the ability to attain higher training intensities over a given training session when compared with firm-ground training venues (Binnie et al., 2013a, 2013b). Therefore, further research is needed to investigate the implications of a higher EC training stimulus on firm ground performance gains, with a specific focus on aerobic and muscular adaptations. Furthermore, research should also be focused over a wide range of training types and performance outcomes to increase the scope of application of sand-based training in team sports. That said, consideration must also be given to the potential limitations associated with sand training in a team sport environment. Specifically, team sports will be unable to complete some components of skill-based training (i.e. passing, shooting, and so on) on a sand surface; therefore, it is necessary to determine the volume of sand training needed for a significant performance benefit, in comparison to the volume of time away from the primary training surface that team sport programs would practically consider. Furthermore, with sand training in different sport environments, space restrictions could ultimately limit the range of training activities possible (i.e. long distance endurance versus short distance jumps and sprints), and therefore the costs and benefits of these various training types must be accurately quantified.

Sand as a low impact training surface

In addition to the higher EC of exercise on sand, the other unique feature associated with sand training is the lower impact nature of the surface. Specifically, the higher absorptive qualities of sand can reduce the peak deceleration forces encountered upon impact with the training surface (Barrett et al., 1997). Consequently, sand training can potentially decrease the rate and extent of musculoskeletal loading experienced during exercise (Barrett et al., 1997; Impellizzeri et al., 2008; Miyama & Nosaka, 2004). This may be particularly pertinent during high intensity exercise such as sprinting, jumping and agility movements, since large demands are placed on the leg muscles, tendons and the muscle-tendon units (Impellizzeri et al., 2008).

Miyama and Nosaka (2004) compared the recovery response following 100 consecutive drop jumps on a sand versus firm (wood) surface. The results showed a significantly smaller decrease in the maximal isometric force of the knee extensors, and a smaller increase in muscle damage (Creatine Kinase concentration) from pre-exercise values in the sand versus the firm ground groups ($P < 0.05$). Further, these values remained significantly different to pre-exercise values at 96 h post-exercise in the firm group only, indicating a faster post-exercise recovery following the sand trial. There were also significantly lower ratings of lower-limb muscle soreness in the sand group. These results suggest that the lower impact forces experienced on sand can limit exercise-induced muscle damage, soreness and associated negative side effects, such as a reduced next-day performance-capacity. There is also evidence to suggest that these recovery benefits can be sustained over a prolonged training period, with significantly lower muscle soreness ratings observed over a 4-week plyometric training programme on sand versus grass training surfaces ($P < 0.001$) (Impellizzeri et al., 2008).

While the recovery benefits of lower levels of muscle damage and soreness are clear, it has also been suggested that exercise-induced muscle damage (EIMD) and the inflammatory response to exercise may be an important stimulus for the muscular repair and adaptation process (Barnett, 2006; Howatson, Goodall, & Van Someren, 2009; Howatson & Van Someren, 2008). Therefore, it is possible that the lower levels of EIMD experienced following exercise on sand compared with firm surfaces could hinder the resultant muscular adaptations. With this in mind, it is important to consider that in both of the aforementioned studies showing reduced muscle damage and soreness on sand (Impellizzeri et al., 2008; Miyama & Nosaka, 2004) there were a set number of contacts (i.e. sets and repetitions) prescribed for each task on the two training surfaces. Therefore, for a given number of contacts, the cumulative loading force and stress placed on the musculoskeletal system is significantly lower on sand, resulting in lower levels of muscle damage and soreness. However, in an applied sport setting, involving unpredictable and dynamic movement patterns, the exact number of contacts with the training surface is more variable.

That established, research by Binnie et al. (2013a, 2013b) observed similar levels of muscle damage (Myoglobin concentration), soreness, and next-day (24 h post-exercise) athletic performance recovery following standardised team sport conditioning sessions completed on both sand and grass surfaces. Here, it is possible that there was a higher frequency of ground contacts during the training sessions completed on sand, despite the workload intervals between surfaces being matched for time. In support of this, it has been shown that running on sand can result in a significantly reduced stride length and an increase in cadence when compared with running at similar speeds on grass (Pinnington et al., 2005). Furthermore, it is possible that the higher relative training intensities achieved on sand during these training sessions (Binnie et al., 2013a, 2013b) may have also influenced the physiological response to exercise, with the degree of muscle damage incurred shown to increase with exercise intensity (Brancaccio, Lippi, & Maffulli, 2010). Overall, it is likely that a combination of a higher relative training intensity, and frequency of ground contacts during exercise on sand, may ultimately counteract the low-impact benefits associated with the training surface.

Alternatively, it could be argued that in an applied team sport setting, a sand training surface can allow for higher training loads to be achieved without any additional detriments to muscle damage, soreness or performance recovery. That said, the effect of a lower impact-training stimulus on resultant muscular adaptations is largely unknown and must therefore be examined further in future research investigations.

In addition to EIMD and soreness, the aforementioned studies (Binnie et al., 2013a, 2013b) also showed similar levels of haemolysis (Serum Haptoglobin concentration) between sand and grass training surfaces following exercise. Exercise-induced haemolysis is the destruction of red blood cells (RBC), which is characterised by increased free haemoglobin and a decrease in haptoglobin levels in the blood, providing an alternative method of measuring the degree of stress placed on the musculoskeletal system during exercise (Helge et al., 2003; Miller, Pate, & Burgess, 1988; Peeling et al., 2009; Telford et al., 2003). Heel-strike is a major cause of haemolysis during running (Miller et al., 1988; Telford et al., 2003), and training variables such as surface type may influence the amount of haemolysis experienced. Therefore, training on sand could potentially lead to lower levels of haemolysis incurred during exercise, due to the decreased impact forces experienced at heel strike (Miller et al., 1988). Alternatively, haemolysis can increase with a higher frequency of ground contacts, and has also been shown to increase with exercise intensity (Peeling et al., 2009), possibly because of the compression of capillary networks by a greater active muscle mass (Miller et al., 1988), or from an increased level of tissue hypoxia leading to oxidative stress within the RBC (Peeling et al., 2009). With this in mind, future research should also consider the haemolytic response to exercise on sand, since it may provide a greater understanding of the physiological response to a lower impact-training stimulus.

Sand training and injury

Consideration should also be given to the effects of sand surfaces on injury prevalence. Previous research is equivocal, with reports that exercise on sand can either increase (Knobloch, Yoon, & Vogt, 2008; Pen, Barrett, Neal, & Steel, 1996; Richie, DeVries, & Endo, 1993) or decrease injury incidence (Impellizzeri et al., 2008; Pinnington, 2005) compared with firm surfaces. The unstable and shifting nature of a soft, dry sand surface is generally thought to increase the risk of musculoskeletal injury in the lower extremity (Barrett et al., 1997). Specifically, a greater range of motion of the ankle joint when running on sand has been linked to exercise-induced medial shin pain, through an increased eccentric muscle activity in the posterior and medial compartments of the lower leg (Richie et al., 1993). Furthermore, in a retrospective survey of elite 'iron men', beach running was perceived to be the most injurious of the race components in terms of the frequency and severity of knee, shin and calf injuries (Pen et al., 1996). In a similar survey conducted by Knobloch et al. (2008), sand running was associated with an increased rate of mid-portion Achilles tendinopathy among elite running athletes, when compared with asphalt.

In contrast, firmer training surfaces are associated with a higher incidence of impact-related (Ekstrand, Timpka, & Hagglund, 2006; Francis, Leigh, & Berzins, 1988), and overuse injuries (Inklaar, 1994; Nigg & Segesser, 1988). Therefore, it could be argued that the lower impact forces experienced on sand could ultimately decrease the risk of injury, and the overall physical strain to a given training session (Almeida, Williams, Shaffer, & Brodine, 1999). More specifically, a sand training surface could be preferred to a firmer surface such as grass during a team sport pre-season period (especially early in this training-phase), since there is a high incidence of overuse injuries during this time (Impellizzeri et al., 2008; Woods, Hawkins, Hulse, & Hodson, 2002). Furthermore, a sand training surface also may be useful for athletes returning from injury, allowing for the improvement of aerobic fitness with a concurrent lower risk of muscle damage and injury (Impellizzeri et al., 2008).

Despite such suggestions, there is a lack of direct causal evidence linking sand surfaces with either an increased or decreased incidence of injury when compared with firmer training surfaces. In the aforementioned training study by Yiğit and Tuncel (1998), 60 participants were initially recruited and split equally (n = 20) into the three training groups (road, sand and control). However, only 51 participants completed the study, with the road running group losing six participants compared with only one in the sand group, and two in the control group. Similarly, in the 4-week plyometric training study by Impellizzeri et al. (2008), there were three dropouts in the sand group compared with four in the grass group. However, there was no reasoning provided for the dropout rates in either of these studies (Impellizzeri et al., 2008; Yiğit & Tuncel, 1998). Therefore, it should be a priority for future research to quantify the incidence and severity of injuries associated with sand versus firm-ground training in order to better understand the implications of using a sand surface in an applied team sport setting.

As an alternate use, soft sand may also serve as an effective rehabilitation surface, since muscle activation strategies to provide stability are emphasised

(Barrett et al., 1997; Pinnington & Dawson, 2001b; Pinnington, 2005). As a result, habitual sand training may act in a similar way to unstable surface training (Cressey, West, Tiberio, Kraemer, & Maresh, 2007), which relies on the simultaneous entrainment of both stability and mobility to reduce lower-limb injury risk and enhance athletic performance through improvements in balance, kinesthetic sense, and proprioception (Brooks & Brooks, 2002; Cressey et al., 2007; Osborne, Chou, Laskowski, Smith, & Kaufman, 2001; Ruiz & Richardson, 2005). Therefore, future research should investigate the use of sand surfaces via these mechanisms, which may identify sand training as an important method of preventing and treating a range of sporting injuries.

Conclusion

A sand training surface can offer a higher EC, and lower impact-training stimulus when compared with firmer and more traditional team sport training venues such as grass. However, consideration must be given to the type of training performed, and the conditions of the sand surface used, since this can significantly alter the resultant training stimulus experienced. Currently, the evidence suggests that the physiological and biomechanical adaptations unique to sand training can positively affect firm-ground performance. Furthermore, the lower impact forces experienced on sand may limit muscle damage, muscle soreness, and the decrements in performance capacity relative to exercise intensity. As a result, using a sand surface for training in team sports may allow greater adaptations to be achieved over a given training period, while reducing the performance limiting effects that may arise from a heavy training load. Despite such suggestions, further research is required to investigate the effects of sand over a greater range of training types and performance outcomes, to increase the application of sand training in team sports.

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