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Understanding how the components of a synthetic turf system contribute to increased surface temperature

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Abstract

Surface temperatures of synthetic turf have become a factor of growing interest and concern, particularly in warmer regions like Australia. However, it is unclear which components of the synthetic turf system contribute to surface temperature. The aim of this paper was to compare the surface temperature of 34 different synthetic turf products that were exposed to the same environmental conditions to ascertain which components of the synthetic turf system and which environmental factors contributed to increased surface temperature. A total of 6,120 observations were taken on the 34 products over the summer months, giving 30 observations for each of the variables on each product. An analysis of covariance (ANCOVA) indicated that the type of infill and shockpad had small-medium, but significant, effects on surface temperature ($p<0.001$ and $p=0.003$, respectively), and the interaction between shockpad and tuft gauge was also significant ($p=0.047$). Level of solar radiation, ambient temperature and relative humidity ($p<0.001$ in all instances) were the only environmental variables that significantly influenced surface temperature. These findings confirm that both the composition of the synthetic turf system and environmental factors contribute to synthetic turf surface temperature, thus providing important information for synthetic turf manufacturers developing new cool climate products, or for local government authorities selecting products and/or informing safe play for end-users.

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Keywords:surface temperature; synthetic turf; heat; environmental variables.

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1. Introduction

Empirical evidence on the surface temperature difference between third generation (3G) synthetic turf and natural grass is limited, however, studies have demonstrated elevated surface temperatures on synthetic playing fields, particularly when exposed to direct sunlight (Aoki, 2005; Williams and Pulley 2003; Devitt et al. 2007; McNitt et al., 2008). Recent research has focused on identifying and understanding how environmental variables impact on the surface temperature of 3G synthetic turf, and it is evident that surface temperature is directly related to ambient temperature (Devitt et al., 2007) and solar radiation (Aoki, 2005; Devitt et al., 2007; McNitt et al., 2008), and inversely related to humidity (Williams and Pulley, 2003). It has also been speculated that the increased surface temperatures recorded on synthetic turf are associated with the crumb rubber infill contained within the synthetic turf system. Consequently manufacturers have started to utilise other infill products and/or developed fibres with cooler properties in an attempt to address the synthetic turf heat issue (Team Sports, 2013; Newturf Solutions, 2012). However, there is a lack of solid empirical evidence on which components of the synthetic turf system contribute to surface temperature, and furthermore how the various components are influenced by other environmental conditions.

To date, only one published peer-reviewed study conducted in the USA has considered differences in surface temperature across a range of synthetic turf components (Devitt et al., 2007). Surface temperatures of eight different components of a synthetic turf system including: black rubber beads; white rubber beads; synthetic grass with white and black rubber beads, respectively; synthetic grass with no rubber beads; black rubber matting; synthetic grass cuttings; and bare sandy loam soil were measured hourly over a 10-hour period (08:00 – 18:00). Measurements consisted of surface temperature using an infrared thermometer, relative humidity and ambient temperatures which were measured 60 cm above each component using a combination sensor, and solar radiation, measured with a pyranometer. Results indicated that the temperature-time curves of all components replicated a bell shaped curve, with surface temperature increasing quickly in the morning hours and decreasing in the early hours of the evening, with the maximum temperature recorded at noon for five of the eight components (Devitt et al., 2007).

Findings also indicated that the addition of white and black rubber beads increased the surface temperature (Devitt et al., 2007). Whilst the maximum surface temperature of the synthetic turf with black rubber beads was 5.3ºC hotter than with white rubber beads, this difference in surface temperature between rubber bead colours only reached significance at midday, where synthetic turf with black rubber was observed to be 9.1ºC hotter than synthetic turf with white rubber. While this study provided initial insight into the differences in surface temperature of some of the different components of a synthetic turf system, it did not statistically compare the contributions of the various components to overall surface temperature. Further, as the components of the synthetic turf system were separated, ecological validity is questionable. Installation of a synthetic turf sporting field is based on a complete system, and therefore, it is unlikely that the components would ever be used in isolation. Additionally, if measured as a complete system, some of the individual components of the system may interact and this may impact on the overall surface temperature.

A series of experiments that considered surface temperature and components of a synthetic turf system have also been conducted at Penn State’s Center for Sports Surface Research (Serensits, 2011). Different fibre colours (gold, white, silver, black and green), fibre types (FieldTurf Duraspine, FieldTurf Revolution and AstroTurf AstroFlect) and infill materials (various colours of crumb rubber, Ecofill and Thermo plastic elastomer [TPE]) were measured independently and 11 fibre-infill combinations were also considered. Testing was conducted indoors, using a 250-watt infrared heat lamp which was reported to have been correlated with sunny outdoor conditions. Despite some differences in fibre and infill temperatures, none of the fibre-infill combinations were significantly lower in temperature than a system which contained standard green fibres and black crumb rubber infill, thus indicating that the lower temperature of individual components may be negated when combined to replicate a complete system. Whilst this study extends the work of Devitt et al. (2007), whether an infrared heat lamp can truly replicate solar radiation is unknown, and other environmental measures known to affect surface temperature were not considered. Accordingly, there is a need for further investigations to determine the variability of surface temperatures across a range of different products that are constructed as a complete system, and explore how different products are influenced by natural weather conditions.

Consequently, this study aimed to compare the surface temperature of a range of different synthetic turf products that were exposed to the same environmental conditions and ascertain which components of the synthetic turf system and which environmental factors contribute to increased surface temperature.

2. Method

A synthetic turf test plot was established in an open area, exposed to environmental conditions in Victoria, Australia. Topsoil was removed and treated pine was used to separate the 34 plots (each 2.5 x 1m). Approximately 10cm of drainage gravel was installed and compacted within each plot and all products were installed by a turf company. Each of the 34 products was installed with a different complete system based on backing type (latex or polyurethane), tuft gauge (5/8 inch or 3/4 inch), stitch rate (14/10cm – 18.5/10cm), pile height (45mm, 50mm, or 60mm), infill material (sand/black crumb rubber, sand/organic infill, or sand/ TPE) and with or without a shockpad. Due to the study design, a quasi-experiment of convenience, the effects of each factor were unavoidably partially confounded, which limited the power of the study to isolate the contributions of each factor.

Surface temperature and environmental conditions were measured on each product during the 2013 summer months (February and March), on days where the ambient temperature was predicted to reach at least 25ºC. Surface temperature, ambient temperature (measured at 1 m from the surface) and relative humidity were measured using a multimeter (Extech HD500 model) which contained an infrared thermometer for measuring surface temperature and an integrated psychrometer for relative humidity. A Digitech anemometer (model QM1642) was used to determine wind speed and solar radiation was measured using a pyranometer (Apogee model MP-200) which captured from a field of view of 180 degrees. A depth gauge was used to determine infill depth on each of the different products.

Data collection was predominantly conducted by two research assistants, however the primary researchers also undertook some testing sessions. Research assistants received extensive training to ensure familiarity with the testing protocol and data collection instruments, and to ensure consistency in reading and accurately recording results. All data were recorded on hard copy data collection sheets and were subsequently double entered and cleaned in Microsoft Excel. Cleaned data were then exported to SPSS (Version 19) for statistical analysis.

Descriptive statistics were generated to provide an overview of the environmental conditions and surface temperatures experienced across the period of testing. To assess differences in surface temperature across all 34 test plots with appropriate adjustment for environmental variation, an analysis of covariance (ANCOVA) was conducted, followed by pairwise post hoc tests or separate regression analyses when appropriate. All environmental variables (ambient temperature, relative humidity, solar radiation and wind) and infill depth were entered as covariates and all other components of the synthetic turf system (type of shockpad, backing, tuft gauge, and infill material) were entered as factors. Pile height was removed from the analysis as it was fully confounded with shockpad type. Partial eta square values (partial η^2) were calculated to determine the amount of variance that could be accounted for by each factor and covariate. Effect size ranges were interpreted as: 0-0.009 = negligible; 0.010-0.089 = small; 0.090-0.249 = medium; and >0.250 = large (Cohen, 1988).

3. Results

A total of 6,120 observations were recorded over 13 days in February and March 2013, giving 30 observations on each of the environmental variables on all 34 products. Environmental conditions varied, however most data were collected during warm and sunny conditions (Table 1).

Table 1: Summary of environmental conditions across the testing period.

Environmental Variable	Mean ± Standard deviation	Minimum	Maximum
Ambient Temperature (ºC)	30.25 ± 3.11	24.30	37.60
Solar Radiation (watt/m^2)	698.10 ± 230.89	44.00	1198.00
Relative Humidity (%)	30.28 ±7.02	19.90	61.00
Wind (km/hr)	5.50 ± 3.69	0.00	22.50

Despite similar average ambient temperatures, average surface temperatures varied considerably between the 34 different products (Fig. 1). Plot numbers 33 and 34 which contained a sand/TPE infill and no shockpad produced the lowest average surface temperatures (43.4ºC and 42.7ºC), whilst plots 1 and 3 which contained a shockpad and sand/black crumb rubber infill produced the highest average values (55.7ºC and 54.8ºC, respectively). Notably, products with a latex backing and a TPE infill (plots 2, 6, 10, 14, 18, 22, 32, and 34) had consistently lower surface temperatures than the other combinations.

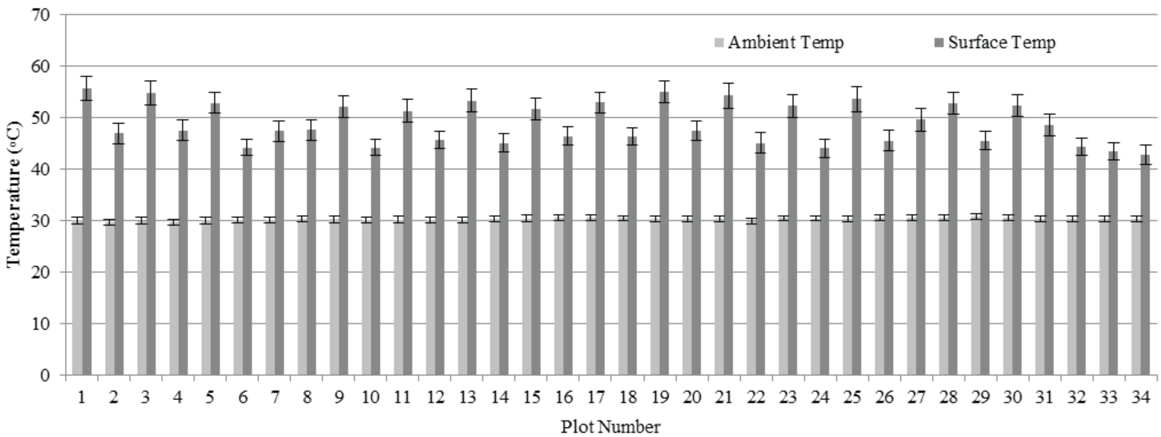

Fig. 1. Mean surface temperature for all 34 products. Error bars indicate standard error of the mean.

Overall, the ANCOVA showed that surface temperature of the 34 products was largely influenced by ambient temperature and solar radiation, with relative humidity having a medium effect (Table 2). Separate regression analyses indicated that increases in ambient temperature, solar radiation or humidity increased the surface temperature. Of the synthetic turf components, shockpad and infill had a significant, small-medium effect on surface temperature and there was also a significant interaction between shockpad and tuft gauge (Table 2). Post hoc pairwise comparisons showed that the mean surface temperature was significantly lower on the products which contained sand/TPE infill (Mean=45.6ºC) compared to a sand/organic infill (Mean=48.1ºC, $p=0.001$) or a sand/black crumb rubber infill (Mean=53.5ºC, $p<0.001$). In terms of shockpad, there was no significant difference in surface temperature between products which contained two types of shockpads ($p=0.986$). However, products with no shockpad were significantly cooler (Mean=48.5ºC) than products with a shockpad (Mean=50.3ºC, $p=0.001$). Analysis of the significant interaction between type of shockpad and tuft gauge indicated that for products with no shockpad, surface temperature increased with a smaller tuft gauge (Mean 49.0ºC and 48.3ºC for 5/8 and 3/4inch, respectively), although the opposite effect was observed for products with a shockpad, that is, surface temperature decreased with a smaller tuft gauge (Mean 50.9ºC and 49.7ºC for 5/8 and 3/4inch, respectively).

Table 2: The effect of environmental covariates and synthetic turf components on surface temperature.

Variable	F value	p value	Partial η^2	Effect size
Ambient temperature	957.98	<0.001*	0.490	Large
Solar radiation	798.39	<0.001*	0.445	Large
Relative humidity	120.27	<0.001*	0.108	Medium
Wind	2.788	0.095	0.003	Negligible
Shockpad	5.860	0.003*	0.012	Small
Shockpad x Backing	0.863	0.422	0.002	Negligible
Shockpad x Tuft gauge	3.951	0.047*	0.004	Negligible
Shockpad x Infill	0.425	0.735	0.001	Negligible
Backing	1.324	0.250	0.001	Negligible
Tuft Gauge	0.253	0.615	0.000	Negligible
Infill	54.544	<0.001*	0.180	Medium
Infill x Backing	2.148	0.117	0.004	Negligible
Infill x Tuft gauge	0.706	0.401	0.001	Negligible
Infill Depth	0.834	0.361	0.001	Negligible

* p values less than 0.05 were considered significant

4. Discussion

The acceptance of 3G synthetic turf for sporting fields worldwide has led to questions about potential effects on health and the environment, with elevated surface temperatures an area of concern (Aoki 2005). Whilst it has been speculated that the black rubber infill contributes to increased surface temperature, there was a lack of empirical evidence on which components of the synthetic turf system contribute to surface temperature, and how the various components are influenced by environmental conditions.

Results from this study have shown that surface temperature of synthetic turf plots, installed as a complete system, vary substantially when exposed to the same environmental conditions, thus indicating that appropriate selection of synthetic turf products is essential, particularly in hot dry environments which are commonly experienced during Australian summers. Consistent with previous studies (Aoki, 2005; Williams and Pulley, 2003; Devitt et al., 2007; McNitt et al., 2008), our findings also indicated that surface temperature was influenced by weather variables including ambient temperature, solar radiation and humidity. As expected, increases in solar radiation and/or ambient temperature were associated with increased surface temperatures, and these two covariates were found to have the largest impact on surface temperature. It was observed that the temperatures of all surfaces declined almost instantaneously during periods of cloud cover, and on some testing occasions when the solar radiation was very low, the surface temperatures were actually lower than the ambient temperature. Relative humidity also had a medium effect on surface temperature, but interestingly, surface temperature increased with increasing humidity which is in contrast to previous findings (Williams and Pulley 2003). Future studies should continue to measure relative humidity so that the contribution of this variable can be more definitively determined. Overall, the effects of solar radiation are critical, not only in future product development but also in the selection of synthetic turf products in regions of the world where high levels of solar radiation are regularly experienced.

In addition to the environmental variables, components of the synthetic turf system including the type of infill and the shockpad were also found to significantly impact on surface temperature. Products with a TPE infill were observed to have significantly lower surface temperatures than products with either an organic or SBR infill. This is an important finding for synthetic turf manufactures, particularly as organic infill has been introduced and marketed in Australia as a way to decrease surface temperature. Whilst the organic infill used in this study was considerably cooler than SBR, further studies should consider measuring different types of organic infill so that manufacturing companies can market products on an evidential basis.

The type of shockpad installed was also associated with surface temperature which indicates that this factor should be considered in future research. Further, as this study only utilised two types of shockpad, the influence of other shockpads commonly installed in synthetic turf sports playing fields should be determined. Shockpad type was also found to interact with tuft gauge. A possible explanation for the increased surface temperature on products with a shockpad and three-quarter inch tuft gauge may be that additional heat was being transferred from the shockpad back to the product through the increased space between the fibres. In contrast, with no shockpad an increased tuft gauge (¾ inch) may have allowed more heat to be dissipated through to the ground, resulting in a cooler surface temperature. However, as this is the first study to compare surface temperature of plots which contain complete synthetic turf systems, further studies in this area are required to fully understand this interaction.

5. Conclusion

This study provides important information for synthetic turf manufacturers developing new cool climate products and local government authorities that are selecting products and/or informing safe play for end-users. It confirms that both the composition of the synthetic turf system and environmental factors contribute to synthetic turf surface temperature. Further studies in this area are required however, particularly to explore whether these findings are consistent with other synthetic turf systems not considered in this study. Increased understanding within this area will inform future development within the turf industry which is required to address the surface temperature issues associated with synthetic turf.

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