The Effect of Running and Jumping on Playfield Playing Surfaces on Vertical Forces and on Safety

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INTRODUCTION

The influence of the playing surface on an athlete's safety needs to be understood. Artificial surfaces, new or old, should be characterized by their capacity to protect athletes from injuries by reducing stresses. Nigg (1984) stated that the frequency of pain during activities is related to the type of playing surface. Furthermore, Bramwell (1972) reported the role of playing surface in producing injuries.

Some researchers (Bramwell, 1972; Keene, Narechani and Clancy 1980; Nigg, 1985) concluded that injury rates on synthetic playing surfaces were higher than on natural grass. No definite comparative studies from an independent source were found to discuss the injury rates during activities played on synthetic playing surfaces. Bowers (1975) demonstrated that the higher injury rates which resulted from playing on a five year old synthetic sport surface were related to the diminished absorbing capacity of the playing surface through use. Manufacturers should realize that they have to produce surfaces which reduce injuries and help to improve athletes' performance.

During running, with each foot plant, the athlete is exposed to a vertical force of a magnitude of 2 to 3 times body weight (BW) (Bates et al., 1985; Cavanagh & Lafortune, 1980; Clark, 1982; Dickinson et al., 1985; Frederick et al., 1981; and Nigg, 1986). The magnitude of the vertical force during running depends on velocity, surface and style. Repeated loading of a large magnitude and for a long period of time may result in injury when the applied forces are not attenuated by the playing surface (Dickinson et al., 1985 and Frederick, et al., 1981).

More attention should be devoted to the contribution of playing surfaces to the risk of injuries during physical activities. The high landing forces which follow jumping for height may cause injuries. Researchers at the Nike Research Center (1982) identified landing forces of 4 times BW and 8 BW upon landing from 1.5 ft (45 cm) and 3 ft (90 cm) respectively. Landing on a hard surface may result in a higher acceleration which could lead to a higher risk of injuries (Bates et al. 1985 & Bowers, 1976).

"Safety" of the playing surfaces can be determined by measuring the impact forces and acceleration. Thus, safety is the inverse of the impact force and acceleration. The lower the impact force and acceleration the safer the playing surface during running and jumping.

The purpose of this study was to examine the effects of running and jumping on various synthetic playing surfaces, manufactured by Playfield Recreational and Commercial Surfaces, on vertical forces and safety during running and jumping. Thirteen independent and six dependent variables were examined to investigate the effect of playing surfaces on safety during running and jumping respectively (see Figure 1 & 2).

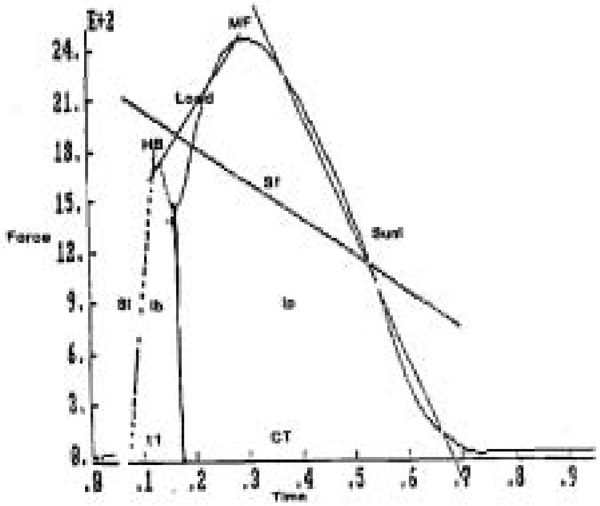

Figure 1: Tested Variables. MF-Maximum Force, CT-Contact Time, IP-Propulsive Impulse, Sf-Rate of Loading on the Foot, Sunl-Rate of Relieving Weight at Take-off, Ib-Braking Impulse, HS-Heel Strike, tl-Time to Heel Strike Force, SI-Rate of Loading at Heel Strike, Load-Rate of carrying weight

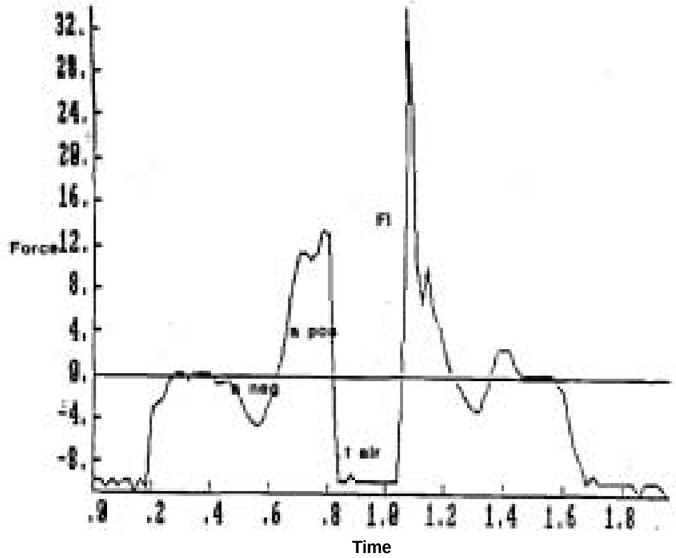

Figure 2: Jumping tgested variables, t air-time in the air, a neg - negative acceleration, a pos -positive acceleration, Fl - landing force.

METHODS

Five healthy male students at Washington State University were volunteers for this study. Their mean (standard deviation) age, weight and height during the activities on new playing surfaces were 25.2 years (5.586), 803 Newtons (76.036) and 181 cm (6.427). However, the means (SD) of their weight during running and jumping on used playing surfaces (after three months) was 808 Newtons (84.79).

The force platform used in this study was 61X91 cm, a modified version of Cooper's design and constructed to measure the three orthogonal components of ground reaction force through the deflection of strain gauges bonded in parallel on cantilevered armatures. In this study, only the vertical portion of the ground reaction force was recorded. The force platform was fitted into a wooden runway built so that the approach for running and jumping were similar to that of competitive situations. The force platform was connected to charge amplifiers and interfaced into a laboratory Tender Analog-to-Digital converter (Scientific Solution, Inc. #020028) and to an IBM portable microcomputer. Two break switch mats were placed 8 meters apart on both sides of the force platform and were connected by a chromoscope switch (Dekan Timer) to control the velocity of running. The instrumentation arrangement used in this study is illustrated in Figure 3. The sampling frequency for recording the running and jumping trials was 100 Hz.

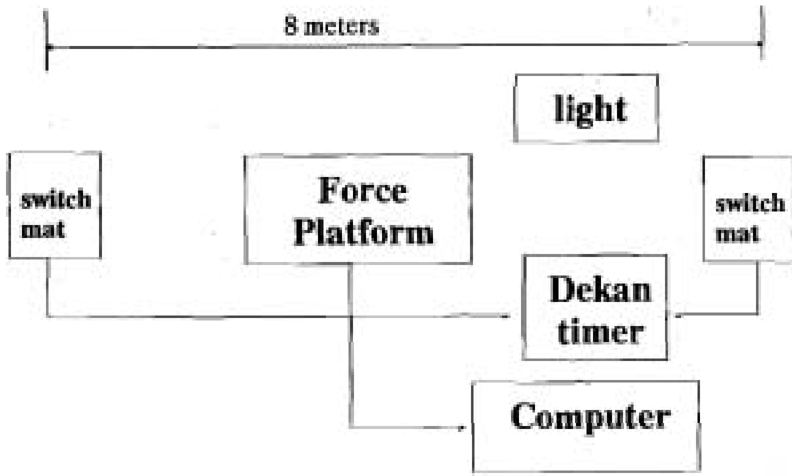

Figure 3: Apparatus arrangement

Six synthetic playing surfaces were tested. All surfaces were provided by Playfield Recreational & Commercial Surfaces. Some of the physical characteristics of these surfaces are shown in Table 1.

TABLE 1:

The Physical Characteristics of the Tested Playing Surfaces

Surface	Yarn	Construction	Thickness	Pitch
Athletic TURF	7600 Denier	Tufted 5/32 gauge	0.437	127.8
PROS's CHOICE	7600 Denier	Tufted 5/32 gauge	0.437	172.8
Titan TURF	11400 Denier	Tufted 3/26 gauge	0.375	144.0
GUARDIAN	5700 Denier	Tufted 3/26 Gauge	0.250	172.8
DORAL	5700 Denier	Tufted 3/26 gauge	0.250	172.8

Four experiments were conducted (two running and two jumping) to test the new and used playing surfaces on the running and jumping test variables. In all experiments, the researcher utilized the same subjects, same surfaces and the same apparatus arrangement. In the first two experiments, the new playing surfaces were tested. The playing surfaces were then subjected to three months of heavy use in business facilities in Pullman and Washington State University's coliseum. The second two experiments, conducted three months later, examined the effect of using these surfaces on safety. During data collection, each subject was instructed to run and jump three times on each playing surface. Therefore, each subject has a total of 72 running and jumping trials on new and used playing surfaces.

Subjects were instructed to start running at a velocity which ranged from 3.5 to 4 m/s from a line which was 6.3 meters from the force platform. The experimenter observed all subjects during running in order to avoid the abnormal footfalls and stride alteration in striking the middle of the force platform. In executing a squat jump, the subjects started from a line 30 cm from force platform. Each took one step forward toward the middle of the force platform and bent knees prior to the jump. During each jumping trial the subject was asked to put his hands on his waist, to take-off and land in the same position, and to minimize flexion and extension of the trunk.

Prior to each trial set, a playing surface was randomly laid out on the force platform surface. Hyperplot software (interactive Microware, Inc.) was used to smooth and to extract the dependent variable measures tested in this study. A Two-Way ANOVA with repeated measures was used in the data analysis and protected Least Significant Difference (LSD) was used to make paired comparisons of the variables of the playing surfaces. Related t-tests were used to examine the effect of using these playing surfaces on the tested variables and safety.

RESULTS

The effect of running and jumping on different surfaces on the means of the tested dependent variables (see Figure 1 & 2) were depicted in Tables 2 and 3.

TABLE 2

Running Variables Means: New and Used Playing Surfaces
SURFACES

Variables		AT	PC	T	G	D	V
MF	New	2120	2227	2244	2178	2175	2251
	Used	2153	2173	2268	2231	2218	2149
MF/WT	New	2.649	2.792	2.808	2.724	2.712	2.922
	Used	2.668	2.762	2.823	2.699	2.769	2.679
F	New	1287	1335	1363	1238	1326	1335
	Used	1303	1301	1327	1316	1319	1290
*CT	New	0.638	0.636	0.630	0.646	0.625	0.634
	Used	0.642	0.654	0.649	0.656	0.647	0.664
*I	New	822	850	860	843	829	849
	Used	837	855	865	864	865	857
S1	New	27403	25574	24635	26048	26814	27149
	Used	28136	23633	26787	25427	26660	27242
Sun	New	6667	6320	7267	6771	7062	7294
	Used	6632	6778	7132	7057	6671	6615
Sf	New	1734	2540	1755	1729	1635	1282
	Used	1918	1612	1793	1743	1621	1263
HS	New	1610	1512	1606	1522	1538	1501
	Used	1572	1510	1675	1446	1504	1538
t1	New	0.070	0.069	0.069	0.066	0.070	0.066
	Used	0.067	0.071	0.070	0.067	0.069	0.069
Ib	New	109	100	100	102	100	99
	Used	103	108	107	96	100	99
•Ip	New	703	728	738	728	712	749
	Used	720	736	750	762	745	737
L	New	5001	5682	5204	5673	5734	5755
	Used	4857	5558	5961	5769	5727	4789

Note: AT = Athletic Turf 1; PC = Pro's Choice; T = Titan Turf; G = Guardian; D = Doral; V = Varsity; MF = Maximum Force; Wt = Body Weight; F = Average Force; CT = Contact Time (Second); I = Impulse; S1 = Rate of Loading at Heel Strike; Sun = Rate of Relieving Weight at Take-off; Sf = Rate of Loading on the foot; HS = Heel Strike Force; t1 = Time to Heel Strike Force; Ib = Braking Impulse; Ip = Propulsive Impulse; L = rate of carrying Weight.* Significant t-test at *0.05.*

TABLE 3

Mean Variables During Jumping on New and Used Surfaces.
SURFACES

Variables		AT	PC	T	G	D	V
Fl	New	2875	2953	3147	2872	3031	2898
	Used	2894	2806	2865	2901	2651	2858
*Fl/Wt	New	3.635	3.692	3.945	3.614	3.797	3.614
	Used	3.519	3.502	3.551	3.505	3.240	3.455
*aneg	New	3.855	4.140	3.191	3.787	4.468	3.653
	Used	3.990	4.087	3.929	3.871	4.036	3.921
*apos	New	11.913	13.236	14.687	13.193	13.076	13.288
	Used	13.839	14.265	14.558	14.318	13.423	13.680
aneg/apos	New	0.295	0.325	0.303	0.371	0.337	0.345
	Used	0.292	0.287	0.295	0.277	0.336	0.291
tair	New	0.183	0.187	0.188	0.185	0.190	0.187
	Used	0.181	0.183	0.181	0.181	0.177	0.184

Note: AT = Athletic Turf 1; PC = Pro's Choice; T = Titan Turf; G = Guardian; D = Doral; V = Varsity; Fl = Landing Force (Newtons); Wt = body weight; **aneg** = Negtive acceleration (gravity); apos = Positive Acceleration (gravity); tair = Time in the Air (Second).* Significant t-test at *0.05.*

Due to the large number of variables verified in the study, the findings were stated and discussed under the following subheadings: (a) maximum, normalized forces in the running, and landing forces of jumping; (b) contact time; (c) rate of loading and unloading; (d) heel strike force; (e) propulsive impulse; (f) negative acceleration; and (g) positive acceleration.

Maximum and Normalized Forces

The new playing surfaces showed significant differences among the maximum forces exerted during running. Moreover, the protected LSD showed that the maximum forces recorded while running on Varsity (2251 Newtons), Titan Turf (2244 Newtons) and Prof's Choice (2227 Newtons) playing surfaces were significantly higher than those recorded on Athletic Turf 1 (2120 Newtons).

Since the lowest maximum forces indicate the lower stiffness (hardness) and the higher absorbing capability of the surface, Athletic Turf 1 may be the safest of the playing surfaces on which to run.

The normalized maximum forces were also significantly different among the tested playing surfaces (see Table 4).

TABLE 4:

Analysis of Vaiance for Normalized Maximum Forces During Running

Source	DF	ANOVA SS	F Value
Subjects	4	0.17669	2.25*
Surfaces	5	0.67544	6.88*
Sub* Surf	20	0.83585	2.13*
Error	60	1.17853	

$P < .05$

Furthermore, protected LSD shows that the normalized maximum forces exerted on Varsity (2.921 BW) playing surface was significantly higher than those exerted on the other playing surfaces. A significant interaction between the subjects and the playing surfaces was found which suggests that different surfaces react differently with different subjects.

The landing forces of new and used tested playing surfaces were not significantly different. The means of landing forces (F1) on new and used playing surfaces were 2963 Newtons and 2928 Newtons, respectively.

Furthermore, no significant differences were found between F1 on new and used playing surfaces ($t = 2.57$). The lower normalized landing forces exerted on used playing surfaces indicate that using these surfaces did not cause a reduction of the absorbing capacity. The normalized landing forces on new and used playing surfaces were 3.716 BW and 3.462 BW respectively. These normalized landing forces on new and used tested surfaces were less than those reported by Nike Research Lab (1982).

Contact Time

Running on the new and used playing surfaces was found not to affect the total contact time (CT) of the foot with the playing surface. However, significant interaction between subjects and surfaces was found during running on the used playing surfaces. An increase in CT was found for running on all used playing surfaces and the decrease of average applied forces was found only when running on Prof's Choice, Titan Turf, Doral and Varsity (see Table 2). Furthermore, significant differences were found between the CT of the new and used playing surfaces ($t = -3.4$).

The average CTs' of running on the new and used playing surfaces (0.635 and 0.653 seconds) were found to be longer than the findings of the reported literature. The longer CT during running and the lower average applied forces indicate that it is safer to run on these playing surfaces, especially Prof's Choice, Titan Turf, and Doral. The longer CT may also reflect the greater absorbing ability and the lower stiffness of these playing surfaces (McMahon & Greene, 1984).

Rate of Loading and Unloading

Significant differences and interaction among the new and used playing surfaces in related to the rates of loading on the foot (Sf). The rates of loading F-values during running on new and used playing surfaces are shown in Table 5.

TABLE 5

F-value of the Rates of Loading on the Foot During Running on New and Used Surfaces.

Condition	Surface	Interaction
New	17.55*	19.09*
Used	4.29*	4.32*

$P < .05$

The means of Sf on the new and used playing surfaces were -1779 N/s and -1689 N/s respectively. The lower Sf on the subjects joints during running on old surfaces indicates that using these surfaces for three months did not affect their absorbing capacity and instead a lower loading rate resulted, which reflected the safety of running on these surfaces. Furthermore, no significant differences were found between the rate of loading on the joints during running on new and used playing surfaces ($t = 1.06$).

The protected LSD test identified significant differences among the Sf values on the joints during running on new and used tested playing surfaces. Running on new Prof's Choice was shown to generate a loading rate (2540 N/s) higher than the other tested playing surfaces. Furthermore, Varsity playing surface was found to produce the lowest Sf when running on new (1281 N/s) and used (1263 N/s) tested surfaces. The lowest Sf of the Varsity playing surface (see Table 2) may indicate that this surface ranks as the lowest on risk of injury during running, and it is the least affected by use.

No significant differences were found in the rate of carrying weight, loading during the time lapse between the heel strike and the peak force, during running on new playing surfaces. However, running on used playing surfaces caused significant differences and significant interaction between subjects and playing surfaces among the rates of carrying weight (L) (see Table 6).

TABLE 6

Analysis of Two Way **ANOVA** of Rate of Carrying Weight on Used Playing Surfaces During Running

Source	DF	ANOVA SS	F-Value
Subjects	4	74966505	17.19*
Surfaces	5	17853276	3.27*
Surf*Sub	20	51579961	2.36*
Error	60	73958009	

$P < .05$

Protected LSD showed that the rate of carrying weight during running on Titan Turf (5961 N/s), Guardian (5762 N/s) and Doral (5627 N/s) playing surfaces were significantly higher than the rate of carrying weight during running on the Varsity (4789 N/s) playing surface. This finding coincides with the previous one (rate of loading on joints) and provides more information about the safety of the Varsity playing surface. The lower rate of carrying weight on the Varsity playing surface may indicate that it is safer to run on (Nigg, 1985).

The means of carrying weight on new and used playing surfaces were 5508 N/s, and 5427 N/s respectively. Using these surfaces did not significantly affect the rate of carrying weight ($t = 0.44$) Significant interaction was found between subjects and surfaces as related to the rate of carrying weight during running on used playing surfaces. Subject 3showed a signficantly higher rate of carrying weight than other tested subjects and that may contribute to the interaction.

Significant differences and significant interaction between the surfaces and subjects were observed during unloading running (Sun) on new tested playing surfaces. The means of unloading rates during running on new and used playing surfaces were 6897 N/s and 6814 N/s, respectively, which were not significantly different ($t = 0.52$).

Protected LSD demonstrated that unloading during running on Varsity, Doral and Titan Turf playing surfaces were significantly higher than unloading on the Guardian, Athletic Turf 1 and Profs Choice (see Table 2). The lower unloading rate could indicate that running on the Guardian, Athletic Turf 1, and Profs Choice is safer because it may be related to the longer unloading time (time lapsed from the maximum force to the zero force).

Heel Strike Force

No significant differences were found among the heel strike forces (HS) during running on new tested playing surfaces. However, significant differences were found among used playing surfaces (see Table 7).

TABLE 7

Analysis of Variance of Heel Strike Forces During Running on Used Playing Surfaces

Source	Df	Sum of SS	F-Value
Subjects	4	2350082	17.52"
Surfaces	5	452925	2.70*
Sub*Surf	20	2053687	3.06*
Error	60	2011820	

$P < .05$

The Protected LSD multiple comparison test showed that Titan Turf had the highest HS which was significantly different from other used playing surfaces. However, it wasn't different from other tested playing surfaces during running on new surfaces. The lowest recorded HS during running on used surfaces was on the Guardian playing surface (see Table 2). The low HS and longer T1 were found during running on new and used Profs Choice and Guardian playing surfaces. This may indicate the safety of running on new and used Profs Choice and Guardian playing surfaces because of low HS and slower rising of these forces. The highest HS during running on Titan Turf (1675 Newtons) combined with the longest time to reach HS indicated that Titan Turf was the least absorbing playing surface but was not unsafe to run on because of the longest time to reach the maximum HS (0.070 seconds).

The means of HS on new and used playing surfaces were 1548 Newtons and 1540 Newtons, respectively. Moreover, time, to HS were nearly the same for new and used playing surfaces.

A significant HS interaction was found and may indicate that different surfaces react differently with subjects. The first tested subject had the highest HS (1751 Newtons) during running on used surfaces and his HS was significantly different from other subjects' heel strike force.

Propulsive Impulse

Significant differences were observed among the propulsive impulses of new tested playing surfaces during running, but no differences were found among the propulsive impulses on used playing surfaces (see Table 8).

TABLE 8

Analysis of Variance of Propulsive Impulse During **Running** on New Playing Surfaces

Source	Df	Sum of SS	F-Value
Subjects	4	4244912	**80.08***
Surfaces	5	21031	**3.17***
Surf*Sub	20	18119	0.68
Error	60	79589	

$P < .05$

The LSD test showed the propulsive impulse during running on Varsity (749 Ns) was significantly higher than the propulsive impulse recorded on **Doral** (712 Ns) and Athletic Turf 1 (703 Ns) playing surfaces. Higher recorded propulsive impulse during running on the Varsity playing surface may contribute to increased collision force (Stanitski, 1974) due to an increase in running speed.

The means of the propulsive impulse during running on new and used playing surfaces were 726 Ns and 742, respectively. Using the playing surfaces was found to produce a significant effect on propulsive impulse ($t = 2.42$) which **may** indicate that running on these surfaces improve performance by increasing running speed. Furthermore, running on used Athletic Turf 1 and Guardian was found to generate the lowest and the highest propulsive impulses (720 Ns and 762 Ns) respectively.

Negative Acceleration

Significant negative accelerations were found during jumping on new playing surfaces (see Table 9). However, no significant differences were observed among the used playing surfaces.

TABLE 9

Analysis of Variance of Negative Acceleration During Jumping on New Playing Surfaces

Source	Df	Sum of Ss	F-Value
Subjects	4	13.355	**4.68***
Surfaces	5	8.464	**2.37***
Sub*Surf	20	27.226	**1.91***
Error	60	42.827	

$P < .05$

Protected LSD (0.617) showed that the "aneg" produced during jumping on Guardian **(4.787g)** was significantly different (higher) than the "aneg" generated when jumping on Profs Choice **(4.140g)** and Athletic Turf **1 (3.855g)** playing surfaces. Jumping on the Varsity playing surface initiated a negative acceleration **(4.563g),** which was significantly higher than the one initiated on Athletic Turf **1.** This finding may indicate **that**-Titan Turf **1 (3.191g)** offered better stabilizing assistance to the joints than other playing surfaces. The significant interaction found among the new tested playiing surfaces may indicate that playing surfaces react differently and initiate different negative accelerations.

The means of negative acceleration of jumping on new and used playing surfaces were **4.334g** and **3.972g** respectively. The lower negative acceleration during jumping on used surfaces indicates that using these surfaces help to increase the stabilizing effect of the muscles around the joints (Lees, 1981) and therefore greater degree of safety can be expected. Furthermore, significant differences were also found between the negative acceleration produced on new and used playing surfaces ($t = 2.45$). Jumping on used playing surfaces was shown to have an inverse effect on negative acceleration **(i.e.** reduction of negative acceleration through use). This finding indicates that using playing surfaces for three months had no effect on their hardness.

The means of positive accelerations (apos) on new and used **playing surfaces** were **13.232g** and **10.015g,** respectively. The "apos" on used playing surfaces was significantly higher then "apos" on new surfaces ($t = 2.86$). Higher "apos" on used playing surfaces indicates that jumping on used surfaces resulted in more reaction to stabilize the joints. Therefore, they are safer to jump on.

SUMMARY AND CONCLUSION

Running on new and used playing surfaces may cause an improvement of performance and safety. The recorded maximum forces during running on these surfaces were within the range of the previous findings. Running on Athletic Turf 1 and Varsity playing surfaces produced, respectively, the lowest and the highest maximum forces. The rate of loading on the foot was affected during running on both new and used playing'surfaces. Furthermore, the rate of carrying weight was affected during running on used surfaces, while the rate of unloading was affected during running on new surfaces.

Forefeet landing, following squat jump, on new or used playing surfaces was found not to have an effect on landing forces. Furthermore, using these surfaces for three months has no effect on the surfaces' absorbing ability. Titan Turf surface helps to stabilize the joints by increasing muscle reaction. Therefore, Titan Turf appears to be the safest tested surface during jumping.

The playing surfaces showed different reactions to the tested variables. No tested playing surface combined the maximum element of the variables which contributed to the improvement of safety. Further testing needs to be conducted under different environmental conditions in order to determine and verify the safety of the tested playing surfaces.

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