WHAT WOULD IT TAKE TO BREAK THE WORLD RECORD IN THE MEN'S TRIPLE JUMP?

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As I'm preparing to collect data on our Aspire athletes at the World Youth Games in Gothenberg, I can't help but recall that iconic moment inside the Ullevi stadium when Jonathan Edwards broke the men's triple jump world record twice in the 1995 World Championships. Inessa Kravets also broke the women's record. Both these world records still stand today, some 24 years later at distances of 18.29 m and 15.50 m respectively. The long jump world records are even older, begging the question why do they remain so elusive in this age of sports science, medicine and technology?

CAN BIOMECHANICS HELP?

I had the privilege of providing biomechanical support to Jonathan Edwards and the British horizontal jumps squads for 21 years, in what was a golden era for jumps in the UK. The focus of the support was to provide information that explained performance and could be used to monitor progress and identify development needs. There was very little information on elite athletes in the early days; researchers therefore had to observe performance and use objective methods to quantify movements and their outcomes. Moving forwards 30 years and we now have 'biomechanics' being an integral part of coach education, organizational structures and manifesting itself in strength and conditioning (S&C) and physiotherapy professions. At a certain level 'everyone is a biomechanist' because video technology and Apps are widely available. Sadly, the subtleties of camera set-up and vantage points are often neglected, which means that even simple measurements and observational comparisons between performances can be inaccurate. This is also often combined with a very limited understanding of fundamental principles. At the 'highest' level you have the 'experts' who often have limited interaction with coaches and believe that sophisticated technology justifies their input. They often provide coaches with information that they already know, or confuse them with overwhelming reports that give them nothing meaningful to work from. Effective biomechanists should assist the coach in developing a technical model of performance, measure appropriate metrics and work alongside the physiotherapist and S&C coach to conduct supplementary assessments to determine if the athlete has the correct physical attributes to deliver the technique. They should utilize technology where appropriate to provide immediate feedback within training sessions (and soon after competition), and have a thorough knowledge of the athlete and understanding of the event to discuss intervention strategies with the coach. Biomechanists have to move on from simply quantifying outcome parameters and reporting movement patterns. If they cannot give the coach, S&C or physiotherapist any tangible advice that assists in performance enhancement then they are not effective.

UNDERSTANDING WHAT COACHES NEED

There have been two to four official biomechanical research projects at World Championships since 1995 – Athens 1997, Berlin 2009, London 2017 and Birmingham 2018, and a project at the Olympic Games in Atlanta 1996. These are amazing resources of interesting metrics and help to develop our understanding of performances in the highest level of competition. They build on previous work done in the 1988 Olympic Games and the 1991 World Championships and the many research articles which were summarized in a review of triple jump[1]. The comments I often hear from coaches is "how do we use it?", and "the analysis of a single performance is interesting, but an athlete performs hundreds of jumps in training and competition each year", "the jump analysed wasn't his seasons best". Coaches need to be able to identify elements of technique that differentiate between the best and less successful jumps. To make biomechanics usable we need to build profiles of our athletes and find practical ways to monitor metrics in training and competition so the information is integral to performance planning.

UNDERSTANDING THE EVENT

Putting it in simple terms: the objective of the triple jump is to create maximal displacement from the front of the board to the heel (or last point of contact) in the sand pit following a fast approach, a hop (landing on the same leg as take-off), a step (landing on the opposite leg) and a jump (landing on two legs in the sand). To make all the athlete's effort count they should also minimize the distance of the toe behind the front of the board, although this is a secondary concern to getting the technique correct.

In the 1990's researchers and coaches were trying to establish if there was an 'optimal phase ratio', the percentage contributions of the hop, step and jump distances relative to the effective distance (figure 1). It became apparent that there was no optimal phase ratio and instead it was suggested that each athlete had their own 'best way' of distributing their effort. There were some good general guidelines, the step distance is almost always the shortest distance (typically accounting for 27-30%), and the longest phase (hop or jump) should not be above 39% (which is still quite excessive). Some coaches like to classify performances as 'hop dominated', 'balanced' or 'jump dominated'[1]. If the longest phase is 2% or more greater than the second longest phase they would be deemed to have a dominance (e.g. hop or jump), if they are within 2% of each other the performance is classed as 'balanced'.

In the mid 1990's we adopted these classifications and examined the developmental aspects of the triple jump phase distances for both male and females from British Championships at youth, junior and senior level and from international grand prix events[2]. We observed stepwise progressions in each phase and switches in emphasis from hop dominated to balanced; jump dominant performances in our data were minimal. We have since extended this database to 452 jumps in the men's triple jump alone covering a performance range from 13.54 m to 17.99 m (effective distance). Jump dominant performances became more common at the elite end. Giving this a little more context, to win a medal in the World Championships or Olympics you would need to jump around 17.60 m, and even using a jump dominant technique you would still need to hop around 5.75 m.

TECHNIQUE

Given the incredibly high ground reaction forces that triple jumpers experience when landing into the step and jump (15 to 20 × body weight [BW]), it is imperative that athletes are conditioned appropriately to withstand these loads. Here lies a dilemma! We can reduce these ground reactions forces very easily by

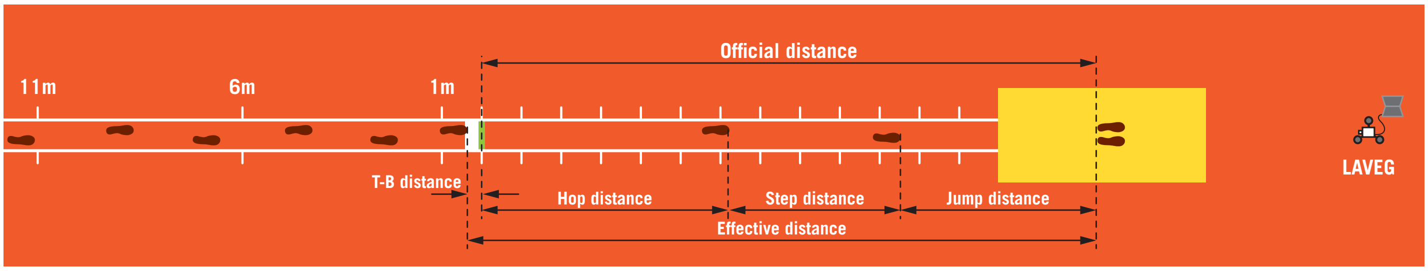

Figure 1: Measurement of phase distances and relationship to official and effective distances.

TABLE 1

Round	Official dist. (m)	Wind speed	Approach speed			Toe-board (m)	Effective distance (m)	Hop		Step		Jump	
			11 - 6 m (m/s)	6 - 1 m (m/s)	Ave. 11 - 1 m (m/s)			Distance (m)	Ratio (%)	Distance (m)	Ratio (%)	Distance (m)	Ratio (%)
1	NJ	1.3	10.24	10.52	10.38	-0.01		5.79		5.09			
2	17.32	0.6	10.37	10.51	10.44	0.14	17.46	5.84	33.4	5.28	30.2	6.43	36.3
3	17.81	0.6	10.32	10.63	10.48	0.11	17.92	6.09	34.0	5.32	29.7	6.51	36.3
4	17.57	1.6	10.30	10.51	10.40	0.03	17.60	5.89	33.5	5.19	29.5	6.52	37.0
5	16.65	0.8	10.47	10.55	10.51	0.06	16.71	6.20	37.1	5.06	30.3	5.45	32.6
6	17.69	0.5	10.40	10.57	10.48	0.06	17.75	6.07	34.2	5.16	29.1	6.52	36.7

Table 1: Approach speed and phase breakdowns for Christian Taylor at the Diamond League, Doha, May 4th 2018.

cushioning the contact, landing on toes and absorbing force with ankle, knee and hip flexion, but this will destroy the performance. Ground contact time will increase, greater losses in horizontal speed and the enhancement and reactiveness from fast stretch-shorten cycles in the muscle-tendon will be diminished. This initial impact force can be used effectively to generate vertical impulse providing they have good technique and the right physical attributes to control it.

Key considerations when the athlete makes contact with the ground:

- Must land on the heel (or at the worst flatfoot), but never on the toes. This helps to establish a firm base of support as quick as possible. Toe contacts can throw the athlete off balance.
- Contrary to popular belief, the leg is planted in front of the body at touchdown. Television (TV) presenters commented that Jonathan Edwards' leg landed directly under his body, but this was an inaccurate observation due to TV footage being reviewed at 25 frames per second (fps). Our analyses from high speed cine film at 100 fps clearly showed that his ankle was in front of his body at touchdown. While the angle of leg plant is less than that in the long jump and high jump it does have an important function acting as a lever to generate vertical velocity.
- The touchdown leg should be active on the landing, i.e. sweeping backwards just prior to contact. This engages the hip extensors and helps to reduce horizontal braking forces and the loss in horizontal velocity.
- The knee should not be fully extended at contact, and should be eccentrically strong enough to resist excessive flexion. As a guide, in the hop take-off the knee should not flex below 135 degrees and in the step and jump 125 degrees[3].
- The trunk should be close to upright and avoid excessive forward flexion. The percentage of total body weight above the hips is around 60%, so control of the trunk position is crucial to maintaining balance in the take-offs.
- In the frontal plane the foot should land underneath the body with slight trunk inclination to the side of the support leg. This reduces the moment arm of the vertical ground reaction force and helps to minimise hip adduction and dropping of the pelvis. This allows the arms and the swinging leg to be used more productively rather than as balancing aids.

WHAT WILL IT TAKE TO BREAK THE WORLD RECORD?

The double Olympic Champion and triple World Champion, Christian Taylor has jumped over 18 m on a handful of occasions and has a personal best of 18.21 m. This is the second longest legal jump in history and is the closest anyone has gotten to the world record. If there is anyone who can break the world record, he is definitely a candidate. With video and speed analysis captured on Christian in both the training environment and in the Doha Diamond League in 2018, we will present some analysis to demonstrate how biomechanics can be used and what it

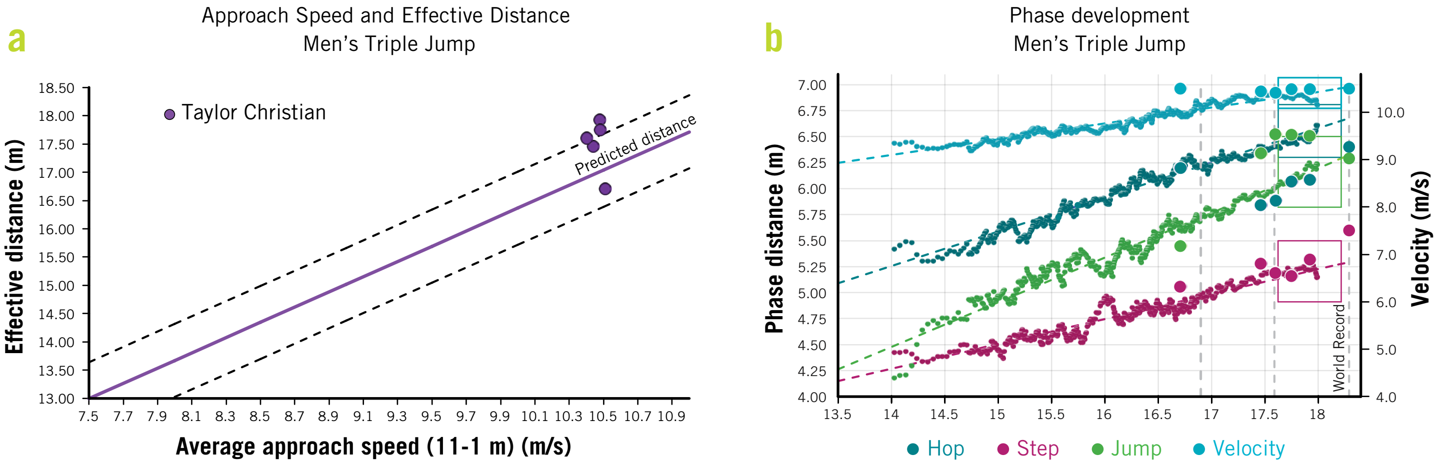

Figure 2: Graphical representation of Christian's speed, and phase distance data against effective distance. Regression lines based on continuation of the work of Graham-Smith and Lees[3,4].

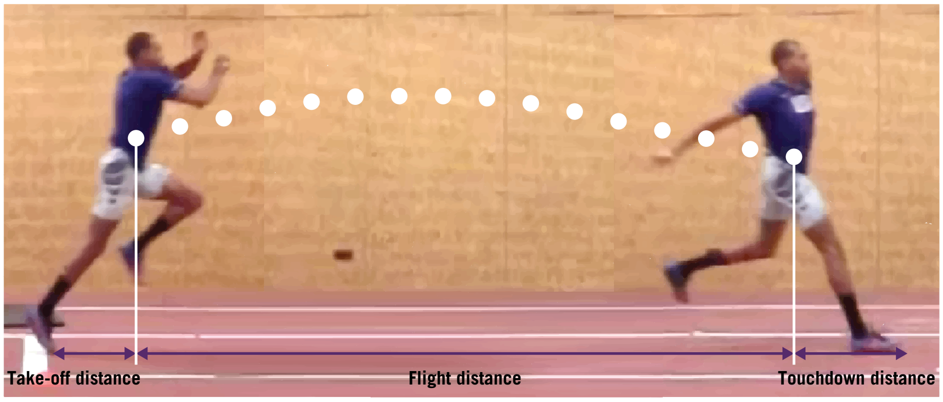

Figure 3: Touchdown, Take-off and Flight distances.

would take for Christian to break the World Record.

Approach speed data was collected using a Laveg LDM 300C device positioned at the end of the pit (Figure 1). From this we extracted the average speeds across 11-6 m, 6-1 m and 11-1 m. Small strips of white tape placed at 1 m intervals provided a calibration reference to determine hop, step and jump distances from positions of the toe in each take-off. The effective distance was calculated by adding the toe-to-board distance to the measured official distance.

From Christian's data in Table 1, the first thing to consider is how well he utilized his approach speed. When we plot his approach speed (11-1 m) against effective distance we see that he jumps further than the predicted distance based on our regression equations (Figure 2a). This indicates that he had good speed utilization and that his technique, control and distribution of effort through the three phases was effective. His hop, step and jump distances map onto the phase distance lines (Figure 2b), albeit that the hop and jump distance are reversed because he is a jump dominant jumper. This demonstrates that there wasn't an imbalance of effort in his phase distribution. With the exception of rounds 1 and 5 it would seem like a phase ratio of around 34.0:29.5:36.5 is appropriate for him. Giving him a notional 5 cm toe-to-board so he doesn't foul, to break the world record he would need an effective distance of 18.34 m. Based on his phase ratio this would be broken down into a 6.24 m hop, 5.41 m step and a 6.69 m jump (assuming zero loss in the landing).

Using video footage from training jumps and the Diamond League we measured the angles of the trunk, hip, knee and ankles of both legs at key instants throughout the jump. Entering these angles and segment lengths into our model allows us to estimate where the centre of mass (CM) is relative to his take-off leg at the instants of touchdown and take-off. From this we can quantify touchdown and take-off distance and how far the CM travelled during each flight phase (see Figure 3). Timings of the flight phases allowed us to determine the horizontal and vertical velocities at take-off and touchdown and changes during contact.

Assuming that Christian adopts similar landing and take-off positions (this is fairly consistent in training) and that the losses in horizontal velocity are similar to his 17.92 m performance in Doha (-0.32 m/s, -0.51 m/s and -2.37 m/s) then a world record performance could be achieved primarily by increasing his approach speed from 10.7 m/s to 11.0 m/s. A small reduction in last step length to 2.00 m (Figure 4) would mean that that he contacts the board with zero vertical velocity rather than -0.10 m/s. To attain the phase ratio of 34.0:29.5:36.5 in an 18.34 m performance the increase in speed would extend his hop by 15 cm without any need to generate more vertical impulse. His landing vertical velocity would increase slightly from -2.67 m/s to -2.76 m/s and he would need to develop a little more vertical impulse to increase the step distance by 9 cm. In reality most of this could come from his ability to resist hip and knee flexion in response to a slightly greater impact force. The hop-step distance would now be 11.66 m, leaving a jump of 6.69 m to break the World Record. Having carried the extra 0.3 m/s horizontal speed through to the jump take-off the vertical landing and take-off velocities would be similar to Doha at -2.40 and -2.50 m/s requiring a total gain in vertical velocity of 4.90 m/s.

There are numerous velocity combinations that could lead to a new world record, but as a coaching strategy this one is plausible, and easily quantifiable in training and competition. An alternative strategy would be to achieve the phase distances by developing greater vertical velocities at take-off. The downside to this

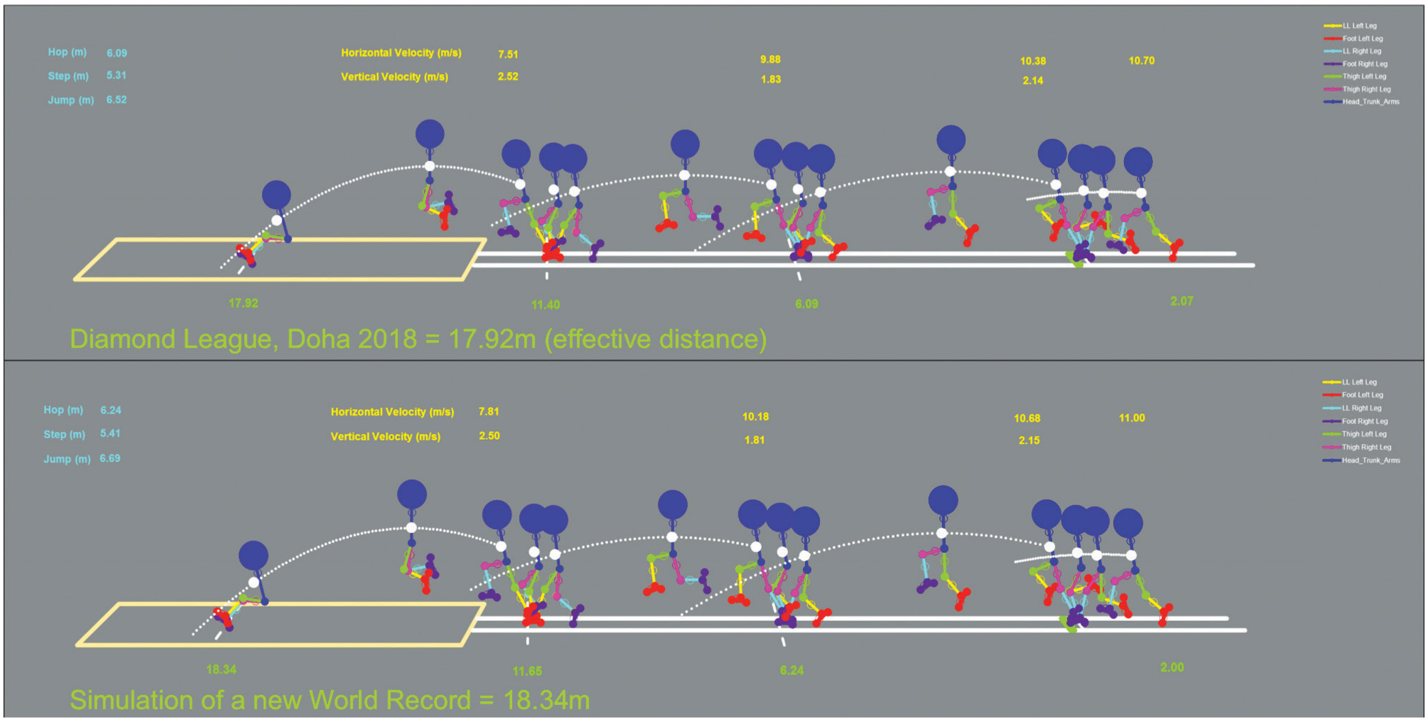

Figure 4: Technical analysis of Christian's Diamond League performance and simulation of a World Record Jump.

is that as the CM goes higher it leads to much greater vertical impact forces which need to be controlled, and this would also be compounded by greater losses in horizontal speed. Given Christian's 400 m sprinting ability, the development of more horizontal speed on the runway would be a safer and more realistic option. An approach speed of over 11.0 m/s is not unreasonable for an elite triple jumper. Mike Conley adopted a jump dominated technique, he was able to approach the board at a similar speed as he did in the long jump, typically 11.0 to 11.3 m/s[5].

PHYSICAL ATTRIBUTES

Whilst approach speed generally has a very strong association with performance[4] the fastest jumpers do not always win. Within fields of world class jumpers, the winner will often be the one who can control their speed and associated forces of impact in the step and jump take-offs, not lose balance and maintain speed through to the jump take-off. To help bridge this connection between speed, technique and 'control' we profiled the physical attributes of UK horizontal jumpers over many years, establishing normative data around speed, strength, power, reactive strength and multi-hop/ bounding ability[6].

Speed:

Athletes perform 3 maximal 40 m sprints to record their best times over 20 m, 40 m and split time (20 m-40 m). We use a Laveg speed gun as we can also get an instantaneous maximum speed, although photocells are another option. One foot is placed 0.5 m behind the 'zero' line to define the starting position.

Strength:

The isometric squat test gives us a very good indication of the athlete's maximal strength in a position that closely resembles the mid part of the take-off. The trunk (body) is upright and the knee angle is set to 135 degrees with the bar, greater trochanter and lateral malleolus in vertical alignment. The aim is to push as hard and as fast in order to generate the greatest force against the force platform, recording peak force. We divide peak force by body weight to determine relative strength.

Isokinetic testing is used to assess eccentric strength of the quadriceps and hamstrings, relating to the athlete's ability to resist collapse in the knee and hip in the take-off phases. We test in a seated position at an angular velocity of 60 deg/s to get a measure of maximal strength. While it can be criticised for not being 'functional', we find it to be the safest method of assessing maximal eccentric strength and our observations over many years indicate that it can differentiate between the level of performers. For male jumpers mean concentric and eccentric peak torques of the quadriceps are 264 ± 30 Nm (3.51 ± 0.35 Nm/kg) and 350 ± 54 Nm (4.77 ± 0.63 Nm/kg) and for the hamstrings 148 ± 23 Nm (1.95 ± 0.25 Nm/kg) and 188 ± 36 Nm (2.49 ± 0.41 Nm/kg) respectively. World class jumpers were typically resisting in excess of 5.5 Nm/kg in eccentric quadriceps and 3.0 Nm/kg eccentric hamstrings.

Power and 'Reactive Strength':

Given the short contact times in the triple jump, the ability to quickly generate force against the ground is essential. We use the countermovement jump to assess power following a relatively low level of eccentric loading (no impact), followed by a 40 cm drop jump which provides a greater stimulus from the impact force in landing. We measure eccentric and concentric power but prefer to provide feedback in terms of jump height which is more tangible to athletes and coaches. The reactivity strength index (RSI) gives a measure of how much time an athlete spends in the air relative to the time spent on the ground, generating vertical impulse. Ideally ground contact time should be between 0.17 to 0.20 s; if less than 0.17 s athletes tend not make appropriate foot contacts; longer than 0.20 s they absorb the force too much. An anecdotal indicator of a jumper's level of conditioning is whether they jump higher in the drop jump compared to the countermovement jump.

Table 2

World class triple jumper	Weight: Body weight (N)	Weight: Body mass (kg)	Speed: Time 0-20m (s)	Speed: Time 0-40m (s)	Speed: Time 20-40m (s)	Strength (isometric squat): Peak force (N)	Strength (isometric squat): Peak force / BW	Power: CMJ jump height (m)	Reactive strength – Drop Jump 40cm: Contact time (s)	Reactive strength – Drop Jump 40cm: Jump height (m)	Reactive strength – Drop Jump 40cm: Reactivity index	Horizontal jumps: SLJ (cm)	Horizontal jumps: 4 bounds & jump (m)	Horizontal jumps: 4 hops & jump L	Horizontal jumps: 4 hops & jump R
	735	74.9	2.46	4.36	1.90	5100	6.94	0.66	0.18	0.63	3.98	347	18.15	17.90	17.86
Excellent	626	63.6	2.57	4.54	1.94	5896	7.29	0.67	0.166	0.71	4.04	335	18.20	18.09	
	641	65.1	2.58	4.57	1.95	5737	7.12	0.65	0.172	0.69	3.91	331	17.99	17.87	
	656	66.7	2.60	4.59	1.97	5579	6.95	0.64	0.179	0.66	3.78	328	17.77	17.65	
	671	68.2	2.62	4.62	1.98	5421	6.78	0.63	0.185	0.64	3.66	324	17.56	17.43	
	686	69.8	2.63	4.65	1.99	5262	6.61	0.61	0.191	0.62	3.53	321	17.35	17.21	
Above average	701	71.3	2.65	4.68	2.01	5104	6.44	0.60	0.198	0.59	3.40	317	17.13	16.99	
	716	72.8	2.67	4.70	2.02	4945	6.27	0.58	0.204	0.57	3.27	313	16.92	16.78	
	732	74.4	2.68	4.73	2.03	4787	6.10	0.57	0.211	0.54	3.14	310	16.70	16.56	
	747	75.9	2.70	4.76	2.05	4629	5.93	0.55	0.217	0.52	3.02	306	16.49	16.34	
	762	77.5	2.72	4.78	2.06	4470	5.76	0.54	0.223	0.50	2.89	303	16.27	16.12	
Average	777	79.0	2.73	4.81	2.07	4312	5.59	0.53	0.230	0.47	2.76	299	16.06	15.90	
	792	80.5	2.75	4.84	2.09	4154	5.42	0.51	0.236	0.45	2.63	295	15.84	15.69	
	807	82.1	2.77	4.87	2.10	3995	5.25	0.50	0.243	0.42	2.50	292	15.63	15.47	
	822	83.6	2.78	4.89	2.11	3837	5.08	0.48	0.249	0.40	2.38	288	15.41	15.25	
	838	85.2	2.80	4.92	2.13	3678	4.91	0.47	0.256	0.38	2.25	285	15.20	15.03	
Below average	853	86.7	2.82	4.95	2.14	3520	4.74	0.45	0.262	0.35	2.12	281	14.98	14.81	
	868	88.2	2.83	4.97	2.16	3362	4.57	0.44	0.268	0.33	1.99	277	14.77	14.59	
	883	89.8	2.85	5.00	2.17	3203	4.40	0.43	0.275	0.31	1.86	274	14.55	14.38	
	898	91.3	2.87	5.03	2.18	3045	4.23	0.41	0.281	0.28	1.74	270	14.34	14.16	
	913	92.9	2.88	5.06	2.20	2887	4.06	0.40	0.288	0.26	1.61	267	14.12	13.94	
Poor	928	94.4	2.90	5.08	2.21	2728	3.89	0.38	0.294	0.23	1.48	263	13.91	13.72	

Table 2: Evaluation of a world class triple jumper from normative data collected on 38 male national squad long and triple jumpers[6].

Horizontal Jump tests:

Whilst the power tests provide good indicators of muscle-tendon performance they are vertical in nature. In order to bridge the gap along a continuum of specificity towards long and triple jumps, it is important to translate strength and power qualities into horizontal jumping. For this reason we measure standing long jump, 5 bounds (alternate legs), and 5 hops (on left and right legs), all finishing off with a landing in the pit. Performance is measured from the toe at the start to the closest mark in the sand. These tests do place a greater emphasis on technique, actively utilising the hip extensors in contact and coordination of the free limbs.

Table 2 gives an example of our jumper's physical qualities evaluation sheet, completed for a world class triple jumper who medalled in a major international competition.

Putting this into perspective, if Christian was to be in the world record breaking condition you would expect that his performance in these tests would be in an order of magnitude around 'Excellent' in the evaluation sheet above. Eccentric strength in the Quadriceps and Hamstrings are likely to be in excess of 5.5 Nm/kg and 3.0 Nm/kg from isokinetic dynamometry and this will ensure that the knee and hip do not collapse excessively upon contact in the step and jump take-offs.

The men's triple jump in Doha 2019 has the potential to be one of the best competitions in history. Three athletes in the all-time top 5 list are still competing, having all jumped over 18 m. In the last two seasons Christian Taylor has jumped 18.11 m, Will Claye 18.14 m and Pedro Pichardo 17.95 m. If there was ever going to be a year when the world record could be broken, 2019 is it.

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