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GROUND REACTION FORCES DURING MOTOCROSS TRAINING

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Abstract

Excessive ground reaction forces (GRF) stress the athlete and increase the injury risk. Motocross is a high risk sport and most of the injuries occur while miscalculated landing or while using a leg for pivoting during turning. The aim of this study was to examine in-shoe (vertical) ground reaction forces (GRF) in motocross riders during training. Nine motocross riders (all participants of the national championship) took part in this study. The athletes performed 5 laps in a motocross track and data were collected with the help of a Teckscan data logger unit. Peaks of GRFs while performing jumps were collected and studied. All data were normalized by body weight. The results have shown that the forces may reach up to 400% of the athlete's body weight in each leg.

Key words: motocross, ground reaction forces.

Introduction

Off road motorsports and especially motocross attracts an increasing number of participants over the last few years. Motocross is a motorsport which takes place in tracks of approximately 2km with human made “natural” obstacles such as jumps and turns. This landscape allows the athletes to perform jumps up to 5m height.

Motocross is considered a high-risk sport, because it includes high jumps and turns at high speed. Gorski et al. mentioned that “…injuries, in motocross, usually result from direct impact against the ground following miscalculated jumps or after loss of control of the motorcycle while in the air” (Gorski et al., 2003). There are several papers showing the high injury rate compared to other motorsports (Gobbi et al., 2005; Tomida et al., 2005; Gobbi et al., 2004; Gorski et al., 2003; Larson et al., 2009). Tomida et al. in his research mentions that motocross has about 21.4 times higher risk than trial biking (Tomida et al., 2005). The same investigators further mentioned that the injury rate is almost three times higher during training than during racing. The overall rate of injury risk in motocross (outdoor and indoor) is about 94.5% per year (Gobbi et al., 2004). There are several papers referring and analysing the severity scores, the injury patterns or even the physiological characteristics of motocross athletes (Adams et al., 2007; Colburn & Meyer, 2003; Gobbi et al., 2004; Gobbi et al., 2005; Gorski et al., 2003; Grange et al., 2009; Konttinen et al., 2007; Konttinen et al., 2008; Larson et al., 2009). The lower extremity injuries scores varies in the literature but all studies conclude that the rate is relatively high (Gobbi et al., 2004; Gorski et al., 2003; Grange et al., 2009; Sanders et al., 2011; Tomida et al., 2005).

Colburn and Meyer reported that the most common fractures (36%) were in foot and ankle (Colburn & Meyer, 2003). The most common injury mechanism is when landing from a badly executed jump or from a hyperextension of the knee while turning (Gobbi et al., 2004; Gorski et al., 2003). Since musculoskeletal injuries (i.e. bone fractures, ligament and muscle raptures, etc.) are caused from high forces and/or moments applied to the human body it is important to understand the level of the external forces applied to the lower limbs

To date there are no data regarding the ground reaction forces (GRFs) in motocross. There are researches that discus the importance and how the GRF can affect the feet and cause an injury (Ali et al., 2014; Saunders et al., 2014; Yeow et al., 2009) but none of them has ever measured them. Nathan et al. mention that the repetitive GRFs occurring during landing in figure skating, may lead to ankle and foot overuse injuries (Saunders et al., 2014). Another relevant study of Ali et al. relates the height of jump with the risk of ACL injury (Ali et al., 2014). It is evident that the study of GRF which occur in motocross training is important for the further knowledge of injury patterns, for improvement of training and for injury prevention.

It was therefore the purpose of this study to provide an indication of these ground reaction forces during motocross training. We expect that the values of these forces would be relatively high compared to other sports activities.

Methods

The study took place at a motocross circuit, with dirt terrain during March of 2014 (Figure1). Because the total length of the track was 2minutes, for the needs of the study only a part of the circuit was used, which included the needed special features.

An approval for the study to be carried out was given by the Ethics Committee of the Faculty of Sports Science at the University of Thessaly.

Figure 1
Motocross track with dirt terrain

Subjects

Nine experienced professional motocross riders (weight 76±12 kg and height 177±10 cm) took part in this study. All riders (including the Greek champion) participate at the Greek National Championship. The consent form was signed by all the participants. Additional information and anthropometric data were collected (full name, age, height, weight and training status).

Instrumentation

An *F-Scan*® System for in-shoe plantar pressure analysis with a data logger (Figure 2) was used to measure the in-shoe vertical forces.

Figure 2
F-Scan® in-shoe plantar pressure analysis with a data logger

Since the distance travelled was more than 0.5km the “data logger” option (“cable” and “wifi” options were the other two) was used. In a pilot study we collected data at a sampling frequency of 500Hz. After studying and analysing these data we then collected data at 250Hz as this sampling frequency was more than adequate to represent the forces exhibited to the foot.

Figure 3
The data-logger adjusted on the rider during the process

Procedure

A certain route was set which included jumps, woops (small continuing jumps like waves), a double jump (table-top), left and right turns. Figures 4, 5 and 6 show an athlete while performing the special features during the procedure.

Figure 4
Motocross athlete while performing a double jump

Figure 5
Motocross athlete while performing a jump

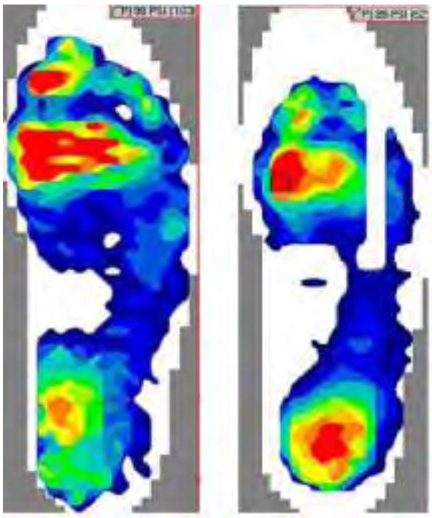
Figure 6
Motocross athlete while performing the woops

Every athlete used his own bike (250cc, 450cc) and there were no limitations in riding style. After their normal warm up on their bikes, the riders were familiarised with the unit and procedure. The F-scan sensors were placed inside their boots, which were cut to the rider's shoe size.

Figure 7
Uncut F-scan sensors

The cuffs were then connected to the sensors and these were connected to the data logger via Lan cables. Cables passed though the motocross trousers, in order to ensure that they will not interfere with the rider. Before closing the boots, a test trial was collected to ensure that the sensors were not misplaced or having a missing trace (Figure 8). Step calibration was used, meaning that each person stand still to each side for a few seconds.

Figure 8
Misplaced Missing trace



Each rider started from the predefined starting line and the data logger unit was set to record. Each trial was also timed with a stopwatch (lap time/total). Every rider had to complete five laps.

Data analysis

The data were transferred to a PC, through a USB cable in order to be analysed. The first and the last lap were excluded (first as a warm up lap, last because of slowing down) keeping three laps for further analysis. After data transfer the movies were examined for possible sensor's deformations during riding. If this was evident a movie was excluded from further analysis.

All movies were filtered in order to exclude the "noise" from around the footprint (possibly created from crumpled edges of the sensor / rocks e.t.c.) that could affect the data collection. The max force vs time series data were transferred to Excel (Appendix example 1). A file for each rider was created with all the data, which also were transferred to the SPSS. All values were normalized to body weight. Each trial was divided in smaller parts and each part was classified depending on the task (jump, woops, turning, etc.). The maximum vertical force of each task for each or both feet was recorded (Appendix example 2).

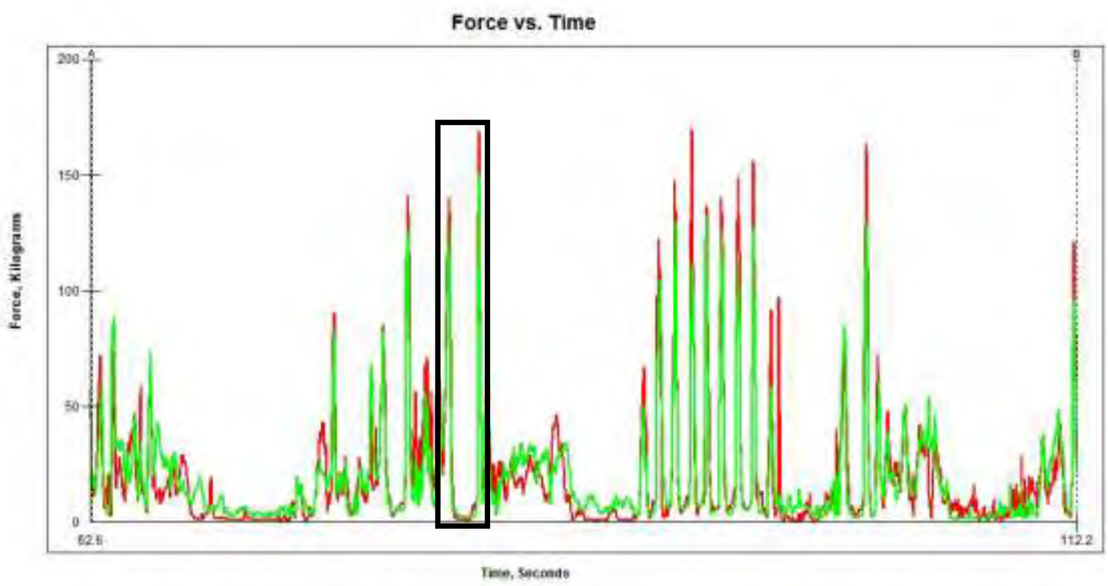
Statistical analysis

Descriptive analysis was used to measure percentiles and more specifically the amount of time expressed as a percentage of the total time that the rider experiences vertical forces of more than 200%, 300% and 400% of body weight. A correlation was performed in order to see if there is a relation of taking off and landing in a jump.

Results

A typical lap included jumps, a double jump and woops. Figure 9 shows the force–time relation for a typical lap for each foot (red: left foot and green: right foot). Time is represented in seconds (sec) and forces were expressed in BW (kg). In this graph it can be seen the peaks off each foot separately while performing the special features.

Figure 9
Vertical force-time data of a typical lap. Right (green) and left (red) sides. The framed part of the graph presents the double jump (Figure 10)



For better understanding of the graph it will be zoomed in a specific part of where a double jump is performed (figure 10).

Figure 10
The peaks while taking off and landing on a double jump

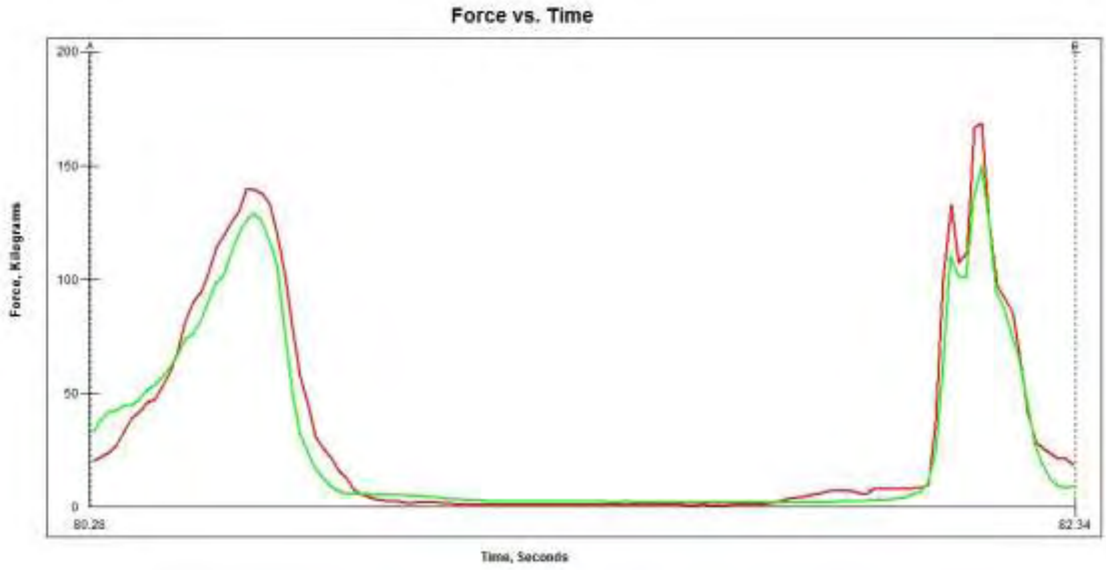


Figure 10 shows the peak force while taking off, during the flight the values tend to zero and then while landing, the values of the forces are upraised sharply. In order to understand exactly the size of the loads shown in Figure 10 it can be seen that while landing the peak rises up to 171.7kg on the left foot and 152.3kg for the right, so considering that the body weight of the athlete is 73.0 kg, then the GRFs are 235% of his body weight for the left and 208% for the right or 443% in both feet.

Table 1
The GRFs in both feet during the 3laps most of the time on the track, was less than one time their body weight.

athletes	Percentage up to 100% B.W.
1	91.1
2	91.1
3	87.2
4	87.6
5	88.7
6	86.4
7	88.0
8	84.7
9	85.3

The excessive forces occurring on their feet while training could possibility lead to an injury. As seen in Table 1 most of the racing time in our track the forces are less than one time the body weight for both feet. That changes when the athletes had to perform the special features of the track. Moreover the GRFs are more hazardous separately for each leg. For that reason the forces that happed in each leg were collected and normalised by body weight. Table 2 shows the time during the 3 laps that the forces excess the 100%, 200% and 300% respectively, of the athletes' body weight in each leg.

Table 2
Percentage of time in which the forces are greater than the 100% of their body weight for each foot

athletes	left>100%	right>100%	left>200%	right>200%	left>300%	right>300%
1	4.34	2.57	0.48	0.04	0.00	0.00
2	5.36	2.14	1.33	0.05	0.10	0.00
3	2.71	4.74	0.43	0.03	0.01	0.00
4	4.70	2.75	0.99	0.24	0.08	0.02
5	3.22	2.56	0.03	0.07	0.00	0.00
6	5.44	3.54	0.50	0.11	0.00	0.00
7	4.06	3.66	0.27	0.11	0.00	0.00
8	6.40	3.28	1.69	0.08	0.18	0.00
9	2.26	4.63	0.09	0.51	0.00	0.02

Percentage when greater than 100% includes the values of 200% and 300%. The same applies for values greater than 200%, which includes the higher rates.

Table 3 represents the maximum peak of each athlete's foot. All the athletes reach more than 200% of their body weight in each foot when performing specific features of the track. In some cases it can exceed up to 400%.

Table 3
Higher value of GRFs in each foot for each athlete

athletes	left_max	right_max
1	264%	235%
2	393%	242%
3	313%	229%
4	424%	348%
5	217%	266%
6	283%	250%
7	257%	227%
8	371%	251%
9	235%	324%

Peaks for each leg are not in the same feature, neither in the same time, they are collected in order to be seen the dreaded GRFs.

Jump / landing

It was shown that while taking off for a jump the peaks of the GRFs were relatively high (Figures 11 and 12). For that reason take-off and landing were tested for significant relation.

Figure 11
Take-off and landing peaks
*red: left foot/green: right foot

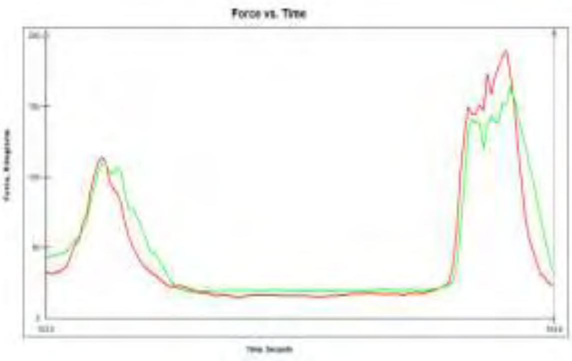
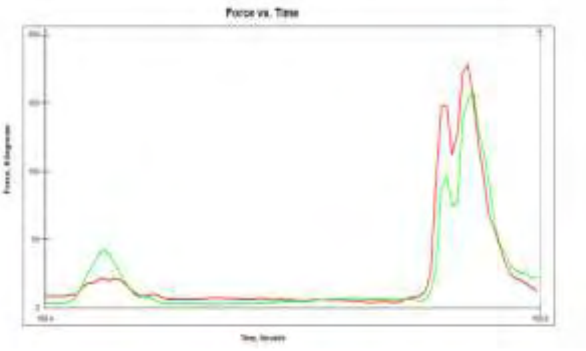
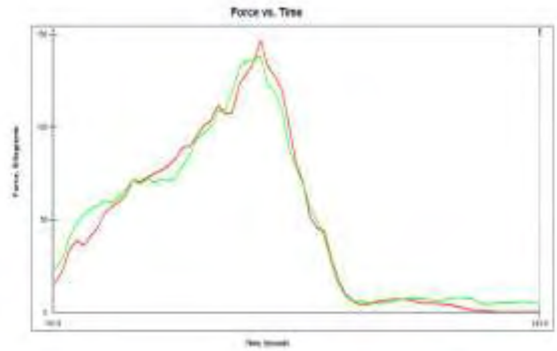


Figure 12
Take-off and landing peaks
*red: left foot/green: right foot

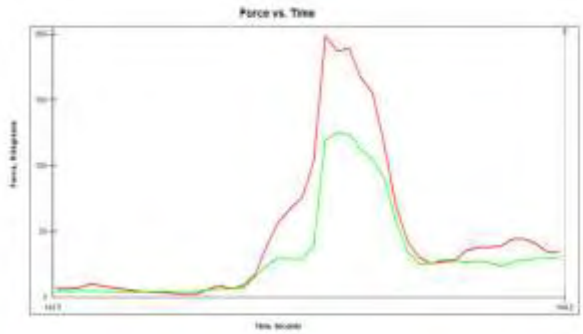


A high positive relation was found between taking off and landing in the cases which take-off was after a left turn, the second jump of every lap. In the second lap the jump - landing correlation was T=0.8 , $p<0.05$ (p=0.005) , in the third lap T=0.8 , $p<0.05$ (p=0.008) and in lap four T=0.8 , $p<0.05$ (p=0.011). This is possibly related to the fact that the athletes had limited time and space to accelerate in order to perform the jump.

take-off
*red: left foot/green: right foot



landing
*red: left foot/green: right foot



In take-off and landing pictures it can be seen the GRFs peaks in both left and right foot. It can be discerned that while in the air the GRFs are close to zero until the moment of touching the ground again.

The hypothesis also assumed that the forces would be also excessive while turning because of using the leg for pivoting. In Figures 13 and 14 can be distinguished the difference between the riding style while using the leg for pivoting or not.

Figure 13
Motocross rider while turning, not using his leg for pivoting

Figure 14
Motocross rider while turning, using his leg for pivoting

Because every athlete has his own riding style they do not all use their leg for pivoting when turning. But even when they do, they do not actually step on it unless if it is necessary. For that reason it was not possible to collect data from all the athletes, and the comparison would not be equal.

Discussion

The aim of this study was to collect and evaluate the GRFs that happen during motocross training. Because of the high rates of injuries in lower extremities and because most of the injuries in motocross happen after losing control of the bike while performing a jump (Barnett & Teasdall, 2008; Gobbi et al., 2004; Gorski et al., 2003; White et al., 1999). In response to that fact the collection and the evaluation of the Ground Reaction Forces (GRFs) considered important.

The jumps in motocross are not like any other sport, deference’s for the athlete because of being on a bike. Although suspensions absorb forces when landing, the peaks of the GRFs that affect the riders are relatively high. In addition to that when a fall happens there are no suspensions to absorb the forces. The results had shown that the loads during training, most of the time, were less than one time their body weight. But there were peaks during performing jumps or woops that the stress could reach up to three or four times their body weight in each leg. That stress is very high and even with the protective gear the injury can be severe, that may even cause long-term morbidity. There are cases in which because of a miscalculation or loss of control of the bike there were severe bilateral ankle injuries (Barnett & Teasdall, 2008; White et al., 1999), which agrees with our hypothesis that excessive GRFs may cause injuries.

The non-significance correlation between taking off and landing for a jump leads to the conclusion that depends to the technique and skills of each rider. Each rider has his own technique of how to control the bike in order to be given a smoother take-off and landing.

Motocross is proven to be a high risk sport; in every training or race the riders are risking their body integrity. This is something that depends from various factors (Gorski et al., 2003; Grange et al., 2009). Some of them cannot be predicted or prevented, but expanding the knowledge in new aspects can prepare and protect the rider. The stress while landing can cause lower extremity injuries, let alone when a fall happens. There are studies that evaluated the GRFs in sports involved populations which shows that the high peaks could lead to an injury (Ali et al., 2014; Saunders et al., 2014; Yeow et al., 2009). Ali et al. in their research the subjects perform a single leg landing from 20cm, 40cm and 60cm platform with GRF peaks 3.36±0.71, 4.62±1.12 and 5.35±1.14 respectively, which results to a higher risk of anterior cruciate ligament injury (Ali et al., 2014).

Although the protective gear is specially designed for the needs of the riders, lower extremity injury rate is still high. So the comprehension of the size of forces that affect the riders are consider important for the further understanding of injury patterns. The most common case of lower extremity injuries, after bad landing, are tearing of ligaments either angle or knee (Barnett & Teasdall, 2008; Colburn & Meyer, 2003; Gobbi et al., 2004; Gorski et al., 2003; Sanders et al., 2011; White et al., 1999). In a motocross race the athlete has to race for at least twenty minutes for two sessions with a small break in between. Another reason for a fall that may happen is because of the muscle fatigue. Most of the injuries are not avoidable because of the falls, for that reason the good physical state of the athlete should be emphasised. Techniques of falling could play a significant role in injury prevention. This information could be applied for the improvement of the riding techniques while training. Until now only the experience of a rider could improve the specific skills, but with this information the comprehension and the improvement of the training methods may help even the new athletes and decrease the possibilities of an injury.

This study revealed the size of the ground reaction forces. This may help to the better understanding of injury mechanisms in motocross, and improvement of training techniques.

Limitations

We acknowledge that the study was run with a small sample and that the level of the athletes was high but only for the Greek standards. The results could be differing if the sample was bigger and the level of the athletes was world championship. If riders of higher level were tested then maybe they could try to use their leg for pivoting when turning, in order to get results for that, which was in the original hypothesis. While riding the athletes are not always standing on the pedals they are also sitting on the seat of the bike. Another limitation was that we did not measure the time and the forces while sited. A factor that may, also, vary the results is the kind of terrain of the track, dirt, sand or mud and the difficulty level with more difficult features. One more parameter that could be evaluated would be the muscle contraction. The use of electromyography, in order to collect data in the same time in order to estimate how, when and which muscles are activated when the GRFs happen.

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Appendix

Example 1. Example of data in Excel basis of an athlete's effort (shortened).

Frames	Time (sec)	Force (kg)			Weight (kg)	Force / Weight
		Left	Right	Total		
12589	50.352	51.6	37.5	89.1	76.0	1.2
12590	50.356	50.0	38.4	88.4	76.0	1.2
12591	50.36	50.7	37.8	88.5	76.0	1.2
12592	50.364	52.8	39.5	92.3	76.0	1.2
12593	50.368	54.6	40.7	95.3	76.0	1.3
12594	50.372	56.0	41.3	97.3	76.0	1.3
12595	50.376	56.5	42.4	98.9	76.0	1.3
12596	50.38	57.5	43.8	101.3	76.0	1.3
12597	50.384	59.5	44.1	103.6	76.0	1.4
12598	50.388	60.2	44.9	105.1	76.0	1.4
12599	50.392	58.8	43.5	102.3	76.0	1.3
12600	50.396	58.2	42.8	101.0	76.0	1.3
12601	50.4	57.8	41.1	98.9	76.0	1.3
12602	50.404	56.2	38.1	94.3	76.0	1.2
12603	50.408	51.8	34.5	86.3	76.0	1.1
12604	50.412	47.6	30.3	77.9	76.0	1.0
12605	50.416	43.7	26.6	70.3	76.0	0.9
12606	50.42	41.2	20.8	62.0	76.0	0.8
12607	50.424	37.4	17.6	55.0	76.0	0.7
12608	50.428	33.5	13.9	47.4	76.0	0.6
12609	50.432	32.1	12.3	44.4	76.0	0.6
12610	50.436	30.0	10.2	40.2	76.0	0.5
12611	50.44	29.0	8.4	37.4	76.0	0.5
12612	50.444	27.2	7.3	34.5	76.0	0.5
12613	50.448	24.5	5.4	29.9	76.0	0.4
12614	50.452	23.9	4.1	28.0	76.0	0.4
12615	50.456	21.7	2.8	24.5	76.0	0.3
12616	50.46	21.3	2.2	23.5	76.0	0.3
12617	50.464	20.1	1.5	21.6	76.0	0.3
12618	50.468	19.5	1.4	20.9	76.0	0.3
12619	50.472	17.9	1.1	19.0	76.0	0.3
12620	50.476	16.2	0.9	17.1	76.0	0.2
12621	50.48	15.6	0.8	16.4	76.0	0.2
12622	50.484	14.5	0.6	15.1	76.0	0.2
12623	50.488	13.1	0.6	13.7	76.0	0.2
12624	50.492	11.9	0.5	12.4	76.0	0.2

Example 2. Example of separated GRFs peaks of an athlete.

	A	B	C	D	E	F	G
1				Round 2			
2		time	left	right	total	weight	
3	Jump						
4	15394	61.572	102,0	88,6	190,6	76,0	2,51
5	15396	61.58	103,5	86,6	190,1	76,0	2,50
6	Landing						
7	15695	62.776	192,3	129,7	322,0	76,0	4,24
8	15701	62.8	184,1	147,3	331,4	76,0	4,36
9	Double						
10	16109	64.432	143,5	117,1	260,6	76,0	3,43
11							
12	Landing						
13	16482	65.924	177,1	116,0	293,1	76,0	3,86
14	16487	65.944	154,5	129,9	284,4	76,0	3,74
15	Woops						
16	18431	73.721	147,6	129,8	277,4	76,0	3,65
17							
18	18653	74.609	158,9	95,8	254,7	76,0	3,35
19							
20	18767	75.065	121,2	109,6	230,8	76,0	3,04
21							
22	18958	75.829	143,7	64,9	208,6	76,0	2,74
23							
24	19116	76.461	84,9	44,5	129,4	76,0	1,70
25							
26	19308	77.229	156,7	84,9	241,6	76,0	3,18
27							
28	19538	78.149	75,7	87,0	162,7	76,0	2,14
29	Jump						
30	20383	81.529	26,0	24,2	50,2	76,0	0,66
31	Landing						
32	20673	82.689	158,8	136,8	295,6	76,0	3,89
33	20678	82.709	157,5	146,8	304,3	76,0	4,00
34	Jump						
35	22805	91.217	60,4	52,4	112,8	76,0	1,48
36	Landing						
37	22980	91.917	106,6	63,1	169,7	76,0	2,23
38	22992	91.965	140,6	62,9	203,5	76,0	2,68

	I	J	K	L	M	N	O
1				Round 3			
2		time	left	right	total	weight	
3	Jump						
4	25795	103.177	103,6	85,6	189,2	76,0	2,49
5	25796	103.181	103,3	86,8	190,1	76,0	2,50
6	Landing						
7	26113	104.449	177,1	120,7	297,8	76,0	3,92
8	26116	104.461	161,9	133,1	295,0	76,0	3,88
9	Double						
10	26507	106.025	154,9	130,3	285,2	76,0	3,75
11	26508	106.029	157,7	127,1	284,8	76,0	3,75
12	Landing						
13	26898	107.589	184,4	134,5	318,9	76,0	4,20
14	26910	107.637	162,7	178,6	341,3	76,0	4,49
15	Woops						
16	28808	115.229	144,2	113,5	257,7	76,0	3,39
17							
18	29015	116.057	174,2	147,0	321,2	76,0	4,23
19	29017	116.065	170,5	151,0	321,5	76,0	4,23
20							
21	29236	116.941	165,7	118,4	284,1	76,0	3,74
22	29420	117.677	153,8	87,8	241,6	76,0	3,18
23							
24	29604	118.413	170,6	112,6	283,2	76,0	3,73
25							
26	29803	119.209	169,0	147,3	316,3	76,0	4,16
27							
28	30006	120.021	149,3	88,3	237,6	76,0	3,13
29	Jump						
30	31071	124.281	27,7	29,1	56,8	76,0	0,75
31	Landing						
32							
33	31367	125.465	140,7	116,9	257,6	76,0	3,39
34	Jump						
35	33462	133.845	62,9	31,6	94,5	76,0	1,24
36	Landing						
37	33648	134.589	135,7	86,5	222,2	76,0	2,92
38	33649	134.593	134,6	87,0	221,6	76,0	2,92

	Q	R	S	T	U	V	W
1				Round 4			
2		time	left	right	total	weight	
3	Jump						
4	36445	145.777	95,5	111,3	206,8	76,0	2,72
5	36448	145.789	96,0	97,4	193,4	76,0	2,54
6	Landing						
7	36758	147.029	200,3	155,5	355,8	76,0	4,68
8	36759	147.033	196,9	156,5	353,4	76,0	4,65
9	Double						
10	37139	148.553	179,1	149,2	328,3	76,0	4,32
11							
12	Landing						
13	37528	150.109	141,8	114,6	256,4	76,0	3,37
14	37531	150.121	137,4	118,9	256,3	76,0	3,37
15	Woops						
16	39401	157.601	83,6	25,5	109,1	76,0	1,44
17							
18	39503	158.009	143,6	124,2	267,8	76,0	3,52
19	39505	158.017	133,4	131,0	264,4	76,0	3,48
20	39719	158.873	114,3	79,7	194,0	76,0	2,55
21							
22	39801	159.201	115,4	79,8	195,2	76,0	2,57
23							
24	40341	161.361	123,0	88,5	211,5	76,0	2,78
25							
26	40580	162.317	112,6	44,5	157,1	76,0	2,07
27							
28							
29	Jump						
30	41259	165.033	17,9	15,0	32,9	76,0	0,43
31	Landing						
32	41664	166.653	136,7	94,2	230,9	76,0	3,04
33	41666	166.661	118,1	111,7	229,8	76,0	3,02
34	Jump						
35	43694	174.773	66,2	52,9	119,1	76,0	1,57
36	Landing						
37	43923	175.689	124,3	63,6	187,9	76,0	2,47
38	43924	175.693	123,9	65,4	189,3	76,0	2,49

Questionnaire

Επώνυμο

Όνομα

Ηλικία

Βάρος

Ύψος

Εμπειρία (πόσα χρόνια προπονείστε)

Παρατηρήσεις / σχόλια