Biomechanical Profile

Contents

Part I

Introduction

Cover page

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What is Biomechanical Profiling?

When designing training programs coaches face the hard decisions of which physical and technical qualities to prioritize. These decisions are often based on experience, intuition and indirect tests. That's where we come in. ***At the SportsMechanist our mission is to provide coaches and athletes with valuable information, taking the guess-work out of decision making***.

In short, biomechanical profiling is the quantification of sporting technique. Biomechanical profiles offer objective sports-specific markers to evaluate athletes' strengths, weaknesses and development, using laws of mechanics.

This report contains three main parts:

1. Background
2. Results
3. Conclusion

Background. The background section provides a throrough scientific review of the triple jump. A good general understanding of the triple is expected, however all readers are encouraged to read it as it provides the scientific basis for the report.

Results. The results section is the backbone of the profile as it provides measures on the selected markers. These are complemented with *commentaries*, providing an expert interpretation of the results.

Conclusion. The results are taken together, discussed and finally technical recommendations are provided.

Part II

Background

1 Triple Jump

The triple jump is one of the most demanding sporting disciplines. It consists of three consecutive jumps: a hop, step and jump. The peak ground reaction forces are the highest recorded in *any human movement*, reaching upwards of 21 times bodyweight in the step (Hay, 1993). On top of this, the athlete still has another take-off left. That is why proper technical execution is imperative to a succesful triple jump. Here we will provide a short overview of the most important biomechanical aspects of the triple jump.

Over the years, some research into the biomechanics of the triple jump has been done, mostly during the 80's and 90's. In addition to these there has been published a number of biomechanical reports from various World Championships over the years (Hommel, 2009; Bae, 2011; Tucker *et al.*, 2017; Tucker *et al.*, 2019) which provides reference values for world class performances. This body of research has been directed in a number of directions:

1. Phase ratio (Allen *et al.*, 2013; Allen, King, *et al.*, 2016; Hay, 1999; Yu and Hay, 1996; Hay, 1992)
2. Velocities (Bayraktar, 2017; Liu *et al.*, 2015; Fukashiro *et al.*, 1981)
3. Take-off leg mechanics (Perttunen *et al.*, 2000; Ramey and Williams, 1985; Hay, 1993; Fukashiro *et al.*, 1981; Dziewiecki *et al.*, 2013; Dziewiecki *et al.*, 2014)
4. Free limb mechanics (Yu and Andrews, 1998; Allen *et al.*, 2010)
5. Balance

Along with each section, we define a set of *Key performance indicators (KPIs)*. KPIs are the most important variables predicting performance. These differ from sport to sport, and not all are intuitive. At the SportsMechanist we've selected the most appropriate KPIs based on scientific literature and biomechanical reports from World Championships.

1.1 Phase ratio

The phase ratio is the length of each phase relative to the total length of the triple jump (e.g. 35%, 30%, 35%). Three techniques have been described (Hay, 1992):

- *Hop-dominant*: the hop distance is at least 2% greater than the next largest phase distance.
- *Jump-dominant*: the jump distance is at least 2% greater than the next largest phase distance.
- *Balanced*: the longest phase distance is less than 2% greater than the next largest phase distance.

As most variables change with technique, this is the first step of an analysis and results should be viewed in light of the technique (Hay, 1992). Whereas the hop-dominant technique used to be favoured, in recent years athletes have transitioned to more balanced and jump-dominant techniques (e.g. Hay, 1992; Tucker *et al.*, 2019). Trying to determine the *optimal* phase ratio has received much scientific attention. It has been suggested that an optimal phase ratio could be dependent on strength levels or the ability to convert horizontal velocity to vertical velocity (Allen *et al.*, 2013; Allen, Yeadon, *et al.*, 2016; Liu and Yu, 2012). Although no single optimal distribution has been found, a conservative picture emerges that *no phase should exceed 39% or be less than 27% approximately*.

Table 1.1: Phase ratio KPIs

Variable	Description
Effective distance	Absolute step length for the hop, step and jump in meters.
Relative distance	Relative step length for the hop, step and jump in percents.
Technique	Whether the technique is hop-dominant, jump-dominant or balanced.

1.2 Velocities

Horizontal velocity. It has repeatedly been established that *the single best predictor of performance is the horizontal velocity in the run-up*, as up to 94% of the results can be attributed to run-up velocity (Fukashiro *et al.*, 1981; Bayraktar, 2017; Liu *et al.*, 2015). Interestingly, run-up horizontal velocity is a better predictor of performance than horizontal velocity at take-off (Bayraktar, 2017). This is potentially because the run-up velocity determines the amount of mechanical energy the athlete will be able to produce in the take-off (Fukashiro *et al.*, 1981).

Take-off angle. The take-off angle is the product of the horizontal and vertical take-off velocity, and as such is determined by their combination. The take-off angle is typically highest in the jump, however this naturally differ with technique. Thus, hop-dominant jumpers tend to reach higher take-off angles in the hop and jump-dominant jumpers reach higher angles in the jump.

Velocity conversion. At each take-off vertical velocity is produced at the expense of horizontal velocity. How well a jumper performs this velocity conversion (minimise the loss of horizontal velocity) has been speculated to influence the optimal phase ratio (Liu and Yu, 2012; Yu and Hay, 1996). However, as the current way of quantifying the velocity conversion requires multiple recorded jumps we cannot as of now provide a measure of this in the profile.

Table 1.2: Velocities KPIs

Variable	Description
Horizontal velocity	Horizontal velocity at take-off for the hop, step and jump in m/s
Vertical velocity	Vertical velocity at take-off for the hop, step and jump in m/s
Take-off angle	Take-off angle relative to horizontal

1.3 Take-off leg mechanics

As the triple jump consists of three consecutive take-offs, take-off mechanics are crucial.

Footstrike. Two types of footstrike motions have been advocated over time (Koh and Hay, 1990). One school advocates an *active landing*, a back-sweeping, pawing motion of the foot. This type of take-off has been described in elite jumpers as early as 1961 by Verhoshanski, and minimises the breaking forces, thus minimizing the loss of horizontal velocity. On the other hand it has been suggested that triple jumpers may benefit from a *blocking landing* in the jump to gain vertical velocity. The way the footstrike motion is quantified is the velocity of the take-off foot relative to the jumpers center of mass just before the foot contacts the ground. To second the observations by Miller & Hay (Miller and Hay, 1986) it can also be noted that all jumpers at major championships have slower foot velocities in the jump than in the prior phases (Hommel, 2009; Tucker *et al.*, 2017; Tucker *et al.*, 2019).

Contact time. Contact times are often reported, however they are a double edged sword. Shorter contact times are correlated with longer jumps, however the relationship is not as straightforward as that. Contact times in the triple jump is mainly thought to be a consequence of horizontal velocity. The faster the velocity, the shorter time the jumper has on the ground before having to take-off again. So what seems a correlation between contact times and result is in fact correlation between horizontal velocity and result. Indeed, it is the target for the jumper to exert the greatest amount of force (impulse) on the ground, and following the impulse equation $F\,t = m\,v$ either increasing the amount of force **OR** time will increase the velocity of the jumper. As noted by Hay (1992), the consequence is that shorter contact times alone are not desirable. As they are reported at every major championship, we provide these measures, but refrain from commenting on them.

Table 1.3: Take-off leg KPIs

Variable	Description
Contact time	Contact time in seconds
Flight time	Flight time in seconds
Absolute foot horizontal velocity	The horizontal velocity of the take-off foot just prior to ground c
Relative foot horizontal velocity	The horizontal velocity of the take-off foot just prior to ground c
Knee angle	Minimal knee angle during contact

Table 1.4: Free limb KPIs

Variable	Description
Thigh angle	Thigh angle at take-off relative to horizontal
Thigh velocity	Mean angular velocity of thigh of the swing

1.4 Free limb mechanics

Arm swing. The free limbs are considered to be the arms and the leg not touching the ground during a contact phase. Especially the arm swing has been the subject of much attention. Yu and Andrews (Yu and Andrews, 1998) found that the arm swing contributes mainly in increasing the vertical velocity and possibly in maintaining balance (definition by Hay (1993)), whilst decreasing horizontal velocity. However, there exists different arm swing techniques - a topic which has almost not been investigated. The different types of arm swings are: 1) The single arm, 2) the double arm and 3) the arm-and-a-half technique. These have all been utilized at world-class level and have been combined in different ways (e.g. hop:single arm, step:double arm, jump:double arm). A modelling experiment has suggested that the double-arm swing is benefitial (Allen *et al.*, 2010), however more work needs to be done before conclusions can be drawn. It is interesting though, that almost all finalists in the 2017 World Championships, nearly all male triple jumpers employed a double-arm swing, whereas all females used a single-arm technique.

Free leg.

Table 1.5: Balance KPIs

Variable	Description
Trunk lean angle	Trunk lean angle
Body inclination angle	Body inclination angle

1.5 Balance

Balance is a concept familiar to most coaches, however the biomechanical definition is less clear. Hay (Hay, 1993) describes it as such:

> "Balance is a state in which the angular impulse exerted about each of the principal axes of a human body is consistent with the change in angular momentum required about that axis."

This statement tells us that angular momentum is at the center of balance. And although.

Many coaches emphasize the importance of upright posture and trunk angle is also reported in WC biomechanical analyses (Hommel, 2009; Tucker *et al.*, 2017; Tucker *et al.*, 2019). So although there are no scientific reports regarding trunk angles, we have included these in our report.

KPI Overview

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Table 2.1: Overview of KPIs

Variable	Description
Phase ratio	
Effective distance	Absolute step length for the hop, step and jump in meters.
Relative distance	Relative step length for the hop, step and jump in percents.
Technique	Whether the technique is hop-dominant, jump-dominant or balar
Velocities	
Horizontal velocity	Horizontal velocity at take-off for the hop, step and jump in m/s
Vertical velocity	Vertical velocity at take-off for the hop, step and jump in m/s
Take-off angle	Take-off angle relative to horizontal
Take-off leg	
Contact time	Contact time in seconds
Flight time	Flight time in seconds
Absolute foot horizontal velocity	The horizontal velocity of the take-off foot just prior to ground c
Relative foot horizontal velocity	The horizontal velocity of the take-off foot just prior to ground c
Knee angle	Minimal knee angle during contact
Free limbs	
Thigh angle	Thigh angle at take-off relative to horizontal
Thigh velocity	Mean angular velocity of thigh of the swing
Balance	
Trunk lean angle	Trunk lean angle
Body inclination angle	Body inclination angle

Part III

Results

3 Profile

In the results' section we go through each technical component, providing:

- KPIs
- Graphs and plots
- Commentaries

Name	Jannick Bagge
Age	26
Bodymass	78.8 kg
Height	1.80 m
PB	15.45 m
Analysed jump	13.97 m
Date	10/5/2020
Comment	10 step approach

3.1 Phase ratio

	Hop	Step	Jump
Relative distance	36%	30%	34%
Effictive distance	4.99	4.10	4.71

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##                                 Technique is Balanced
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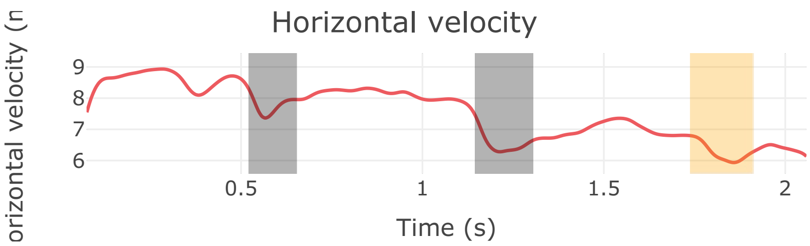
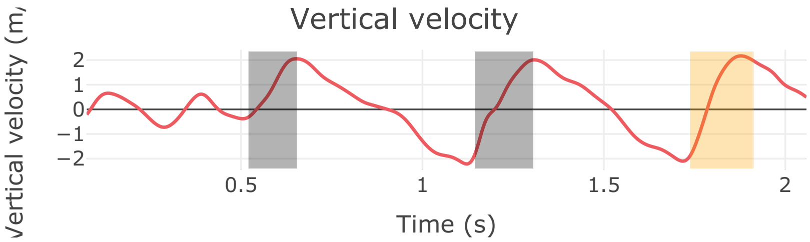
3.1.1 Commentary

Jannick is employing a balanced technique with a 30% step phase. The rest of the analysis will be viewed in light of this.

3.2 Velocities

	Hop	Step	Jump
Horizontal velocity	7.95	6.67	6.26
Vertical velocity	2.05	2.01	2.01
Take-off angle	14ř	17ř	18ř





3.2.1 Commentary

When looking at the horizontal velocity it is important to remember that the jump is from a short approach, thus velocity is not as high.

Quite a bit of horizontal velocity is lost in the step, whereas the loss is kept very low in the two other take-offs. The vertical velocities are very reasonable, almost comparable to those achieved at world-class level (Miller and Hay, 1986; Allen *et al.*, 2013), with the exception of the jump which is not high. It is apparent from the take-off angles that the step is probably too high (with a big loss of horizontal velocity), whereas the jump becomes too shallow.

Strengths

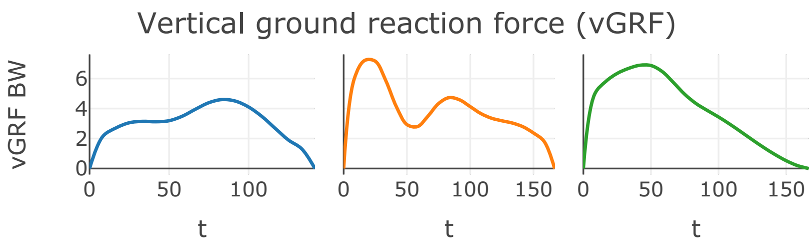
- Good maintenance of v_h in hop and jump
- Ability to produce high v_v

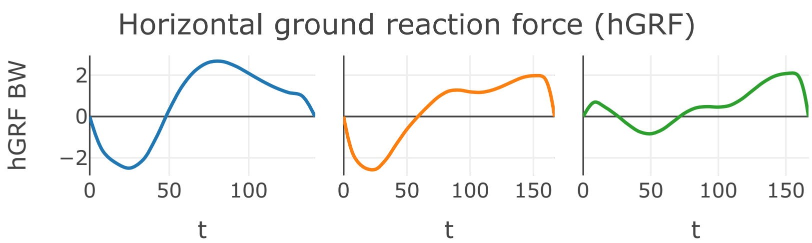
Challenges

- Excessive loss of v_h in step
- Step too steep
- Jump too shallow

3.3 Take-off leg mechanics

	Hop	Step	Jump
Contact time	0.12	0.15	0.17
Flight time	0.50	0.44	0.56
Absolute foot horizontal velocity	2.75	2.01	1.81
Relative foot horizontal velocity	-5.63	-5.52	-4.99
Minimal knee angle	146ř	129ř	133ř





3.3.1 Commentary

Again, the step and jump are the phases which demand attention. The vertical forces produced during the hop looks very reasonable. However, it seems excessive for the step and insufficient in the jump - the second peak of the jump GRF doesn't appear.

Jannick employs active landings in all phases at reported world-class level (Koh and Hay, 1990).

Strengths

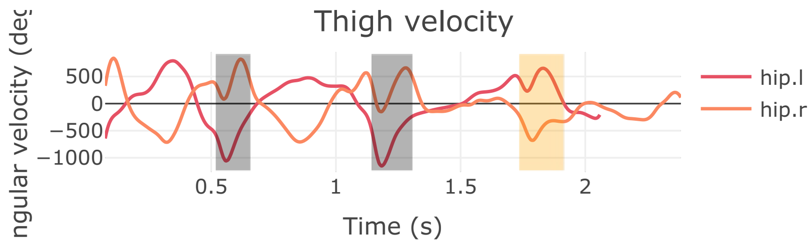
- Active landings

Challenges

- Excessive vertical force in step
- Insufficient vertical force in jump

3.4 Free limb mechanics

	Hop	Step	Jump
Thigh angular velocity	688ř/s	700ř/s	451ř/s
Thigh angle	-9ř	-7ř	-28ř



3.4.1 Commentary

If we turn our attention to the jump, we can really see the lack of swinging speed during the jump! In the graphs we're looking at the negative velocities during support, and neither peak or mean velocities are nowhere near what the were during the hop or step. The performance during hop and step are on level with world-class athletes. Taken together with the fact that the swing ends much further from horizontal, the vertical impulse generated from the free limbs could be much greater.

Strengths

- Good thigh velocity in hop and step
- Good thigh angles in hop and step

Challenges

- Inadequate thigh velocity in jump
- Low thigh angle in jump

3.5 Balance

	Hop	Step	Jump
Trunk angle at TD	7ř	1ř	10ř
Trunk angle at TO	14ř	13ř	8ř
Inclination angle at TD	-19ř	-18ř	-17ř
Inclination angle at TO	31ř	33ř	30ř

3.5.1 Commentary

The trunk angle suggests that Jannick has a pronounced forward lean, something that could potentially explain the steep step take-off angle, loss of horizontal velocity and eventually the inefficient jump phase.

Strengths

- Manages forward rotation

Challenges

- Excessive forward lean

KPI Summary

4

	Hop	Step	Jump
Phase ratio			
Relative distance	36%	30%	34%
Effictive distance	4.99	4.10	4.71
Velocities			
Horizontal velocity	7.95	6.67	6.26
Vertical velocity	2.05	2.01	2.01
Take-off angle	14ř	17ř	18ř
Take-off leg			
Contact time	0.12	0.15	0.17
Flight time	0.50	0.44	0.56
Absolute foot horizontal velocity	2.75	2.01	1.81
Relative foot horizontal velocity	-5.63	-5.52	-4.99
Minimal knee angle	146ř	129ř	133ř
Free limbs			
Thigh angular velocity	688ř/s	700ř/s	451ř/s
Thigh angle	-9ř	-7ř	-28ř
Balance			
Trunk angle at TD	7ř	1ř	10ř
Trunk angle at TO	14ř	13ř	8ř
Inclination angle at TD	-19ř	-18ř	-17ř
Inclination angle at TO	31ř	33ř	30ř

Part IV

Conclusion

5 Conclusion

Primary errors

The analysis highlighted three primary errors:

1. Forward lean
2. Steep step
3. Inefficient jump

Interpretation and discussion

Jannick looses excessive horizontal velocity during especially the step. The ineffective jump might well be caused by the forward lean. We were able to tell that in the jump he produces insufficient vertical velocity (and force) and that seems mainly caused by a lack of swinging of the free leg and probably arms. Swinging motions, especially by the arms, have a great effect on the vertical velocity produced at the cost of horizontal velocity (Yu and Andrews, 1998). However, in the jump this trade-off offers a good deal.

Recommendations

In conclusion, we recommend that the technical training focuses on upright posture and achieving greater height in the jump, mainly through improving the active free limb motions.

Recommendations

1. Upright posture
2. More shallow step, maintaining v_h
3. Steeper jump, with active free limb swinging

Strengths

- Balanced technique
- High levels of v_v production
- Active landings

Challenges

- Excessive forward lean
- Steep step
- Excessive loss of v_h in step
- Shallow jump
- Inadequate swinging motions in jump

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