Title

An examination of the jump-and-lift factors influencing the time to reach peak catch height during a Rugby Union lineout

Running title

Modelling jump-and-lift variables in rugby lineout

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Keywords

Biomechanics; Lineout; Mathematical Modelling; Rugby Union**.**

Abstract

The goal of an offensive Rugby Union lineout is to throw the ball in a manner that allows your team to maintain possession. Typically, the player catching the ball jumps and is lifted upwards by two teammates, reaching above the opposing player who is competing for the ball also. Despite various beliefs regarding the importance of the jumper's mass and attempted jump height, and lifters' magnitude and point of force application, there is negligible published data on the topic. The squeeze technique is one lifting method commonly employed by New Zealand teams during lineout plays, whereby the jumper initiates the jump quickly and the lifters provide assistance only once the jumper reaches 20-30 cm. While this strategy may reduce cues to the opposition, it might also constrain the jumper and lifters. We developed a model to explore how changes in the jumper’s body mass and attempted jump height, and lifters’ magnitude and point of force application influence the time to reach peak catch height. The magnitude of the lift force impacted the time-to-reach peak catch height the most; followed by the jumper’s (attempted) jump height and body mass; and lastly, the point of lift force application.

Introduction

In rugby union, the lineout is used to restart play after the ball goes into touch, that is after the ball has been knocked, kicked, or carried onto or over the touchline. The lineout typically involves three to eight players (usually forwards) from each of the two teams who form two front-facing parallel lines one metre apart from one another at right angles to the touchline. The lineout must be formed no less than five and no greater than fifteen meters from the touchline from where the ball is being thrown (Rugby, 2016). A player (usually the hooker) from the team in possession throws the ball into play from outside the touchline. The ball must travel in a straight line, perpendicular to the touchline, and above the gap between the two lines of players formed by the opposing teams.

The offensive team during the lineout has a clear advantage given that it determines the ball’s travelling speed, trajectory, timing, and target. The offensive team also dictates the number of players forming the lineout (at least two), which the opposition must not exceeded (Rugby, 2016). Prior to 1999, lineout players were required to jump unassisted to catch the ball. Since 1999, the International Rugby Board allows teammates to lift and support players jumping for the ball as long as the support is provided above the shorts when from behind or above the thighs when from the front (Rugby, 2016). Jumpers typically wear wraps or bandages around their mid-thigh region that "lifters" can use as gripping strongholds.

Winning teams are reported to lose fewer balls during their lineout plays compared to losing teams (Ortega, Villarejo, & Palao, 2009; Vaz, Rooyen, & Sampaio, 2010), with 50% of the possession source of tries during the 2015 Rugby World Cup coming from lineout plays (Analysis, 2015). Offensive teams implement various strategies to catch the thrown ball unopposed, such as the use of codes to conceal the jumper's identity and to inform their teammates of the planned ball trajectory. The defensive team attempts to predict where the ball is going to be thrown and beat the offensive jumper to the ball, giving them possession of the ball.

There are a number of published articles on the rugby lineout; however, these have predominantly focused on the biomechanics and strategies associated with ball throwing (Croft, Chong, & Wilson, 2011; M. Sayers, 2003; M. G. L. Sayers, 2011; Trewartha, Casanova, & Wilson, 2008), with surprisingly little data pertaining to the jump-and-lift components of the lineout. Amongst professional rugby forward coaches, there is disagreement regarding how to maximize jump height while minimizing jump time. There are arguments over the relative importance of the jumper’s body mass and attempted jump height, and lifters' magnitude and point of force application. A common lineout strategy used in New Zealand is the squeeze technique, where the jumper leaves the ground quickly, minimizing both the countermovement and arm swing motion, and the lifters provide assistance to the jumper after take-off by “squeezing the jumper up”. This squeeze technique involves two lifters grabbing and vertically lifting the jumper once the jumper is ~20-30 cm above the ground, with the lifters initially pushing towards each other and the jumper in a “squeezing” motion. However, how to minimize the time to reach peak catch height using the squeeze technique is currently based on player trial-and-error and coaching speculations rather than scientific evidence.

Our aim was to examine the influence of the jumper’s body mass and attempted jump height, and lifters' magnitude and point of lift force application on the time to reach peak catch height of the Rugby Union lineout.

Methods

Pilot testing

In the first instance, the peak catch height was determined from a preliminary study undertaken with the Chiefs Super XV Rugby team. Players typically involved in the lineout during matches formed various groups of two lifters and a jumper, and were instructed to try to reach peak catch height as quickly as possible. Players were filmed at 60 Hz using one video camera (Canon XA 10 HD, Canon Inc., Tokyo, Japan) placed on a 1.5 m tripod, which was positioned 11.5 m from and perpendicular to a specified lineout lift area to capture sagittal plane 2D kinematics. Players were provided with real-time feedback regarding the height reached (ground to fingertips) and jump time (toe-off to peak height), with data being extracted for analysis using Siliconcoach Pro version 7 (The Tarn Group Ltd, Dunedin, New Zealand). The Siliconcoach 2D video analysis software was calibrated prior to data capture using a 4 m vertical pole. The distance from the ground to the fingertips of each jumper while reaching upwards with heels on the ground was measured and subtracted from the peak catch height to estimate the vertical lift distance (h_{lift}) of the centre of mass of the jumper. The five quickest lifts were completed in a mean and standard deviation time of 0.5 ± 0.03 s, with peak catch heights of 4.1 ± 0.1 m and vertical lift distances of 1.7 ± 0.1 m. The players who generated this data gave informed consent in accordance with the requirements of the University of Waikato Ethics Committee (ethics number FEDU111/16), for their data to be used in the working model described below.

Working model

From the pilot data, we applied a series of equations to develop a working jump-and-lift 2D mathematical model that would consider our main variables of interests, which were the body mass (m) and attempted jump height (h_{jump}) of the jumper, and the magnitude (F_{lift}) and point of application (d_{lift}) of the lift force. The net external force (F_{net}) acting on the jumper considered the propulsive forces applied by the two lifters (i.e., F_{lift}) and the resistive gravitational forces (F_g) due to the mass of the jumper and gravitational acceleration (g = -9.81 m/s²). **Figure 1** illustrates the jump-and-lift technique and different components of the 2D mathematical model.

Equation 1. $F_{net} = F_{lift} + F_g$

Equation 2. $F_g = m*g$

Model assumptions

For the purpose of this study, a series of assumptions were stipulated. The change in height of the jumper's centre of mass was set to 1.7 m in agreement with the h_{lift} observed during pilot testing. F_{net} was modelled as being constant, implying constant F_{lift} and F_g throughout the movement, despite the actual F_{lift} likely to change due to alterations in muscular and mechanical advantage throughout the movement (Lieber & Fridén, 2000). We also assumed that the two lifters applied an equal and constant force at an identical location. Horizontal, frictional, and drag forces were considered negligible and excluded from the model.

Model computations

With no F_{lift}, F_g causes a constant deceleration of the jumper from take-off until zero vertical velocity at peak jump height (h_{jump}). For this analysis, take-off velocities (v_{to}) were calculated for a series of h_{jump} up to 70 cm, which was the peak height reached by one of our jumpers during pilot testing. The v_{to} can then be derived from h_{jump} using standard equations (Linthorne, 2001).

Equation 3. $v_{to} = \sqrt{(2*g*h_{jump})}$

If F_{lift} equals F_g, then the net acceleration of the jumper is zero ($a_{net} = 0$) and the vertical lifting velocity equals the velocity of the jumper at the point of F_{lift} application. However, if F_{lift} does not equal F_g, there is a resulting net acceleration (or deceleration) of the jumper.

Equation 4. $a_{net} = F_{net}/m = (F_{lift} + F_g)/m$

If F_{lift} is applied at the very start of the jump ($d_{lift} = 0$), then the initial lifting velocity (v_{lift}) equals v_{to}. A statistical spreadsheet was created that used v_{to} (equation 3) to set the initial lifting velocity, and then a_{net} (equation 4) was used to calculate the instantaneous velocity (v_i) from the velocity at the previous time-point ($v_{(i-\Delta t)}$, equation 5), distance travelled (d_i, equation 6), and time elapsed (t_i) in incremental time periods of 1 milliseconds (Δt) until 1.7 m was reached. The time taken to reach 1.7 m was extracted from the spreadsheet ($t_{1.7\mathrm{m}}$).

Equation 5. $v_i = v_{(i-\,\mathrm{t}\Delta)} + (a_{net}*\Delta t)$

Equation 6. d_i = average velocity*t_i

If F_{lift} is applied after the jumper has left the ground ($d_{lift} > 0$), then the statistical spreadsheet described above can be employed to return v_{lift} and t_{lift} knowing v_{to} (equation 3) and a_{net} (equation 4, $a_{net} = g$) by calculating v_i and t_i in incremental time periods of 1 millisecond until $d_i = d_{lift}$. Finally, $t_{1.7\mathrm{m}}$ can then be calculated by updating the value of a_{net} to account for F_{lift} (equation 4), the distance travelled to d_{lift}, and the time already elapsed ($t_i = t_{lift}$).

Variable manipulations

During the pilot work, one of the quickest $t_{1.7m}$ recorded was by a 110 kg jumper who had a 70-cm vertical jump and was lifted by the two lifters immediately upon leaving the ground (i.e., $t_{1.7m} = 0.50$ s, $m = 110$ kg, $h_{jump} = 70$ cm, and $d_{lift} = 0$ cm). Inserting these values into our working model returned an $F_{lift} = 945$ N. These data values were subsequently employed as reference to investigate the effects of 10, 20, and 30% changes in F_{lift}, d_{lift}, m, and attempted h_{jump} on $t_{1.7m}$. These relative changes reflect absolute changes of 94.5, 189, and 283.5 N in F_{lift}; 11, 22, and 33 kg in m; and 7, 14, and 21 cm in attempted h_{jump}. The latter increments were also employed to investigate the effects of change in d_{lift} given that the highest d_{lift} could be 70 cm and that a 10% change in the initial reference value (i.e., 0 cm) could not be determined. The absolute and relative (%) difference in $t_{1.7m}$ between the reference condition and the other conditions were computed, as was the difference in the distance reached (d_{diff}) in 0.50 s. We considered that our reference values leading to a $t_{1.7m}$ of 0.50 s were best practice and therefore investigated the effects of increasing m and d_{lift}, and decreasing F_{lift} and attempted h_{jump} as these alterations would negatively impact $t_{1.7m}$.

A second analysis was undertaken to specifically explore the squeeze lifting technique given its practical relevance and frequent use in New Zealand. Since this technique typically involves lifters grabbing and lifting the jumper at ~20-30 cm above the ground, $t_{1.7m}$ for d_{lift} values of 20, 25, and 30 cm were computed.

Finally, a reference table for a 110 kg jumper was generated to outline the effect of absolute changes in the various jump-and-lift parameters on $t_{1.7m}$. Similar reference tables were generated for jumpers of higher and lower body mass, which has been included as supplemental online material.

Results

The effect of a 10, 20, and 30% increase in m and d_{lift}, and a 10, 20, and 30% decrease in F_{lift} and attempted h_{jump} on $t_{1.7m}$ is summarized in **Figure 2** and on d_{diff} in **Figure 3**. For the same relative change, a change in F_{lift} impacted $t_{1.7m}$ the most, followed by a change in the jumper-related factors of m and attempted h_{jump} which had similar effects on $t_{1.7m}$, with a change in d_{lift} influencing $t_{1.7m}$ the least. Findings were similar with respect to effects of change on d_{diff} (**Figure 3**). Lifting at 20 to 30 cm from the ground rather than at ground level slowed $t_{1.7m}$ by 20 to 34% (**Figure 4**) and affected d_{diff} by 16 to 25% (**Figure 5**). The modelled $t_{1.7m}$ for a 110 kg jumper utilizing various jump-and-lift techniques is presented in **Table 1**.

Discussion

There are approximately 26 lineout plays per match at international Rugby Union competitions (Analysis, 2015), with the ability to maintain ball possession during the lineout reported to be a discriminative trait between winning and losing teams (Ortega et al., 2009; Vaz et al., 2010). The squeeze technique is one of the most frequent strategies employed by lineout players in New Zealand. Minimising the time from when the jumper leaves the ground to the peak height of the lift during a lineout is a key component to beat the opposition to the ball. Although several studies have addressed biomechanical factors associated with the accuracy of the lineout throw (M. Sayers, 2003; M. G. L. Sayers, 2011; Trewartha et al., 2008), our study is one of the first to report on factors potentially impacting the jump-and-lift component of the lineout. Our main finding was that, with a 10% detrimental change in the investigated jump-and-lift parameters, the magnitude of the vertical lift force had the greatest impact on the time-to-reach peak lift height (10% difference in $t_{1.7m}$); followed by the (attempted) jump height and body mass of the jumper (8%); and lastly, the point of lift force application (6%). Although the effect of these changes on the time to peak height (6 to 10%) or distance reached in 0.50 s (10 to 15 cm) in isolation might be considered relatively small, having the players with the greatest F_{lift} generation capacities acting as lifters, the player with the greatest h_{jump} and lightest m being the jumper, and initiating the lift as close to the ground as possible could substantially impact $t_{1.7m}$ and d_{diff} and be an effective means to a successful lineout in an optimal combination.

With limited knowledge on how much difference in $t_{1.7m}$ or d_{diff} between two jumpers ensures lineout success, it is difficult to categorically state how much change in the lineout variables explored herein is practically meaningful to Rugby Union coaches and players. A lineout jumper typically tries to catch the ball using both hands to ensure the greatest ball control and additional protection from the opposition, similar to recommendations for ball carrying (Worsfold & McClymont, 2014). However, all other factors being equal, the opposing lineout jumper might be able to reach higher by extending upwards with one hand only rather than two, as long as the other arm and legs are not lifted in relation to the trunk (McGinnis, 2013). If the hand of the opposing jumper is above those of the attacking jumper, there is an opportunity to disrupt the ball's trajectory and the intended outcome of the throw. Our pilot work suggests that the hands of the opposing jumper needs to be approximately 30 cm higher than the attacking jumper to gain a clear advantage against the attacking jumper, which may be a preliminary indication of what constitute a meaningful difference in d_{diff} and $t_{1.7m}$. However, a more detailed biomechanical investigation on this particular matter is required to confirm our pilot data.

In this study, we chose to specifically investigate the factors contributing to minimizing $t_{1.7m}$ during a jump-and-lift involving three players, as well as critically examining the squeeze technique. However, the time to peak catch height may not be the most crucial factor to lineout success, especially when the opponent has less effective lineout strategies. Professional rugby teams are resorting to a large number of different lineout strategies (M. Sayers, 2003) to misguide the opponent, which is imperative to avoid predictable lineout plays (Morris, Sayers, & Stuelcken, 2015). The time advantage gained by implementing a specific deceptive strategy has the potential to offset a suboptimal or slow jump-and-lift technique. That said, given that the goal of most professional rugby teams is to implement best practice, a holistic understanding of all variables in play during the lineout is required to enhance lineout success and the current investigation contributes to that pool of knowledge. Evidently, consideration of the accuracy of the lineout throw also needs consideration, as even experienced players can deviate from the intended target by up to 1 m when throwing 14 m out from the touchline (Trewartha et al., 2008), which would undoubtedly influence the lineout jumper. If the ball is thrown with spatial and temporal accuracy to the hands of the lineout jumper at the peak of the lift, then it may be worthwhile to minimize the time to peak catch height. Conversely, with an inaccurate throw, the benefits associated with a rapid lift could be lost.

Performing a countermovement jump with arm swing increases v_{to} and jump height by approximately 10% and 9 cm, respectively (Feltner, Bishop, & Perez, 2004; Hara, Shibayama, Arakawa, & Fukashiro, 2008). In addition, our results indicate that d_{lift} should be close to zero to decrease $t_{1.7m}$. Hence, the lifters should be prepared and in a position to lift as soon as the jumper leaves the ground. Unfortunately, both these movements provide the opposition with cues in relation to where the lift is occurring and probable ball trajectory. The longer these movements take, the easier it is for the opposition to counter the lineout jumper. Several New Zealand-based Super Rugby teams attempt to initiate the jump quickly by minimizing the amount of countermovement and arm swing of the jumper and providing a lift force only once the jumper has left the ground. Our results indicate that with such techniques (i.e., lower attempted h_{jump} and higher d_{lift}), the time needed to reach peak lift height increases. There is an obvious trade-off between the time gained from a quick jump initiation versus the time lost from resorting to a suboptimal jump-and-lift combination, which could be of practical relevance and interesting to investigate in future studies.

The data provided in this paper offer evidence that the usual squeeze technique employed in New Zealand, which involves lifting once the jumper has reached a height of 20 to 30 cm, increases $t_{1.7m}$ by 20 to 34% (0.10 to 0.17 s) and involves a d_{diff} of 28 to 43 cm when compared against the reference technique (**Figures 3 and 4**). However, before coaches and players consider altering their jump-and-lift approaches, pros and cons should be taken into account. Although $t_{1.7m}$ might increase, the advantages of the classical squeeze technique include a greater chance of deceiving the opposition and, performed correctly, a greater mechanical advantage for certain of the key joints involved in lifting the jumper when considering force-length relationships (Jones, Round, & de Haan, 2004). For example, the knee and hip are in a more extended position in the classical squeeze technique compared to our modelled reference (i.e., a d_{lift} of 0 cm would place the lifters in deeper knee and hip flexion), and this more extended position has the potential to increase the lifters vertical force production (Kulig, Andrews, & Hay, 1984; Marcora & Miller, 2000) and peak power

(Gheller et al., 2015). The disadvantages are the slower $t_{1.7m}$ due to the late lift initiation and potentially reduced vertical lift force generation.

The commencement of the squeeze technique requires both lifters to push horizontally towards each other to a certain extent, which means that the vector of F_{lift} is not purely vertical (Lipscombe, 2009). Given its relative importance for $t_{1.7m}$ (**Figure 2**), it appears ideal for all of the F_{lift} to be directed vertically rather than horizontally. That said, the pre-activation of muscles prior to the vertical lift might actually potentiate the ensuing vertical force given that acute muscle force output can be enhanced as a result of contractile history through a phenomenon known as pre-activation potentiation (Robbins, 2005). The horizontal squeeze movement might also solicit an eccentric contraction of the upper-body muscles, primarily the triceps brachii and pectoralis muscles, prior to their concentric contraction, with the resulting stretch-shortening cycle enhancing the concentric muscle action (Nicol, Avela, & Komi, 2006), although the muscle activation patterns of lifters would need to be explored to confirm these speculations. Practically, we can recommend that lifters practice to be quicker in every aspect of their role, which involves moving laterally to deceive the opponent, crouching into a lifting position, gripping the jumper, applying a horizontal "squeeze" force, and lifting vertically.

We assumed that both lifters were always equally and similarly involved during the lift. **Figure 1** illustrates the forces involved during the jump-and-lift technique and typical process whereby the front lifter often lifts before the rear one and has a more distal point of force application (i.e., lower-to-mid thigh for the front lifter versus upper thigh for the rear lifter). We also assumed that the force applied was constant, whereas the muscular force output throughout the movement would change with joint angle (Jones et al., 2004). Furthermore, for simplicity, we neglected the horizontal component of F_{lift}, but this component is also required to balance and hold the jumper and is an integral part of the squeeze technique. Despite its limitations, we believe our model provides valuable information regarding the effect of various factors on the Rugby Union lineout, and serves as a platform from which future studies can be developed. With more data and refinement of our model, it may be possible to reduce the assumptions made in our 2D mathematical model to more accurately represent the different components of F_{lift} and how they vary through the jump-and-lift motion.

Lifters must not only be quick, but also powerful. In this paper, we estimated the vertical force needed to displace the centre of mass of a jumper by 1.7 m, resulting in a specific amount of work (work = force*distance) being completed in a set amount of time (power = work / time). Since force is the product of mass and acceleration, lifting a 200 kg jumper at 1 m/s^2 requires the same amount of force as lifting a 100 kg jumper at 2 m/s^2. In our model, we assumed that lifters were able to produce a predetermined level of force and had sufficient power to complete the work required in the set amount of time. While lifters may be strong enough to generate the required levels of force, they may be too slow and have insufficient power to complete the lifting motion in our targeted 0.50 s. Our discussions with various New Zealand-based Super Rugby teams suggest that little specific conditioning for lineout lifters is undertaken. We propose that such a specific conditioning could involve a lineout lifting exercise, where the goal is for each lifter to be able to lift at least half the mass of the various jumpers 1.7 m vertically in 0.50 s (i.e., average velocity of 3.4 m/s). The hang snatch is an example of such an exercise during which players can achieve such high velocities at the aforementioned load based on Gymaware data (Kinetic Performance Technology, Mitchell ACT, Australia) with concentrated efforts. Once achieved, the movement velocity could be increased or the exercise included in an endurance session to assess whether the lift-exercise performance can be maintained in a fatigued state.

The lack of published data on the lineout meant that we needed to rely on pilot data to develop our model. More data from a greater number of professional rugby players would provide a better representative data set from which to base further analyses. The model used in this study also needs validation against objective data, such as through the use of force platforms to determine the actual magnitude of the forces in play and how these change when manipulating certain variables. The addition of kinematic analysis to kinetic data would lead to a more comprehensive investigation of the lineout, such as studying the effect of change in the point of lift force application on the time to reach peak catch height.

Conclusions

The novel mathematical modelling undertaken in this study provides practical insights into the effects of key variables on the time to peak catch height during the Rugby Union lineout, which have not been previously documented. While some of the assumptions made during modelling were fundamentally simplistic and need validation, there are several key findings and new knowledge gained from our study. All else being equal, a 10% change in the vertical force generated by the lineout lifters had the greatest impact on the time to peak lift height, with the point of lift force application having the least. The jumper's attempted jump height impacted the time to peak height similarly to that of the jumper's body mass. Although reducing countermovement and arm swing to jump quickly and providing a lift force only once the jumper has left the ground might reduce the time to initiating the jump and cues to the opposition, the time to peak catch height increases. Whether the disadvantages of a slower time to peak height outweighs the advantages of a quicker jump initiation or deceptive strategy is a difficult question to answer, which warrants further exploration. Given that most professional Rugby Union teams strive towards implementing best practice, understanding all the variables in play during the lineout is important to enhance lineout success.

List of abbreviations

a_{net}, net acceleration
d_i, distance travelled
d_{lift}, distance from the ground to the point of lift force application
F_{lift}, lift force
F_{net}, net external force
F_g, gravitational force
g, gravitational acceleration
h_{jump}, vertical jump height
h_{lift}, lift height (distance travelled by the centre of mass)
m, mass of the jumper
$t_{1.7m}$, time to reach 1.7 m
t_i, time elapsed
t_{lift}, time from take-off to the lift force application
v_i, instantaneous velocity
v_{lift}, initial lifting velocity
v_{to}, take-off velocity

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Figure Captions

Figure 1. Illustration of the jump-and-lift technique highlighting some of the variables considered in the 2D mathematical model. F_g, gravitational force due to the mass of the jumper; *GRF*, ground reaction forces are proportional to the jumper's attempted jump height; F_{lift}, magnitude of the lift force; and F_{net}, net forces acting on the jumper. The point of lift force application (d_{lift}, not illustrated) would be 0 cm if F_{lift} was applied as the jumper left the ground.

Figure 2. Effect of 10, 20, and 30% change in the magnitude of the lift force (F_{lift}), jumper's mass (m), jumper's attempted jump height (h_{jump}), and point of lift force application (d_{lift}) on the absolute and relative difference in time to reach 1.7 m (Δtime) compared to our reference best-practice values. The 10, 20, and 30% relative changes reflect decreases of 94.5, 189, and 283.5 N in F_{lift}; increases of 11, 22, and 33 kg in m; decreases of 7, 14, and 21 cm in h_{jump}; and increases of 7, 14, and 21 cm in d_{lift}.

Figure 3. Effect of 10, 20, and 30% change in the magnitude of the lift force (F_{lift}), jumper's mass (m), jumper's attempted jump height (h_{jump}), and point of lift force application (d_{lift}) on the absolute (m) and relative (%) difference in distance reached in 0.5 s (d_{diff}) compared to our reference best-practice values. The 10, 20, and 30% relative changes reflect decreases of 94.5, 189, and 283.5 N in F_{lift}; increases of 11, 22, and 33 kg in m; decreases of 7, 14, and 21 cm in h_{jump}; and increases of 7, 14, and 21 cm in d_{lift}.

Figure 4. Effect of the different points of force application (d_{lift}) used in the squeeze lifting technique on the absolute (m) and relative (%) time to reach 1.7 m (Δtime) compared to our reference best-practice values. Reference values are for a d_{lift} of 0 cm with lift force of 945 N, a jumper of 110 kg, and an attempted jump height of 70 cm.

Figure 5. Effect of the different points of force application (d_{lift}) used in the squeeze lifting

technique on the absolute (m) and relative (%) difference in the distance reached in 0.5 s (d_{diff}) compared to our reference best-practice values. Reference values are for a d_{lift} of 0 cm with lift force of 945 N, a jumper of 110 kg, and an attempted jump height of 70 cm.

Table 1. Reference table of the time to reach 1.7 m (s) for a 110 kg lineout jumper with various magnitudes of lift force (F_{lift}), points of lift force application (d_{lift}), and attempted jump heights (h_{jump}).

	d_{lift} (cm)																		
F_{lift} (N)	0	10	20	30	0	10	20	30	0	10	20	30	0	10	20	30	0	10	20
1962 (200 kg)	0.34	0.36	0.39	0.43	0.35	0.38	0.42	0.46	0.37	0.40	0.45	0.51	0.39	0.43	0.49	0.58	0.41	0.47	0.56
1766 (180 kg)	0.35	0.38	0.41	0.45	0.37	0.40	0.44	0.49	0.39	0.43	0.47	0.54	0.41	0.46	0.52	0.62	0.44	0.51	0.61
1570 (160 kg)	0.37	0.40	0.43	0.47	0.39	0.43	0.47	0.52	0.42	0.46	0.51	0.58	0.45	0.50	0.57	0.68	0.48	0.55	0.67
1374 (140 kg)	0.40	0.43	0.46	0.51	0.42	0.46	0.50	0.56	0.45	0.50	0.55	0.64	0.49	0.55	0.63	0.77	0.54	0.62	0.76
1178 (120 kg)	0.43	0.47	0.51	0.56	0.47	0.51	0.56	0.63	0.51	0.56	0.63	0.73	0.56	0.63	0.74	0.94	0.63	0.74	0.95
981 (100 kg)	0.49	0.53	0.57	0.64	0.53	0.58	0.65	0.76	0.59	0.66	0.77	0.99	0.68	0.80	1.04		0.83	1.09	
	70				60				50				40				30		
	h_{jump} (cm)																		

Supplementary online material

Table A. Reference table of the time to reach 1.7 m (s) for a 80 kg lineout jumper with various magnitudes of lift force (F_{lift}), points of lift force application (d_{lift}), and attempted jump heights (h_{jump}).

	d_{lift} (cm)																		
F_{lift} (N)	0	10	20	30	0	10	20	30	0	10	20	30	0	10	20	30	0	10	20
1962 (200 kg)	0.29	0.32	0.34	0.38	0.3	0.33	0.36	0.4	0.31	0.34	0.38	0.44	0.33	0.37	0.42	0.49	0.34	0.39	0.47
1766 (180 kg)	0.3	0.33	0.36	0.39	0.32	0.34	0.38	0.42	0.33	0.36	0.4	0.46	0.34	0.39	0.44	0.52	0.36	0.42	0.5
1570 (160 kg)	0.32	0.35	0.38	0.41	0.33	0.36	0.4	0.44	0.35	0.38	0.43	0.48	0.37	0.41	0.47	0.55	0.39	0.45	0.53
1374 (140 kg)	0.34	0.37	0.4	0.44	0.36	0.39	0.43	0.47	0.38	0.41	0.46	0.52	0.4	0.44	0.5	0.6	0.42	0.48	0.58
1178 (120 kg)	0.37	0.4	0.43	0.47	0.39	0.42	0.46	0.51	0.41	0.45	0.5	0.57	0.44	0.49	0.56	0.66	0.47	0.54	0.65
981 (100 kg)	0.4	0.43	0.47	0.51	0.43	0.46	0.51	0.57	0.46	0.5	0.56	0.64	0.5	0.56	0.64	0.78	0.55	0.63	0.78
784 (80 kg)	0.46	0.49	0.54	0.59	0.49	0.54	0.6	0.68	0.54	0.6	0.68	0.82	0.61	0.7	0.83	1.14	0.7	0.85	1.17
	70				60				50				40				30		
	h_{jump} (cm)																		

Table B. Reference table of the time to reach 1.7 m (s) for a 100 kg lineout jumper with various magnitudes of lift force (F_{lift}), points of lift force application (d_{lift}), and attempted jump heights (h_{jump}).

	d_{lift} (cm)																		
F_{lift} (N)	0	10	20	30	0	10	20	30	0	10	20	30	0	10	20	30	0	10	20
1962 (200 kg)	0.32	0.35	0.38	0.41	0.33	0.36	0.4	0.44	0.35	0.38	0.43	0.48	0.37	0.41	0.47	0.55	0.39	0.45	0.53
1766 (180 kg)	0.34	0.36	0.39	0.43	0.35	0.38	0.42	0.46	0.37	0.4	0.45	0.51	0.39	0.44	0.5	0.59	0.42	0.48	0.57
1570 (160 kg)	0.36	0.38	0.41	0.45	0.37	0.41	0.44	0.49	0.39	0.43	0.48	0.54	0.42	0.47	0.53	0.63	0.45	0.52	0.62
1374 (140 kg)	0.38	0.41	0.44	0.48	0.4	0.44	0.48	0.53	0.43	0.47	0.52	0.59	0.46	0.51	0.58	0.7	0.5	0.57	0.69
1178 (120 kg)	0.41	0.44	0.48	0.52	0.44	0.48	0.52	0.58	0.47	0.52	0.58	0.67	0.51	0.58	0.66	0.82	0.57	0.66	0.82
981 (100 kg)	0.46	0.49	0.54	0.59	0.49	0.54	0.6	0.68	0.54	0.6	0.68	0.82	0.61	0.7	0.83	1.14	0.7	0.85	1.17
784 (80 kg)	0.53	0.58	0.64	0.74	0.6	0.67	0.78	1.01	0.69	0.81	1.16		0.87						
	70				60				50				40				30		
	h_{jump} (cm)																		

Table C. Reference table of the time to reach 1.7 m (s) for a 120 kg lineout jumper with various magnitudes of lift force (F_{lift}), points of lift force application (d_{lift}), and attempted jump heights (h_{jump}).

	d_{lift} (cm)																		
F_{lift} (N)	0	10	20	30	0	10	20	30	0	10	20	30	0	10	20	30	0	10	20
1962 (200 kg)	0.35	0.38	0.41	0.44	0.37	0.4	0.44	0.48	0.39	0.42	0.47	0.53	0.41	0.46	0.52	0.61	0.44	0.5	0.6
1766 (180 kg)	0.37	0.4	0.43	0.47	0.39	0.42	0.46	0.51	0.41	0.45	0.5	0.57	0.44	0.49	0.56	0.66	0.47	0.54	0.65
1570 (160 kg)	0.39	0.42	0.45	0.5	0.41	0.45	0.49	0.54	0.44	0.48	0.54	0.61	0.47	0.53	0.61	0.73	0.52	0.6	0.72
1374 (140 kg)	0.42	0.45	0.49	0.53	0.45	0.48	0.53	0.59	0.48	0.53	0.59	0.68	0.53	0.59	0.68	0.85	0.58	0.68	0.85
1178 (120 kg)	0.46	0.49	0.54	0.59	0.49	0.54	0.6	0.68	0.54	0.6	0.68	0.82	0.61	0.7	0.83	1.14	0.7	0.85	1.17
981 (100 kg)	0.52	0.56	0.62	0.7	0.57	0.63	0.73	0.88	0.65	0.75	0.93		0.79	1.02			1.13		
784 (80 kg)	0.64	0.73	0.96		0.8														
	70				60				50				40				30		
	h_{jump} (cm)																		

Table D. Reference table of the time to reach 1.7 m (s) for a 140 kg lineout jumper with various magnitudes of lift force (F_{lift}), points of lift force application (d_{lift}), and attempted jump heights (h_{jump}).

	d_{lift} (cm)																		
F_{lift} (N)	0	10	20	30	0	10	20	30	0	10	20	30	0	10	20	30	0	10	20
1962 (200 kg)	0.38	0.41	0.44	0.48	0.4	0.43	0.47	0.52	0.42	0.46	0.51	0.58	0.45	0.51	0.58	0.69	0.49	0.56	0.68
1766 (180 kg)	0.4	0.43	0.46	0.5	0.42	0.46	0.5	0.56	0.45	0.49	0.55	0.63	0.49	0.55	0.62	0.76	0.53	0.62	0.75
1570 (160 kg)	0.42	0.46	0.49	0.54	0.45	0.49	0.54	0.6	0.49	0.54	0.6	0.7	0.53	0.6	0.7	0.87	0.6	0.7	0.87
1374 (140 kg)	0.46	0.49	0.54	0.59	0.49	0.54	0.6	0.68	0.54	0.6	0.68	0.82	0.61	0.7	0.83	1.14	0.7	0.85	1.17
1178 (120 kg)	0.51	0.55	0.6	0.68	0.56	0.62	0.7	0.83	0.63	0.72	0.86	1.37	0.75	0.92			0.97		
981 (100 kg)	0.59	0.65	0.75	1.05	0.69	0.82			0.93										
	70				60				50				40				30		
	h_{jump} (cm)																		