MEASUREMENT METHODS: DETERMINATION OF ERGONOMIC SPORT SURFACES IN TERMS OF SPORTIVE PERFORMANCE

Katkat Dursun

Physical Education and Sport Sciences, Ataturk University, 25240 Erzurum, Turkey TURKEY

Received: August 22, 2011 / Accepted: February 15, 2012

Abstract The aim of the present study was to examine the effects of different sport surfaces on sportive performance by means of muscle performance. 112 elite athletes, aged between 17 and 26, participated in this study. This study was executed on 8 different sport surfaces: asphalt, synthetic grass, natural grass, tile powder, soil, wooden parquet, full polyurethane and EPDM (Ethylene Propylene Diene Monomer). Leg strength (LS), back strength (BS) and vertical jumping height (VJH) were measured at rest and after a given training protocol on each surface. Asphalt and synthetic grass were the most fatiguing, natural grass, soil and tile powder were moderately fatiguing, parquet and polyurethane were the least fatiguing surfaces. Then the surface compliance was evaluated with a drop test using a medicine ball and it was observed that achieved results were consistent with those obtained in LS, BS and VJH tests. According to the test results as the hardness of the surface increased the performance of the athletes was decreased. The results of the present study suggest that it is better to use parquet and polyurethane in construction of indoor sport surfaces.

Jpn J Phys Fitness Sports Med, 61(2): 237-241 (2012)

Keywords : Ergonomic sport surfaces, sportive performance, sportive surface flexibility

Introduction

There are different kinds of surfaces on which the subjects play sports, e.g. natural grass, asphalt and wooden parquet. Besides, synthetic surfaces for sport and recreational usage have been manufactured. One of the important aspects in construction of sport surfaces is to improve athletic performance^{4,12,23}. It has been suggested that the main feature of a sport surface that can affect the athletic performance is the energy storage and return^{4,12}. These studies have argued that if some of the energy that an athlete requires for each step, stride, jump, landing, etc. can be reused, through energy return from the surface, the athlete can perform the same movement more efficiently. In other words, one can achieve a given physical activity by using less energy and, therefore, he continues his activity during a longer period.

Several studies have revealed a relationship between the compliance of the sport surface and performance. The analytic model of McMahon and Greene²⁴) has predicted a slight speed enhancement on tracks of intermediate compliance by comparison with running on a hard surface. Kerdok *et al.*²⁰) have postulated that an increased energy rebound from the compliant surfaces contributes to the enhanced running economy. It has been also reported that the reuse of elastic energy increases the muscular work efficiency in jumping⁵).

If there is a relationship, whether it is positive or nega-

tive, between surface compliance and sport performance, the same relationship is expected to exist between surface compliance and muscle performance. That is to say, the effect of a given training programme on muscle performance will be different on surfaces having distinct compliance.

According to the authors' knowledge, a noticeable feature of the existent studies in the literature, except few^{13,30}), is that they deal with experimental surfaces not with real sport surfaces. The aim of the present study was to search the effects of different real sport surfaces on athletic performance by means of muscle performance and, therefore, to determine the most appropriate material(s) in building of sport surfaces.

Materials and Methods

Subjects One hundred twelve elite athletes (Basketball player n=20, Tennis player n=14, Handball player n=18, Volleyball player n=16, Athletics n=24, Football player n=20), aged between 17 and 26, participated in this study. Subjects volunteered to participate this study after they had been fully formed of the nature of the test and the associated risks in agreement with the recommendations of the local Ethics Committee.

Procedure

General This study was executed on 8 different sport surfaces: asphalt, synthetic grass, natural grass tile pow-

der, soil, wooden parquet, full polyurethane and EPDM. Leg strength (LS), back strength (BS) and vertical jumping height (VJH) were measured during the unfatigued condition twice, and the greater value was taken for further analyses. The same measurements were made after a given training protocol (described below) on 8 different sport surfaces, on separate days for each surface. The procedure was repeated once again on separate days for all surfaces. Then, the mean values calculated for each surface.

The subjects were asked to avoid vigorous activities for 24 h before each test, to have a good sleep, to consume same foods in the mornings of the test days, and to wear the same sportswear and shoes on all surfaces.

Training protocol for elite athletes: At the beginning, a warm up opportunity with a running exercise at a tempo that they ran 800 m in 5 min. was given to the participants. Then they carried out following exercises in indicated order:

- 1) A 10-minute shuttle run test (20 m x 100 times; completed by all the subjects in equal time, i.e. in 10 minutes)
- 2) A 25-m sprint run with maximal effort (repeated 5 times)
- 3) A double-leg hop test [jumping onto a gymnastic table that was 60 cm in height and landing on the surface consecutively along 5 tables arranged in a row (Fig. 1); repeated 5 times]
- 4) A jump rope test [500 times in 5 minutes; repeated 2 times]

Measurements

Leg Strength (LS)/Back Strength (BS): Back/leg dynamometer (Takei Kiki Kogyo, Japan) was used to measure leg strength and back strength. After familiarization with the test, the subjects stood on a platform with their feet apart at a comfortable distance of shoulder width for balance. Their hands grasped each end of a bar. The subject was asked to flex at their knees to approximately 110 degrees. The back was kept straight and the hips were positioned directly over the ankle joints. In this way, the activation of back muscles was eliminated. The chest was kept forward and the head was held in an erected position. The subject took in a large breath and slowly exhaled as they attempted to extend their knees smoothly and as forcefully as possible. LS/BS was expressed as kilogram.

Vertical jumping height (VJH): The vertical jumping test consisted of leg flexion from the standing position immediately followed by a maximal jump with the hands free.

These jump test were monitored with a digital jump meter (Takei Kiki Kogyo, Japan), which recorded the jump height.

Surface compliance: A medicine ball weighing 5 kilograms, which is filled with air and, thus, bouncing, was used to assess the surface compliance. The ball was let to drop freely from the height of one meter near a scale, which was vertically positioned on the floor (100 cm in length). This process was recorded by a video camera. The highest point that the bottom of the bounced ball reached after hitting on the surface was determined in slow motion by means of the meter in the image on the camera screen. The measurement was repeated 35 times for each surface, each time on a different place of the measured surface.

Statistics: Ordinary statistical methods including means and standard deviations were used. Differences between mean values were tested for significance by the one-way ANOVA and Post Hoc LSD test.

Results

The mean values of leg strength, back strength and vertical jumping height, obtained at rest and on 8 different sport surfaces were presented in Table 1.

Analysis of variance showed significant differences among surfaces in terms of leg strength ($F=8.65$; $P<0.001$), back strength ($F=6.73$; $P<0.001$) and vertical jumping height ($F=34.28$; $P<0.001$). Post hoc test of LSD revealed that the rest values for LS, BS and VJH were significantly higher than those obtained after training on all surfaces. Besides, the LS and BS values that are measured on parquet were quite higher than the LS and BS values measured on the either surfaces ($P<0.05$).

The mean LS, BS and VJH measured on asphalt were lower than those measured on the other surfaces. On the other hand, the difference between LS, BS and VjH values on synthetic grass and asphalt and the difference between LS, BS values of the tile powder and asphalt were not significant ($P<0.05$).

The mean LS, BS (not for soil) and VJH recorded on parquet were greater as compared to those noted on tile powder, synthetic grass and soil ($P<0.05$). The mean LS, BS and VJH achieved on EPDM were higher than those obtained on synthetic grass, and on tile powder and synthetic grass, respectively ($P<0.05$). The mean VJH measured on natural grass was higher than that obtained on synthetic grass ($P<0.05$).

Table 2 shows the bouncing heights of a given ball that was let to free drop from a constant level on examined surfaces. According to these results, the seven surfaces were arranged, from the stiffest to the softest, as follows: asphalt, synthetic grass, tile powder, soil, EPDM, parquet, polyurethane and natural grass.

Fig 1. Double-leg hop test

Table 1. The leg strengths, back strength and vertical jumping distances of athletes [mean (SD)] obtained at rest and on different sport surfaces after training (n= 112)

	At Rest	After Training								
		Asphalt	Synthetic Grass	Natural Grass	Tile Powder	Soil	Polyurethane	Parquet	EPDM	F
Leg Strength (kg)	154,3* (16,3)	137,9‡ (16,8)	141,7 (16,8)	143,7 (16,9)	140,9 (16,8)	140,1‡ (16,9)	142,8 (16,4)	144,8 (16,5)	143,5 (16,6)	8,65
Back Strength (kg)	123,8* (16,7)	109,9¶ (16,7)	112,3¶ (16,4)	113,8 (16,3)	112,4¶ (16,5)	112,4¶ (16,4)	115,8 (16,6)	117,2 (16,6)	113,9 (16,4)	6,73
Vertical Jumping (cm)	60,7* (8,3)	50,0† (5,7)	51,0† (5,8)	52,8† (5,8)	51,7† (5,8)	51,9† (5,9)	57,2 (7,0)	57,5 (7,0)	54,3 (7,3)	34,28

* Significantly different from all the others (for parquet, polyurethane and EPDM, $p < 0.05$; for the rest, $p < 0.001$)

† Significantly different from parquet, polyurethane and EPDM for LS ($p < 0.05$)

‡ Significantly different from parquet, polyurethane and EPDM for VJH ($p < 0.05$)

¶ Significantly different from parquet for BS ($p < 0.05$)

Table 2. Bouncing height of the ball on different sport surfaces [mean (SD)]*

	Asphalt	Synthetic Grass	Natural Grass	Tile Powder	Soil	Polyurethane	Parquet	EPDM
Bouncing height of the ball (cm)	60.1 (0.5)	54.2 (0.7)	44.9 (0.8)	52.3 (0.8)	51.5 (0.9)	50.6 (0.7)	49.1 (0.7)	51.6 (0.8)

* All values are significantly different from each others ($p < 0.001$).

Discussion

The purpose of this paper was to investigate the effect of different sport surfaces on muscle performance by means of leg strength and vertical jumping height after a given training programme. In the present study, the mean LS, BS and VJH values before training were significantly higher than those obtained on all surfaces after training. These findings showed that the training programme was fatiguing. In the present study, the results of the drop test showed that the hardest surface was asphalt. This finding is in consistent with the previous ones^{3,24}. Unpublished energy return values quantified with drop tests (material testing using a shot) provided values between 40 and 70% for athletic surfaces and close to 0% for asphalt⁴). The order of the other surfaces used in this study was, from hardest to most compliant, as follows: synthetic grass, tile powder, soil, EPDM, full polyurethane, parquet and natural grass. These data are in consistent with the results of LS, BS and VJH except for natural grass which had the lowest bouncing height although it was not the least but a moderately fatiguing surface. This inconsistency can be explained by the energy dissipating nature of natural grass instead of its compliance. Therefore, if we rule out natural grass, the most compliant surface was wooden parquet. This kind of surface is composed of three layers: a tartan layer at the bottom, a wooden joist layer in the middle (in which the wooden joists are placed in a parallel and spaced manner) and a wooden parquet layer on the top. This construction gives the surface a compliant feature.

Natural grass, soil and tile powder were moderately

fatiguing surfaces. Because the mean LH, BS (not for tile powder) and VJH values achieved on these three surfaces were significantly greater than only those obtained on asphalt and, only for VJH of natural grass, synthetic grass. If a surface is less fatiguing, one can achieve a given training programme on that surface with less oxygen consumption compared with a more fatiguing one, i.e. sport surfaces affect athletic performance. The most important characteristic of a sport surface, which may be related to performance, seems to be its compliance. A person increases his leg stiffness (the stiffness of the integrated musculoskeletal system that behaves as a single linear spring during locomotion) when he is running or hopping on a compliant surface compared with running or hopping on a hard one^{5,6,7,16,17,20,25,26}). Similarly, Daniel *et al.*¹¹) have reported that runners adjust leg stiffness for their first step on a new running surface. They found a %29 decrease in leg stiffness between the last step on a soft surface and the first step on a hard surface (from 10.7 kN m⁻¹ to 7.6 kN m⁻¹, respectively). On the other hand, Tillman *et al.*³⁰) have found that the kind of surface have no significant effect on lower extremity kinematics in running. The results of a recent study have also suggested that it is not possible to generalize the effects of sports surfaces on lower extremity kinematics¹³). At least for Tillmann *et al.*'s study, a possible reason of this inconsistency is the relative similarity in hardness of the surfaces used in that study. All participants in the one-leg jump task were found to decrease their leg stiffness by about 15% when imposed height changed from 55 to 95%²¹). These contradictions can be explained by the style of the tasks performed²¹),

the difference in running speed, and the difference in surfaces selected. Indeed, the results of Farley et al.'s¹⁵⁾ study have indicated an increase in leg stiffness with the increase in hopping height in the two-leg jump. The increased stiffness of the leg spring on compliant surfaces may lead to a lower energetic cost compared with hopping or running on hard surfaces. The results of Kerdok et al.'s study²⁰⁾ have suggested that the spring stiffness of the leg is progressively increased and that the metabolic cost of running is progressively reduced as surface stiffness is decreased from 945.7 to 75.4 kN/m. Arampatzis et al.^{1,2)} have suggested that an increase in leg stiffness causes an increase in the energy transmitted to and recovered from the sprung surface and simultaneously a decrease in the energy produced by the subjects.

The data obtained in this study support the results of the previous ones, which have found a negative relationship between surface compliance and oxygen consumption^{1,2,8)}. It has been proposed that a compliant elastic surface will passively store and return energy with each step, reducing the mechanical work performed by the runner's muscles¹⁷⁾. In the same way, Kerdok et al.²⁰⁾ have suggested that a reduction in metabolic cost occurs as the elastic rebound provided by a compliant surface replaces that otherwise provided by a runner's leg. The results of one study have suggested that inflexibility in certain areas of the musculoskeletal system may enhance running economy by increasing storage and return of elastic energy and minimizing the need for muscle-stabilizing activity¹⁰⁾.

On the other hand, Hardin et al.¹⁹⁾ have found a decrease in oxygen uptake as the leg stiffness increased, but with increasing surface hardness. Therefore, they have suggested that metabolic cost is higher in more compliant surfaces. They have explained this inconsistency by differences in surface construction because their subjects mentioned a sensation of "running on sand" indicating that the surface may have had too much damping or inertia to effectively produce a "rebound" effect as in other surfaces used. Indeed, running on sand increases energy expenditure compared to running on hard surfaces^{20,29,31)}, grass²⁸⁾ and force platform²⁷⁾ because sand doesn't return energy, absorbed in the earlier phase of each step, and thus, this lost energy must be replaced by the muscles' activities at later phase of each step^{9,22)}. This is also true for jumping on the surfaces with very high shock absorption other than sand^{14,26)}.

In locomotion the energy cost is thought to be determined by two factors together: the energy required for performing mechanical work and the energy required for generating muscular force^{9,10)}. By increasing leg stiffness on a compliant elastic surface, the human reduces the mechanical work done by the leg and increases the mechanical work done by the surface, and lowers the energy cost of generating muscular force¹⁸⁾. Because both the amount of work done by the person and the amount of force generated by the muscles would be reduced, the energetic

cost of hopping or running is likely to be lower on a compliant elastic surface than on a hard surface¹⁶⁾.

Conclusion

In this study, muscle performance was found to be affected by the compliance of a sport surface. Parquet, full polyurethane and EPDM were more compliant and less fatiguing surfaces, whereas asphalt and synthetic grass were hard and most fatiguing ones. Besides, natural grass, soil and tile powder were moderately compliant and fatiguing surfaces. The results of the present study suggest that it is better to use parquet, full polyurethane and EPDM in building of indoor sport surfaces. Although relatively the best results achieved from parquet, full polyurethane and EPDM, the outdoor surfaces must be built with EPDM and natural grass due to the unsuitable usage of parquet at outdoor. In addition, the usage of natural grass will have aesthetic and visual impacts and contribute to the amount of urban green area.

References

- 1) Arampatzis A., F.Schade, M.Walsh, G.P.Bruggemann (2001) Influence of leg stiffness and its effect on myodynamic jumping performance. *J.Electromyogr.Kinesiol.* 11: 355-364.
- 2) Arampatzis A., G.P.Bruggemann, G.M.Klapsing (2001) Leg stiffness and mechanical energetic processes during jumping on a sprung surface. *Med.Sci.Sports Exerc.* 33: 923-931.
- 3) Arampatzis A., S.Stafilidis, G.Morey-Klapsing, G.P.Bruggemann (2004) Interaction of the human body and surfaces of different stiffness during drop jumps. *Med.Sci.Sports Exerc.* 36(3): 451-459.
- 4) Baroud G, B.M.Nigg D.Stefanyshyn (1999) Energy storage and return in sport surfaces. *Sports Engin.* 2: 173-180.
- 5) Bosco C., R.Saggini, A.Viru (1997) The influence of different floor stiffness on mechanical efficiency of leg extensor muscle. *Ergonomics* 40: 670-679.
- 6) Bret C., A.Rahmani, A.B.Dufour, L.Messonnier, J.R.Lacour (2002) Leg strength and stiffness as ability factors in 100 m sprint running. *J.Sports Med.Phys.Fitness* 42: 274-281.
- 7) Butler R.J., H.P. 3rd Crowell, I.M.Davis (2003) Lower extremity stiffness: implications for performance and injury. *Clin.Biomech.* 18: 511-517.
- 8) Chelly S.M., C.D.Penis (2001) Leg power and hopping stiffness: relationship with sprint running performance. *Med.Sci.Sports Exerc.* 33: 326-333.
- 9) Chet T.M., T.F.Claire (2003) Human hopping on damped surfaces: strategies for adjusting leg mechanics. *Proc.Biol.Sci.* 22(270): 1741-1746.
- 10) Craib M.W., V.A.Mitchell., K.B.Fields, T.R.Cooper, R.Hopewell D.W.Morgan (1996) The association between flexibility and running economy in sub-elite male distance runners. *Med.Sci.Sports Exerc.* 28: 737-743.
- 11) Daniel P.F., K.Liang, T.F.Claire (1999) Runners adjust leg stiffness for their first step on a new running surface. *J.Biomech.* 32: 787-794.
- 12) Daren J.S., B.M.Nigg (2003) Energy and Performance Aspects in Sport Surfaces. Third Symposium on Sports Surfaces (August), Calgary, Canada.

- 13) Dixon S.J., A.C.Collop, M.E.Batt (2000) Surface effects on ground reaction forces and lower extremity kinematics in running. *Med.Sci.Sports Exerc.* 32: 1919-1926.
- 14) Durá J.V., L.Hoyos, J.V.Lozano, A.Martínez (1999) The effect of shock absorbing sports surfaces in jumping. *Sports Engin.* 2: 103-108.
- 15) Farley C.T., H.H.Houdijk, C.Van Strien, M.Louie (1998) Mechanism of leg stiffness adjustment for hopping on surfaces of different stiffnesses. *J.Appl.Physiol.* 85: 1044-1055.
- 16) Ferris D.P., C.T.Farley (1997) Interaction of leg stiffness and surface stiffness during human hopping. *J.Appl.Physiol.* 82: 15-22.
- 17) Ferris D.P., M.Louie, C.T.Farley (1998) Running in the real world: adjusting leg stiffness for different surfaces. *Proc.Biol.Sci.* 265(1400): 989-994.
- 18) Gleim G.W., N.S.Stachenfeld, J.A.Nicholas (1990) The influence of flexibility on the economy of walking and jogging. *J.Orthop.Res.* 8: 814-823.
- 19) Hardin E.C., A.J.Van Den Bogert, J.Hamill (2004) Kinematic Adaptations during Running: Effects of Footwear, Surface, and Duration. *Med.Sci.Sports Exerc.* 36: 838-844.
- 20) Kerdock A.E., A.A.Biewener, T.A.McMahon, P.G.Weyand, H.M.Herr (2002) Energetics and mechanics of human running on surfaces of different stiffnesses. *J.Appl.Physiol.* 92: 469-478.
- 21) Laffaye G., B.G.Bardy, A.Durey (2005) Leg stiffness and expertise in men jumping. *Med.Sci.Sports Exerc.* 37: 536-543.
- 22) Lejeune T.M., P.A.Willems, N.C.Heglund (1998) Mechanics and energetics of human locomotion on sand. *J.Exp.Biol.* 201: 2071-2080.
- 23) McMahon T.A., G.Valiant, E.C.Frederick (1987) Groucho running. *J.Appl.Physiol.* 62: 2326-2337.
- 24) McMahon T.A., P.R.Greene (1979). The influence of track compliance on running. *J.Biomech.* 12: 893-904.
- 25) Moritz C.T., C.T.Farley (2004) Passive dynamics change leg mechanics for an unexpected surface during human hopping. *J.Appl.Physiol.* 97: 1313-1322.
- 26) Moritz C.T., C.T.Farley (2005) Human hopping on very soft elastic surfaces: implications for muscle pre-stretch and elastic energy storage in locomotion. *J.Exp.Biol.* 208: 939-949.
- 27) Muramatsu S., A.Fukudome, M.Miyama, M.Arimoto, A.Kijima (2006) Energy expenditure in maximal jumps on sand. *J.Physiol.Anthropol.* 25: 59-61.
- 28) Pinnington H.C., B.J.Dawson. (2001) The energy cost of running on grass compared to soft dry beach sand. *J.Sports Sci. Med.* 4: 416-430.
- 29) Pinnington H.C., D.G.Lloyd, T.F.Besier, B.Dawson (2005) Kinematic and electromyography analysis of submaximal differences running on a firm surface compared with soft, dry sand. *Eur.J.Appl.Physiol.* 94: 242-253.
- 30) Tillman M.D., P.Fiolkowski, J.A.Bauer, K.D.Reisinger (2002) In-shoe plantar measurements during running on different surfaces: changes in temporal and kinetic parameters. *Sports Engin.* 5: 121-28.
- 31) Zamparo P., R.Perini, C.Orizio, M.Sacher, G.Ferretti (1992) The energy cost of walking or running on sand. *Eur.J.Appl. Physiol.* 65: 183-187.