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Original Article

Is it safe to use sand surface during rehab when training basic skills in early stages? How sand surface and inertial sensor position affect Drop Jump landing's G-forces and it's application in injury recovery

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A R T I C L E I N F O

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A B S T R A C T

En el ámbito deportivo, el uso de la arena como superfície de trabajo dentro del proceso de recuperación de las lesiones, ha disfrutado de muy buena aceptación y de un creciente interés en los últimos años. Desafortunadamente, el número de estudios en los que se ha analizado sus efectos continúa siendo reducido. Por ello, en este estudio se analiza la existencia de posibles diferencias en la magnitud del impacto generada durante un Drop Jump (DJ) de 45 cm, en función de la zona corporal analizada, de la superficie de contacto y de la altura en la que es colocada una unidad de movimiento inercial (IMU). Para ello se analizaron a 6 participantes mediante 3 sensores IMU (WIMU PRO™) que se utilizaron para medir las fuerzas G en la fase de aterrizaje del DJ. Los resultados sugieren la existencia de diferencias estadísticamente significativas al comparar superfícies (arena vs. césped), zona corporal (tobillo y lumbar) y lugar de colocación del dispositivo (zona torácica vs. tobillo).

A B S T R A C T

In sports, the use of sand surface as a tool in the injury recovery process has received very good acceptance and an increased attention in recent years. Unfortunately, the number of studies in this area continues being scarce. Therefore, this study analyzes the existence of possible differences in the magnitude of the impact generated during a 45 cm Drop Jump (DJ), depending on the body area analyzed, the contact surface (sand or grass) and the height (thoracic spine and ankle) at which a jump is placed. To that purpose, 6 participants were analyzed by wearing 3 IMU sensors (WIMU PRO™) to measure G foreces in the landing phase of the DJ. The results suggest the existence of statistically significant differences when comparing surfaces (sand vs. grass),

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body area (ankle and lumbar) and location of device placement (thoracic area vs. ankle).

Introduction

In recent years, an increased amount of studies oriented to return to train and competition have been observed.[1–3] In this studies, risk factors, new protocols and training methodologies are investigated, but there do not exist specific proposals of treatment, specially in high performance athletes. Many of these studies, use body impacts as a tool to improve mechanical response in body tissues[4] and sport injury treatments. Because of this, the control of training loads and their effects during training are essential.[3,5]

Training in sand has already been proposed as an effective methodology to increase performance and rehabilitation, reducing the body acceleration and the magnitude of impacts, increasing muscle activation due to instability, and raising heart rate and metabolic consumption, thus also growing the perception of effort up.[5–7]

Along this way, over the last 20 years, our entity has developed a custom system of work, in the area of the return to train and competition, based in the use of different training surfaces as the sand, trying to obtain the best benefit, depending on the healing moment of the injury.

The use of sand as a training surface as an alternative training method is not new[8]. It began to be studied in the 1960s, when the differences between the metabolic cost of walking on sand[9,10] and on dry land,[9] in healthy subjects, were analyzed. Subsequently, various studies have demonstrated its benefits,[11–14] through plyometric training and the analysis of the running technique and its biomechanics.[12,13,15–17]

This use of sand has been applied basically in the field of sports sciences and performance, but not to injury recovery field until recent years. When discussing about the return to play process, it is to be accepted it is a very young field that do not have powerful science behind yet, so it is growing up through experience.

In this context, the use of sand has been applied in recent years in the recovery of injured players, among other reasons, due to its effects on reducing the impact forces generated between the body and the ground during the exercise,[12,17,18] which reduces post-activity muscle damage and pain.[5] In addition, a reduction is also observed in the stress levels that the soft tissues and joint structures of the lower extremity must hold.[19] Besides, many studies show that sand allows an improvement in performance, at least at the same level as other surfaces.[4,11,20–25]

On the other hand, during daily training sessions, the use of global positioning system (GPS) devices has become widespread as a tool to control external load. These apparatus allows to obtain information about players' position from triangulation obtained from a satellite network, while using inertial movement units that includes 3 triaxial accelerometer and 3 gyroscopes to improve kinematic information. Although, these transductors allow us to monitor the magnitude of the impacts generated during the movement, they present some limitations such as not knowing the magnitude of the impact in different body parts, since the device is placed at level of the T4 vertebra and the values obtained refer to the load at this level. This assessment is relevant, if we consider that there is a direct relationship between the load that a tissue receives and its adaptive response.[26,27]

For all these reasons, and considering that the amount of information available on this topic is still scarce, this work is based on the hypothesis that there should be significative differences in the level of load recorded by GPS, depending on the type of surface where we test and body area where the sensor is placed. The main objectives of this study are: 1) to determine the existence of differences in loads (gravity forces) depending on the surface (sand and grass) where players jump and, 2) to analyze how does the location (ankle, low back, thoracic spine at T4 level) of the device influence the rated load recorded.

Material and methods

Study design

Descriptive study of the prevalence of the effect of the surface (sand vs. grass) on the magnitude of the impact received at the two moments of landing a Drop Jump (C1TG and CFG), measuring this effect in 3 body segments located in different body areas (ankle, low back and thoracic spine). DJ was chosen for testing as it is technically standarized and has low risk of technical alterations, and it is related to landing and jumping, what takes part of most of the actions performed in team sports like football. The participants were randomly distributed based on the first surface on which they performed the test, through the RANDOMGROUP app. (downloaded on September 3, 2022).

Participants

Six male participants were included in this study (see characteristics in Table 1). The inclusion criteria were: 1) not having any injury or musculoskeletal problem in the last 6 months prior to their participation, 2) not being carrying out a lower body strength training or plyometrics program at the time of the test or two weeks before it and, 3) not having participated in exhaustive physical activity in the last 48 h before the study. The FCB-Bihub ethics committee approved this study, in accordance with the recommendations of the Declaration of Helsinki, revisited in 2013 (CEIC 2022FCBX25). All the participants signed and informed consent document, prior to carrying out the tests.

Instruments

Three inertial motion sensors (WIMU PRO™, Realtrack Systems S.L., Almería, Spain) (500 Hz) were used to analyzed the G Forces (G;1G=9,8 m/s^2) recorded in landing phase of a Drop Jump from a 45 cm box. Validity and reliability of the WIMU device for the assessment of vertical jumps were previously confirmed both for Counter Movement Jump and Squat Jump.[28] During the jumps, Participants were instructed to fix their upper extremities with "hands in the pelvis" position, dropping from the box to the floor, and performing a reactive action to execute a vertical jump as quickly and as high as possible. All measurements were carried out by a highly experienced technician and were recorded during a period of 4 weeks. The information obtained was carried out using the SPRO v.990 system.

Experimental procedure

Standardized warm-up (5′ free self-pace aerobic running, 3–5′ active stretching, 2 × 10 Spanish double-leg squat, 1 × 8 front lunge, 1 × 6 lateral lunge, 1 × 12 bridge bipodal, free skipping, 1 × 5 Squat Jump and 1 × 5 Drop Jump of 45 cm) was carried out before tests.

Immediately after complete warm-up, participants' skin was dried with alcoholic solution and the GPS devices were placed on 3 different

Table 1
Demographic characteristics of the participants.

	Height	Weight	Age
Average	177,42	74,58	38
Median	176,00	74,25	39
Sample variance	37,44	12,44	64
Standard deviation	6,12	3,53	8

selected places: 1) Thoracic spine T4 region (at the interscapular level), 2) at L5-S1 vertebrae and 3) at 2 fingers above the peroneal malleolus in the ankle joint. After placing, and always 3 min after the warm up had ended, participants performed 2 DJ45 cm repetitions on each surface tested followed by the 3 valid jumps as a familiarization phase. In order to avoid fatigue influence, the order from the surfaces were randomized. All assessments were performed at the same time of day. All measurements were carry out without shoes.

Statistical analysis

For the parametric measurements, different descriptive statistics as mean, standard deviation (SD) and 95 % confidence interval (CI) were calculated, while for a non-parametric measurements quartiles and Interquartile values (IQR) were studied. Shapiro-Wilk test was used to calculate normality sample response. When comparing surfaces, parametric test (Paired *t*-test) or a non-parametric test (Wilcoxon test) were calculated, depending normality. With respect to sensor position, the Friedman non-parametric test has been used, since it treats 3 related samples. Once it is confirmed that the differences are statistically significant, to carry out the 2 to 2 differences between the recording heights, a Wilcoxon test or Paired *t*-test (non-parametric or parametric, respectively) was used. All inferential statistical analysis has been carried out with the R statistical software. A significance of $p < 0.05$ has been considered.

Results

The characteristics of the participants in this study can be consulted in Table 1.

The results obtained in our study show how there were significant differences in the tested values obtained, depending on the moment of the jump analyzed and the height position of the recording device. Also, statistically significant differences were shown in the analysis of the work surface, confirming the hypothesis raised at the beginning of this study.

Table 2 shows impact magnitudes on jump reception depending on the surface, showing statistically differences at the ankle level ($p = 0.03125$) and low back region ($p = 0.03125$), while no statistically significant differences were observed in thoracic spine T4 height ($p = 0.2621$). Also, no statistically significant differences were observed in any of the recorded heights measured ($p = 0.1402$; $p = 0.6875$; $p = 0.9783$), as shown in Table 3.

The comparison of all the impact records for the same surface without taking into account the jumping height can be consulted in Table 4. The results obtained show, at the C1TG moment, how there are statistically significant differences both in the sand ($p = 0.002479$), as in the grass (0.002479), and also shows significant differences in the CFG moment for both surfaces, the sand (p = 009,404) and the grass (p = 005,704).

In the comparative analysis by paired segments (Table 5), we observed that there were statistically significant differences in the C1TG moment, when we compared the segments of the ankle-low back region, ankle-thoracic spine T4 region and low back-thoracic spine T4 region, for sand (p = 0. 03,125 $p = 0.03125$ and $p = 0.03125$ respectively) and for grass ($p = 0.03125$; $p = 0.03125$ and $p = 0.03125$ respectively). On the other hand, in the analysis for the CFG moment we observed that there were no statistically significant differences in the analysis of the ankle-low back region in the sand ($p = 0.5625$), but differences are shown in the ankle- thoracic spine T4 region and low back- thoracic spine T4 2 segments ($p = 0.04822$ and $p = 0.03125$, respectively), as well as in all the analyzes for the 3 regions carried out on the grass ($p = 0.009628$; $p = 0.00546$ and $p = 0.007464$ respectively).

Discussion

The results obtained in our study confirm our previous hypothesis, about the existence of differences in the G forces during jumps, not only depending on the jumping surface, but also on the height where the recording device was placed.

Previous studies, described similar results when they compare different surfaces. Although they hypothesized that performing jumps on soft surfaces, such as sand, could generate lower impulses, and consequently a worse jump height, reality suggested that this not shouldn't necessarily happens because jumping pattern could change. First, while the sand would reduce the level of elastic energy used during jumps, it could also increase levels of electromyographic activation. This could be possible because jump duration could be increased to compensate the force decreased, according to the function:

$$(F * t = m * v)$$

Where, F= Ground applied force; t= time during ground force is applied; m= jumper body mass; v= Body velocity at jump beginning.

Although the main objective of this study was not to assess the influence of the type of surface on jump height, this fact is especially important, since it represents a change in the movement pattern, which represents a decrease in the levels of specificity of the task, requiring it's combination with other specific methodologies, especially in the final phases of return to train., according to the dynamic correspondence principle proposed by Verkhoshansky & Siff.[29] Similar results have been

Table 2

G-Force magnitudes. For the parametric measurements, mean and Dev. Est (SD) were calculated. For non-parametric variables, the quartiles Q_0 (Min), Q_1, Q_2 (median), Q_3 and Q_4 (Max), and in addition to the Interquartile value (IQR) were calculated. for the non-parametric measurements, in each recorded body segment and for the two surfaces analyzed at the time of contact of the first toe on the ground (C1TG) and at the time of contact of the entire foot on the ground (CFG).

	C1TG						CFG					
	Ankle		Low back		Thoracic spine		Ankle		Low back		Thoracic spine	
	Sand	Grass	Sand	Grass	Sand	Grass	Sand	Grass	Sand	Grass	Sand	Grass
Subject 1	16,17	16,13	4,93	3,9	1,7	1,5	10,67	25,93	14,57	7,9	6,2	8,27
Subject 2	13,89	11,5	3,07	2,36	1,28	0,96	19,04	51,93	14,21	17,03	8,83	8,68
Subject 3	13,7	13,01	9,8	8,49	4,45	4,14	39,04	21,23	13,6	16,53	9,82	10,4
Subject 4	13,74	11,55	2,94	2,58	1,4	1,07	23,21	25,95	15,37	13,66	11,56	8,79
Subject 5	18,82	16,59	3,74	3,38	3,06	1,94	13,3	29,73	12,08	12,71	6,93	5,89
Subject 6	31,39	31,08	9,8	8,68	5,13	5,72	11,92	53,02	23,99	18,3	10,69	12,13
Average	17,95	16,64	5,71	4,90	2,84	2,56	19,53	34,63	15,64	14,36	9,01	9,03
Stand. Dev.	±6,88	±7,41	±3,24	±2,91	±1,65	±1,94	±10,67	±14,09	±4,24	±3,80	±2,11	±2,10
Min	13,70	11,50	2,94	2,36	1,28	0,96	10,67	21,23	12,08	7,90	6,20	5,89
Q_1	13,78	11,91	3,24	2,78	1,48	1,18	12,26	25,94	13,75	12,95	7,41	8,37
Q_2 (Median)	15,03	14,57	4,34	3,64	2,38	1,72	16,17	27,84	14,39	15,10	9,33	8,74
Q_3	18,15	16,48	8,58	7,34	4,10	3,59	22,17	46,38	15,17	16,91	10,47	9,99
Max	31,39	31,08	9,80	8,68	5,13	5,72	39,04	53,02	23,99	18,30	11,56	12,13
IQR	4,37	4,56	5,34	4,56	2,63	2,41	9,91	20,44	1,42	3,96	3,07	1,62

Table 3
Shows the significant differences in the study variable at each recording height, depending on the jumping surface (sand and grass), both at the time of C1TG and at the time of CFG, with the statistical significance value. (p-value) and its 95 % CI.

		C1TG					CFG				
	Statistical	Sand	Grass	Test	P-valor	Confidence interval	Sand	Grass	Test	P-valor	Confidence interval
Anlke	Median	15,03	14,57	Wilcoxon	0.03125	—-	19,53	34,63	Paired *t*-test	0.1402	[−37.263 - 7.061]
Low back	Median	4,34	3,64	Wilcoxon	0.03125	—-	14,39	15,10	Wilcoxon	0.6875	—-
Thoracic spine	Average	2,84	2,56	Paired *t*-test	0.2621	[−0.291 - 0.853]	9,01	9,03	Paired *t*-test	0.9783	[−1.866 - 1.825]

Normality is assumed.

Table 4
Differences depending on the height of the device and the surface (sand or grass) at C1TG and CFG.

		C1TG					CFG				
	Statistical	Ankle	Low Back	Thoracic spine	Test	P-valor	Ankle	Low Back	Thoracic spine	Test	P-valor
Sand	Median	15,03	4,34	2,38	Friedman	0.002479	16,17	14,39	9,33	Friedman	0.009404
Grass	Median	14,57	3,64	1,72	Friedman	0.002479	27,84	15,10	8,74	Friedman	0.005704

Table 5
Shows the statistical significance (p-value) when comparing the height of the devices with each other on the two surfaces tested, at the time of C1TG and at the time of CFG, with a 95 % CI at the time of CPS.

	C1TG				CFG					
	Sand		Grass			Sand			Grass	
Height of the sensor 2 Vs 2	Test	P-valor	Test	P-valor	Test	P-valor	Confidence interval	Test	P-valor	Confidence interval
Ankle- Low back	Wilcoxon	0.03125	Wilcoxon	0.03125	Wilcoxon	0.5625	—	Paired *t*-test	0.009628	[7.472 - 33.080]
Ankle – Thoracic spine	Wilcoxon	0.03125	Wilcoxon	0.03125	Paired *t*-test	0.04822	[0.121 - 20.929]	Paired *t*-test	0.00546	[11.525 - 39.686]
Low back – Thoracic spine	Wilcoxon	0.03125	Wilcoxon	0.03125	Wilcoxon	0.03125	—	Paired *t*-test	0.007464	[2.169 - 8.491]

observed in body acceleration during vertical jumping when fatigue appears.[30]

On the other hand, when we impact on sand, almost 100 % of impacting energy is absorbed,[31] because sand surface dissipates ground reaction forces and decreases elastic energy accumulated during eccentric phase from stretch-shortening cycle, increasing the energy expenditure.[6] Despite this, performance in the execution of explosive actions does not appear to decrease, as a result of an increased motor unit recruitment,[32] that should compensate elastic energy lost. Studies published seem to indicate similar improvements in height jumping when they were developed in sand or green ground, especially with respect to the inertial loads generated by our body mass during the first stage of the acceleration during jumps and sprints. All this suggest that the type of surface to be used will depend on the objective pursued, which means that there is no one best surface.

On the other hand, in relation to the location of the device, we observe statistically significant differences when comparing the impact of the first toe on the grass ground with regard to sand ground, in the ankle and low back recording segments, but do not show statistical significance of the registration at the thoracic spine T4 level. This fact should make us consider the real influence and effect of the impact that we register during the training sessions monitored with the digital external load recording system that is located at the thoracic level; It does not have the same effect and magnitude at the thoracic level as on joints and musculoskeletal structures of the lower limb. We cannot really predict the effect and mechanical stress that the structures receive during training load through a result at the thoracic level that records impact values that have possibly been subjected to various automatic cushioning mechanisms by the body itself.

This statistical significance is not presented in the values of the second phase of landing, at the CFG moment, where the values do not show statistically significant differences. This fact could be explained by the cushioning role of the leg muscles, mainly the triceps surae and plantar flexors, anterior and posterior tibialis and peroneal muscles among others, which are activated at the moment of contact of the first toe on the ground to give stability to the ankle and foot, thus preparing the landing. Therefore, an energy absorption and impact cushioning effect occurs between the first and second moments of contact. This damping would cause the magnitude of the upward force vector generated at the moment of first toe contact to decrease.

There are several studies that validate the use of the sand surface as a valid surface to work on plyometrics, in conditions similar to those used to carry out this study, but none of them analyze the importance of the impact received or the incidence of ground contact moments. It is therefore an open door to continue investigating to determine the real incidence that this impact has on the joints and the absorption mechanisms that the body has.

These significant differences in the magnitude of the impact, which show that it is lower when working on a sand surface than on grass, support the argument of the work carried out in entities such as FC Barcelona, where the use of sand is seen as a useful resource for early work in the recovery of sports injuries, as long as the characteristics of the surface do not have a detrimental effect on it.

In any case, it must be taken into account that our entity work proposal usually contemplates running propulsion tasks. In this tasks, anteroposterior and medio-lateral ground reaction forces are the main protagonists against the vertical component. These components try to improve propulsion, change of direction (COD) and braking patterns that are widely used in team sports. Even the minor role, vertical forces are always present in all actions, so the magnitude of the impact can be relevant for the process. Sand work is usually applied in early periods of injury recovery, and that is why plyometrics work is not considered a priority content, as the priority is the development of basic motor skills such as linear running or the slalom. This patterns like COD produce torsional forces that should be study in future researches, that although they are difficult to evaluate they are the protagonist of our sports.

Limitations of the study

This study has some limitations. First, although the number of participants studied in this research is limited, from an ecological point of view, the samples analyzed should be as low as possible. Despite it, future studies with larger samples should be developed and assess different population groups since the results obtained could change, when different anthropometric characteristics are evaluated. Aspects such as the level and amount of body mass, tissue stiffness and body segments proportions should be considered, too, as they can affect landing mechanics.

On the other hand, it's difficult to maintain the same mechanical patterns in the different surfaces studied. It is expected that when the jumps are performed in the sand, foot position during ground contact it is expected to be different from the position adopted on other surfaces. This fact, should change fascia plantae stiffness, which could modify the level of acceleration transmitted from the ground to the rest of the segments involved. All of this suggests that the pattern studied could undergo certain modifications, which are difficult to modify. Therefore, it should be considered as a limitation.

Conclusions

The results obtained in this study suggest that the level of acceleration in sand is lower than in grass surface. The magnitude of this impact evaluated seems to have an incremental value when the WIMU recording device is located in a segment closer to the feet. The results obtained reinforce the proposition that sand is an interesting work surface that can be suitable for recovering from sports injuries, allowing early work to be carried out safely.

Future studies should be develop to stablish easy protocols to monitor accelerations levels in different body segments as foot or ankle, which would offer a more real and reliable information of how impacts are absorbed in each joint.

Conflicts of interest

None

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