Module 4. Profiling and Monitoring for the Overhead Athlete

In overhead athletes and those with high upper body demands, force and rate of force development ability underpins critical aspects of performance. How easy is it for a baseball pitcher to throw over 90 mph consistently, a rugby player to absorb force in a tackle, or a boxer to deliver a knockout punch? In addition, as with the lower extremity, it is thought that sufficient upper body force production capabilities may optimise athletic resilience by helping athletes to buffer against increased fatigue and build tolerance to spikes in training and competition loads (Littlewood et al., 2013). Physical demands vary depending on the type of activity required in each sport. In contact and collision sports, the shoulder is exposed to considerable impact forces (3400 N in rugby) (Myers et al., 2015) often in vulnerable positions, with potential for dislocations and other traumatic injuries (Lum & Barbosa, 2019; Kubo et al., 2001). In baseball, shoulder rotation angular velocities greater than 7000°/s are generated (Holt et al., 2016). Matching neuromuscular capacity to demand requires that practitioners build a clear quantifiable profile of the athlete. This can direct areas for individual development or necessary intervention, which may enhance performance and reduce the burden of shoulder and elbow injuries which are responsible for a large number of days lost per season and pose a high cost to athletic performance in the overhead athlete.

4.1 The Scope

Dynamic Tests

Upper-limb rate of force development is an important characteristic across sports containing repeated short-duration actions (McLaine et al., 2016; Couch et al., 2021). Practitioners within these sports should be aware of tools that permit the assessment of an athlete's ability to produce more explosive upper-limb force, both to determine their current capacity to monitor training program driven adaptations (Portlock et al., 2019; Cools et al., 2014) and potential maladaptation/poor recovery from load of competition and training. Relative to the use of force platforms in lower extremity neuromuscular performance in jump-land tests, their use in the assessment of dynamic upper body performance is relatively new, with far less evidence across the 3 key applications: profiling, load-response monitoring of the healthy athlete, and monitoring in rehabilitation/return to sport (RTS). Isokinetic (IKD) testing research has been the principal source of upper body strength & power / neuromuscular performance data. However, this data has mainly been cross-sectional rather than longitudinal. Even in a high-performance setting with access to this technology, where repeated IKD testing may be feasible during the rehabilitation of individual athletes, time constraints mean that at least in team sports, it is unlikely that practitioners can routinely implement IKD testing on a frequent enough basis to enable the practitioner to define the individual athlete's responses to load throughout a competitive season or training block.

Isometric strength testing of the shoulder complex can provide an alternative, rapid and low "cost" (time and load-wise) means of regularly monitoring upper body neuromuscular performance with potential to provide similar fatigue-recovery profiling as, for example, the lower body posterior chain test. However, force platforms provide the practitioner working with upper body athletes the potential to also characterise dynamic explosive multi-joint performance, using push-ups and their variations. Studies in rugby have shown that ballistic/plyometric push-up (BPU / PPU) performance at 24/48 hours is responsive to the competition demands (Michener et al., 2021; Hams et al., 2019; Roe et al., 2016) and has potential as a tool to monitor upper limb fatigue-recovery in rugby and other sports. Data from an elite boxing cohort suggest that the PPU could provide information about upper limb muscular power output corresponding to the requirements of a punching action (Bonello et al., 2021). Therefore, a push-up has the potential to be used in a similar way as the CMJ is in the lower extremity –as a global measure of upper extremity neuromuscular performance.

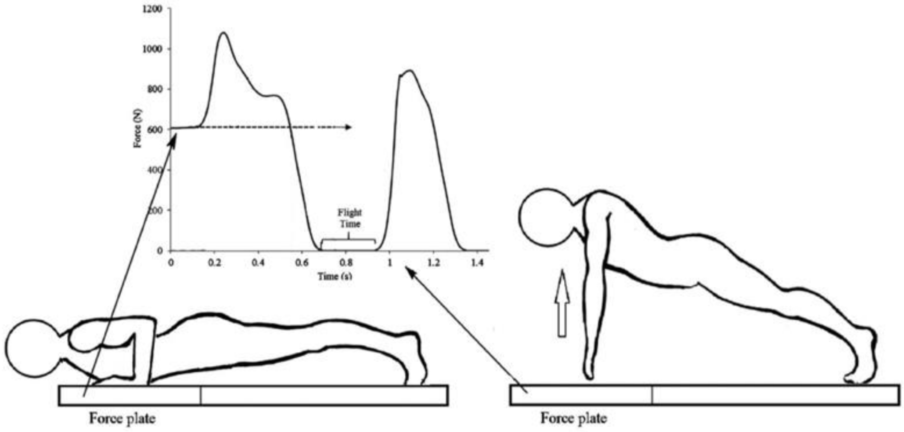
Plyometric/Ballistic Push-up

The plyometric (countermovement) and ballistic push-up are the most common variants in the force platform push-up assessment literature and used in applied practice. It is important to be clear that, as for the CMJ, terminology varies, and the practitioner should always refer to methods sections of research when cross referencing with their own data. In the present section, we refer to plyometric push-up PPas one which begins in an extended arm position involving a rapid descent and push off so that the upper body leaves the platform. This has also been referred to as a countermovement push-up, has a similar kinetic profile as the countermovement jump, and can, with some caveats, be analysed in a similar way. We define the ballistic push up (BPUas a movement that begins in a flexed (approximately 90°) position and is followed by the same rapid push off as the plyometric push-up. It therefore differs from the plyometric push-up in that there is no descent/countermovement "eccentric" phase, and in a parallel with the SJ evaluates performance in the upward ("concentric") phase. Both tests capture impact/landing kinetics. Below we use the X-PU to denote the family of the "explosive" push ups - including the BPU and PPU and variant, all of which comprise a ballistic "takeoff".

Strong, significant correlations ($p=0.001$) are reported between a number of kinetic performance measures in the BPU and the bench throw, mean power and peak power ($r^2 = 0.75$ and 0.74, respectively) and strong correlations were found between the 1RM bench and the 1RM predicted by the BPU ($r^2 = 0.87$) (Bartolomei et al., 2018). In a separate study, a multiple regression analysis was used to define the following 1RM bench press prediction equation using kinetic BPU performance measures: 1RM = 0.31 x Mean Force - 1.64 x Body Mass + 0.70 ($r^2 = 0.837$, standard error of the estimate [SEE] = 11 kg) (Folland et al., 2014). Later studies reported similar findings and concurred that BPU is a valid and reliable means to estimate upper body mean power and peak power (explaining 83.7% of the total variance in a 1RM bench press). The BPU is also considered easier to implement than a Smith machine bench press throw (Bonello et al., 2021; Del Balso & Cafarelli, 2007), another measure of upper body power.

Figure 1 below shows a two-force platform BPU set up, in which both hands are placed on one platform, from which the force-time curve and key events and variables of interest are derived (Del Baso & Cafarelli, 2007), therefore designated as the upper limb (UL) platform. The second platform which the feet are placed on is essentially used to ensure the capture of system mass, data which does not provide additional metrics, but which is integrated into velocity and power calculations, the lower limb (LL) platform. We denote that as a "single UL-LL" (a single upper limb platform and a single-lower limb platform) configuration to distinguish it from other configurations commonly found in performance and research settings, for example a dual-UL configuration with left and right hands placed on different platforms. The single-UL (with no LL platform) results in a similar force-time as seen in figure 1, but this configuration undermines the ability to accurately determine velocity and variables derived from it, such as power (as discussed further below). Between 69%-75% of body weight is supported by the hands in plyometric push-ups (Suprak et al., 2018).

Figure 1: Ballistic push-up (BPU) performed on a pair of force platforms (single platform-UL single platform LL) and sample force-time profile



Overview of takeoff, flight and landing phases shown in a BPU (i.e. no countermovement) push up and sample force-time profile from the UL platform.

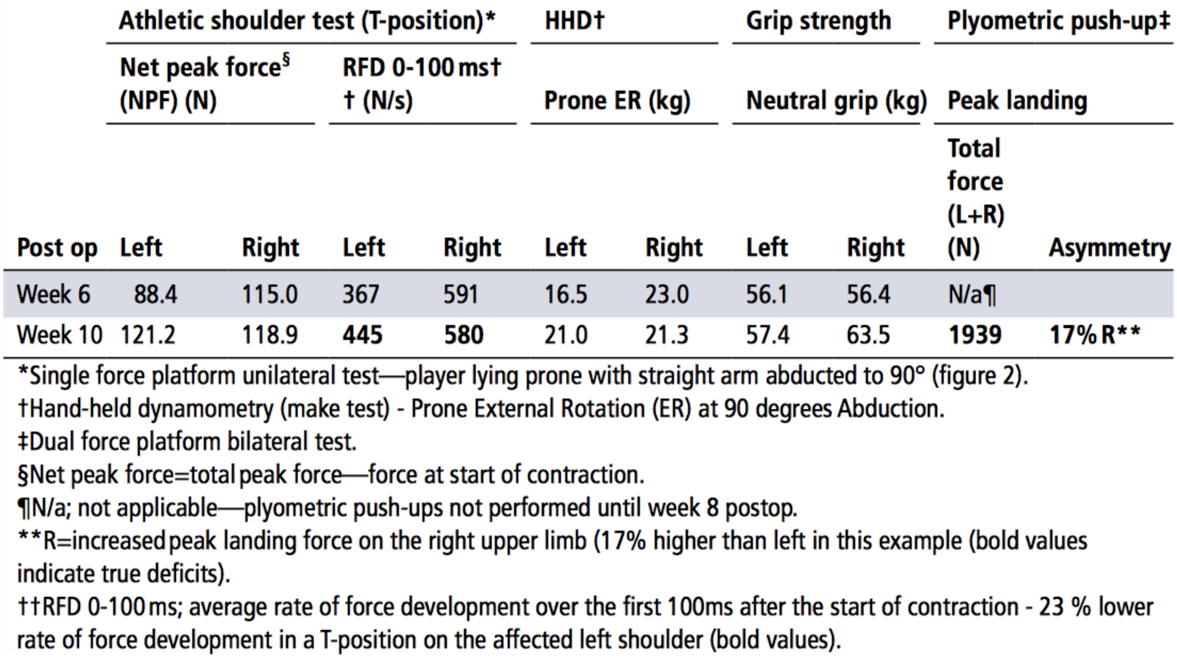
Source: Bartolomei et al., 2018

The dual-UL configuration generates a vGRF curve, as well as the simultaneous measurement of left and right outputs and symmetry in force and impulse during the test, as obtained in dual platform CMJ assessments.

Until the advent of widespread access to force platforms, the countermovement bench throw and medicine ball throw were the tools available/commonly used to quantify and profile dynamic high velocity upper body neuromuscular performance (Popchak et al., 2021). Similar kinetic/kinematic patterns between the BPT and medicine ball throw and BPU have encouraged practitioners with access to force platforms to explore what kinetic data obtained from the force platform test. In particular, there has been a focus on peak power, force, rate of force development during the "take-off" phase. For contact/collision athletes, the PPU can be described as an assessment tool that closely mimics the demands of dynamic, closed-chain movements in collision sport such as falling, fending and landing (Portlock et al., 2019).

While the eccentric/downward phase has not been specifically examined, partly because of the methodological issues with identifying the end of the phase (as discussed below), we have found that a flight time to contraction time ratio is a reliable means to capture changes in time taken to get to push off and which is comprised of the eccentric and the concentric duration. However, in a recent editorial, we also highlighted the potential value of force absorption/attenuation asymmetries on the "landing" (Ashworth and Cohen., 2019), describing a case study of an elite goalkeeper returning following a shoulder injury. Plyometric push-up peak landing force asymmetry (measured with dual-UL configuration) and isometric ‘rate metrics’ (ASH Test– T-position), respectively, were used in conjunction with other tests of upper limb neuromuscular function (HHD and handgrip dynamometer isometrics) to quantify capacity to develop and absorb force and inform regarding athlete readiness following injury (table 1). In rugby players returning from shoulder injuries, we have also observed that PPU landing phase avoidance strategies were evident (parallelling that seen post knee ligament injury). Also, isometric rate of force development metrics in the ASH test showed delayed recovery, relative to HHD peak force after upper limb injury (table 1), analogous to that reported following lower limb ligament and muscle injuries (Mirkov et al., 2017; Taberner & Cohen, 2018). In the upper limb, RFD may also prove to be a more sensitive marker of explosive performance and capability for joint protection as suggested with respect to the lower limb (Zebis et al., 2011).

Table 1. Upper body strength during rehabilitation following shoulder surgery



	Athletic shoulder test (T-position)*				HHD†		Grip strength		Plyometric push-up‡	
	Net peak force[§] (NPF) (N)		RFD 0-100 ms† † (N/s)		Prone ER (kg)		Neutral grip (kg)		Peak landing	
Post op	Left	Right	Left	Right	Left	Right	Left	Right	Total force (L+R) (N)	Asymmetry
Week 6	88.4	115.0	367	591	16.5	23.0	56.1	56.4	N/a¶	
Week 10	121.2	118.9	**445**	**580**	21.0	21.3	57.4	63.5	**1939**	**17% R****

*Single force platform unilateral test—player lying prone with straight arm abducted to 90° (figure 2).
†Hand-held dynamometry (make test) - Prone External Rotation (ER) at 90 degrees Abduction.
‡Dual force platform bilateral test.
§Net peak force=total peak force—force at start of contraction.
¶N/a; not applicable—plyometric push-ups not performed until week 8 postop.
**R=increased peak landing force on the right upper limb (17% higher than left in this example (bold values indicate true deficits).
††RFD 0-100 ms; average rate of force development over the first 100ms after the start of contraction - 23 % lower rate of force development in a T-position on the affected left shoulder (bold values).

Note: From *Force awakens: a new hope for athletic shoulder strength testing,* by B. Ashworth & D. D. Cohen, 2019, British Journal of Sports Medicine.

In parallel with that, described in jump tests (Bonello et al., 2021), asymmetries in this bilateral task are proposed to be indicative of adaptation, injury, or deficit in sporting performance by the more utilized side when compared to initial values. Therefore, take-off phase and force/impulse asymmetries or trends in these asymmetries may also provide relevant information in profiling and monitoring UL athletes.

Importantly, no significant correlation between peak torque values for concentric shoulder internal rotation (IR) (58.8-59.5 N.m.kg^{-1}) and external rotation (ER) (44.6-44.8 N.m.kg^{-1}) at 90°/s and plyometric push-up performance measures (take-off and landing PF, eccentric deceleration phase impulse, concentric impulse, and landing impulse) were found (Fanning et al., 2021). These authors suggest that the plyometric push-up variants may provide additional insight into an athletes' upper body function and readiness to return to performance, by creating demands that reflect the dynamic, closed-chain movements in collision sports such as falling, fending and landing.

It is recommended that whenever these plyometric tests are implemented, a consistent, standardised protocol is set that most closely mimics normal biomechanics. In addition, the objective kinetic data, as in lower body assessments, and maybe more so in the upper body due to the athlete's ability to manage their kinematics, observation of qualitative aspects of performance during this test can provide useful additional information, even if a trial is discarded from the kinetic analysis. It is important to quality assure the data at the point of acquisition and note the trials displaying aberrations, which would be excluded from the analysis of mean performance for the athlete but may be kept on record to build the practitioners library and understanding of kinetic-kinematic associations. Athletes are highly likely to "cheat" (compensate) in order to achieve a better score. Evaluating progress, therefore, should be focused not only on the quantitative outcome measures, but also on the context in which those numbers are produced. As well established in lower limb testing and monitoring (different examples of achieving the same vertical jump height with a different strategy), the same output can be produced with varied strategies and is, therefore, not the same result –some of which may be expressed in load distribution shifts in the X-PU but may also manifest in other kinetic variables. How an athlete chooses to generate and transfer force into the test apparatus from their base of support is an important consideration in testing and monitoring athletes.

Plyometric Protocols

Fanning et al., 2021 describe push-up variants to profile upper body performance in a similar way as lower limb –across a range of concentric only (BPU) to long SSC (PPU) to short SSC (Box Drop Landing (BDL)) (figure 3). Three trials were recommended, following two familiarisation trials.

PLYOMETRIC PUSH-UP – (also referred to as "countermovement push-up")

- Start in a push-up position with arms fully extended, one hand on each force plate, 90° shoulder flexion, legs and torso straight and feet together. Inter-hand distance can be self-selected by the participant during the practice trials but should then be measured and used consistently by a given athlete as hand width can significantly affect peak force (Morrison et al., 2021) and potentially reproducibility of protocols. As for use of lower extremity assessments, the practitioner has to balance time cost of increasing levels of standardisation against ability to implement regularly

- Stability in the elbows straight position, during which a weight is obtained.

- Following a 3-second countdown, the athlete rapidly lowers their torso toward the force plate, then immediately pushes away vertically to obtain maximal height and trunk elevation, elbows extended and hands clearing the force plates, landing back on the force plates with both hands at the same time but no further coaching cues are given about the landing (unless the practitioner is specifically coaching the landing).

- Return to the starting position in preparation for the next repetition if repetitions are being performed and wait for recording to be ended before leaving platforms.

Box Drop Landing (BDL)

- Identical starting position as PPU except that the hands were placed on 20 cm raised boxes and positioned 65 cm apart, lateral to the landing position.

- The athlete drops off the box with both arms simultaneously, decelerates themselves as quickly as possible on contact with the force plates and finishes with elbows fully extended push-up position, held for 2 s before relaxing.

BPU (or “press jump”)

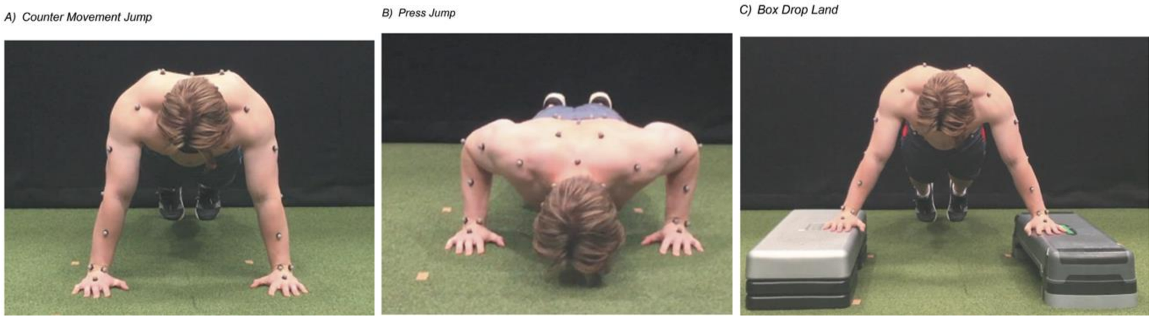
- Same position as for the PPU

- Trunk lowered to a press-up approximately 90 degrees position, held for 1–2 seconds until cued to push away from the ground as quickly as possible, taking off with the elbows fully extended (as for the PPU).

- No landing cues given and return to starting position.

- Trial repeated if countermovement observed

Figure 2: Push up variants

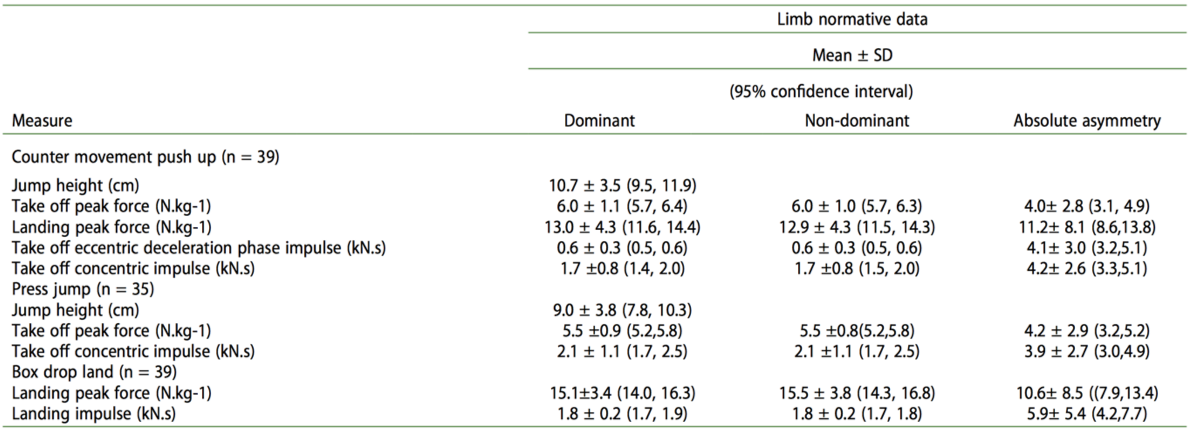


(a) PPU/Countermovement “jump” (b) BPU/Press “jump”(c) Box drop land.

From *Biomechanical upper-extremity performance tests and isokinetic shoulder strength in collision and contact athletes*, by E. Fanning et al., 2021, Journal of sports sciences.

The descriptive data from this article may be used as a comparative baseline for injured athletes when performing the above tests (table 2).

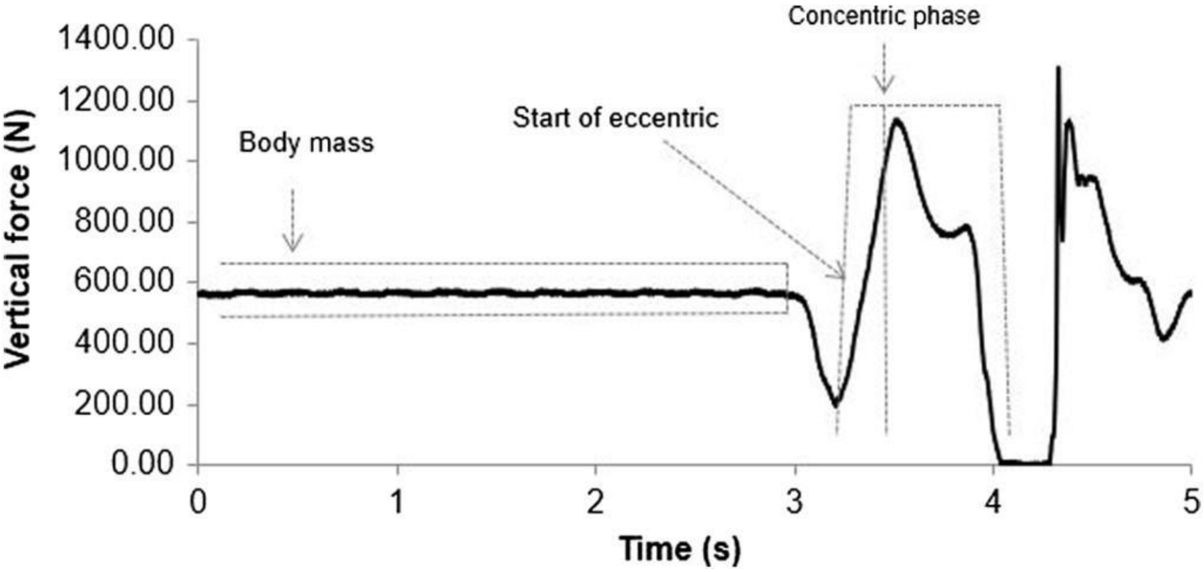
Table 2. Push up variant normative data in healthy male collision athletes.



	Limb normative data		
	Mean ± SD		
	(95% confidence interval)		
Measure	Dominant	Non-dominant	Absolute asymmetry
Counter movement push up (n = 39)			
Jump height (cm)	10.7 ± 3.5 (9.5, 11.9)		
Take off peak force (N.kg-1)	6.0 ± 1.1 (5.7, 6.4)	6.0 ± 1.0 (5.7, 6.3)	4.0± 2.8 (3.1, 4.9)
Landing peak force (N.kg-1)	13.0 ± 4.3 (11.6, 14.4)	12.9 ± 4.3 (11.5, 14.3)	11.2± 8.1 (8.6,13.8)
Take off eccentric deceleration phase impulse (kN.s)	0.6 ± 0.3 (0.5, 0.6)	0.6 ± 0.3 (0.5, 0.6)	4.1± 3.0 (3.2,5.1)
Take off concentric impulse (kN.s)	1.7 ±0.8 (1.4, 2.0)	1.7 ±0.8 (1.5, 2.0)	4.2± 2.6 (3.3,5.1)
Press jump (n = 35)			
Jump height (cm)	9.0 ± 3.8 (7.8, 10.3)		
Take off peak force (N.kg-1)	5.5 ±0.9 (5.2,5.8)	5.5 ±0.8(5.2,5.8)	4.2 ± 2.9 (3.2,5.2)
Take off concentric impulse (kN.s)	2.1 ± 1.1 (1.7, 2.5)	2.1 ±1.1 (1.7, 2.5)	3.9 ± 2.7 (3.0,4.9)
Box drop land (n = 39)			
Landing peak force (N.kg-1)	15.1±3.4 (14.0, 16.3)	15.5 ± 3.8 (14.3, 16.8)	10.6± 8.5 ((7.9,13.4)
Landing impulse (kN.s)	1.8 ± 0.2 (1.7, 1.9)	1.8 ± 0.2 (1.7, 1.8)	5.9± 5.4 (4.2,7.7)

Note: From *Biomechanical upper-extremity performance tests and isokinetic shoulder strength in collision and contact athletes*, by E. Fanning et al., 2021, Journal of sports sciences.

Figure 3: Sample force time profile during a PPU.



Adapted from *The Test-Retest Reliability of Force Plate-Derived Parameters of the Countermovement Push-Up as a Power Assessment Tool*, by G. N. Parry et al., 2020, Journal of sport rehabilitation.

Reliability/ validity

The inter-day reliability of the three tests was also examined in this cohort of 39 contact / collision athletes, the majority of which from Gaelic football, and rugby (72% amateur and 28% semi-professional) and found to be moderate to excellent (ICC 0.67-0.97) Fanning et al., 2021). A moderate to very high reliability (ICC = 0.88 -0.98) of force platform-derived kinetic parameters of a countermovement push-up was reported in the 10 college-level athletes with weightlifting experience (CV 5.5%-14.1%; peak force: 7.5%; mean force: 8.6%, and rate of force development: 11.2%). Peak force, mean force, RFD, and impulse were shown to be reliable (ICC = 0.8-0.96) in sub-elite rugby league players and within subject reliability of < 10% was noted for the majority of performance measures (CV% = 4.3-7.6) except for RFD (CV% = 11) (Hogarth et al., 2013). High test-retest correlations for peak force (ICC = 0.85-0.97) were shown for a variety of plyometric push-up exercises. Therefore, force platforms kinetics derived during the PPU and variants appear to be reliable in both untrained and sub-elite sporting populations in a similar pattern as described in jump-land tests, whereby force and impulse show greater ICC and lower CVs than RFD measures.

- ***RFD***

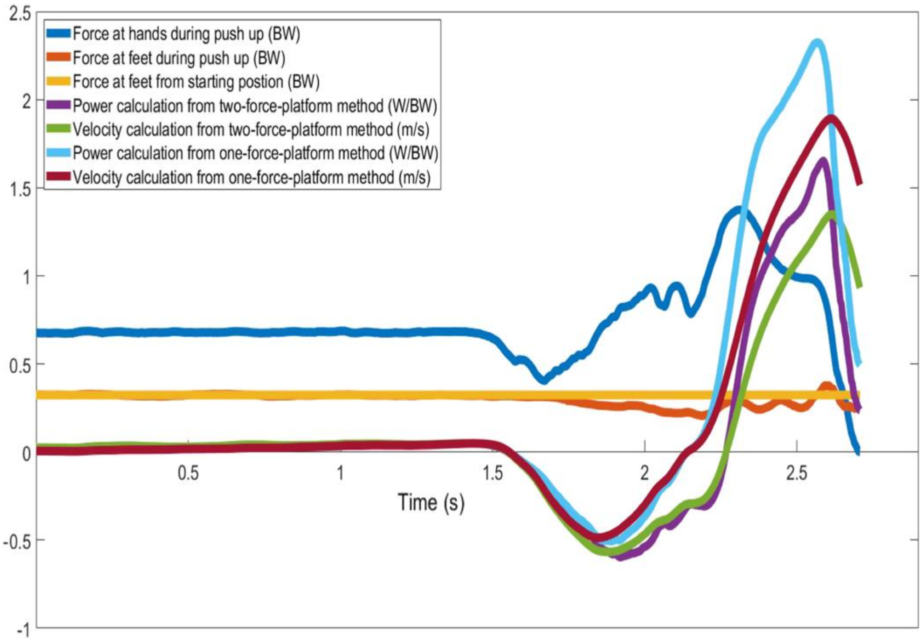
As highlighted above in relation to lower body isometric tests and other parts of this certificate, despite poorer reliability (Hogarth et al., 2013), RFD remains of interest due to its potential as a key performance indicator. As in lower body assessments, it is recommended that caution should be exercised in the interpretation of X-PU RFD measures, particularly in athletes with poor familiarity with the assessment. However, RFD measures should not be discarded and may prove to be a valuable marker for some athletes. Use should be considered on a case-by-case basis –with establishing (day to day) reliability in the athlete in question as a first step.

- **Validity**

Currently, the X-PU literature is young (relative to that of the lower limb), more research and applied practice is needed to conclusively define the most discriminatory and sensitive variables for the purposes of profiling and monitoring, respectively. Some normative data is available, however, comparisons between data you might collect and that in the literature should be approached with caution

It is not always clear from methodology sections of the studies how a specific variable is calculated –such as RFD–, which requires a specific start and end point, in order to replicate its calculation and therefore compare values. Similarly, for one of the most commonly reported variables –peak power–, studies using UL only configurations do not tend to describe in detail the data processing performed to calculate these values. Accurate determination of velocity and power (force x velocity) based on Newtonian physics and the application of jump metric calculation to X-PU assessments depends on assumptions being met with respect to system mass on the platforms and linear motion. The proportion of body weight measured in the UL single force platform configurations in the starting push-up position is approximately 0.64 (female) to 0.67 (male) (Hinshaw et al., 2018). Accurate velocity and power –time curves for the upper body measures of interest also depend on there being a constant force applied to the feet– i.e., system mass at the start of the movement being the same as at the end. Using an UL-LL configuration Sha & Dai, 2021 showed that assumptions are not being met using an UL single platform configuration, finding that force in the LL platforms decreased during the push-up, principally due to a shift of the centre of mass (COM) in a circular arc around the pivot of the fixed toes –during the descent load increases on the UL and decreases on the LL (Dhahbi et al., 2017; Sha & Dai, 2021). They demonstrated that, as a result, the values for velocity and power obtained with the single platform UL configuration are overestimated (see figure below).

Figure 4: Force-, velocity- and power-time profiles of BPU from one force platform (single UL) two force platform (single UL-single LL) configurations.



Force-time data recorded during BPU using UL (dark blue) LL (orange) single force platform configuration derived velocity-time and power-time curves calculated using data 1) from the UL platform only (velocity: dark red; power: light blue) and 2) from the LL + UL platform (velocity: green; power: purple). The yellow line illustrates the force value on the LL plate at start to facilitate the visualisation of the deviation from that value beginning at the arrow where LL force decreases below initial values and implies an increase in the UL plates. This deviation undermines the assumptions underlying the UL velocity and power calculations applied with a UL only configuration and is the source of discrepancy in velocity and power-time curves derived with the LL and UL methods.

BW=Bodyweight (i.e., force expressed as multiples of bodyweight).

From *The validity of using one force platform to quantify whole-body forces, velocities, and power during a plyometric push-up*, by Z. Sha & B. Dai, 2021, BMC Sports Science Medicine and Rehabilitation.

Interestingly, a number of studies using push-up provide velocity and power values without a UL-LL configuration, and, in some cases, peak power is central to their analysis. However, if a UL only configuration is used and the positioning of the body is carefully standardised in terms of hand position and consequently UL: LL CoM distribution; we can still have some confidence in the detection of *change* in velocity and power over time or in a pre-post monitoring application, bearing in mind that the absolute values calculated at each timepoint are not accurate. Furthermore, Shu (2021) presented a logistic regression which allows the estimation of whole-body force, velocity, and power from the UL only. However, the authors suggest caution, given the single population this study was based on. They highlight despite significant correlations between directly measured and estimated values, only vGRF was r of > 0.9, while velocity and power were around 0.6. The author's view is that any peak power and velocity data in the literature values should be treated with caution and, while as described above for monitoring purposes, these variables, with the caveats described, practitioners and researchers should endeavour to identify other variables that present less of a challenge in calculating accurately, which are useful in their performance and injury related questions.

- **Variables**

With the limitations described, paradoxically, the variable most commonly reported in X-PU literature may also be the one of the least valid, unless a UL-configuration is available. Overall, there are few studies of load-response using BPU upon which firmly conclude which other variables should be used. However, the following are suggested based on a combination of reliability, validity, value shown in equivalent LL tests, and the authors' observations of longitudinal data in elite boxers.

1. **Flight time:** As a raw characteristic, reflecting take-off and landing from the plate and requiring minimal processing, i.e., it is the definition of the threshold for those two events; and as for the CMJ, it is highly correlated with concentric impulse and with (concentric) peak power.
2. **Contraction time:** As highlighted with respect to CMJ, in the PPU, if the athlete is stable prior to the descent and performs the descent rapidly, start of movement determination or detection by software algorithms is easily achieved and accurate, as well as reliable. Determining the eccentric and concentric phases is more complex, but as changes in either will impact on contraction time, this would be adequate and also allow the estimation of flight time: contraction time. The use of X-PU FT: CT has not been reported in the literature, but both components have shown reliability; authors suggest that it may be, as in the lower body, a useful index of neuromuscular efficiency in that it can capture potential changes in both the output (flight) and the time it takes to get off the ground (contraction time). As for the CMJ and any variable that embed eccentric performance within it, the countermovement must be coached to be rapid, or these measures become highly variable and lose their value in neuromuscular profiling and monitoring.
3. **Peak force:** It has shown to be reliable, and as a raw and discrete value, which occurs during the mid-late concentric/upward phase, this variable doesn't depend on processing. As described above, values derived from UL-only configurations have an r of > 0.9 correlation with whole body values.
4. **Mean force:** It is raw value as per peak force; however, mean force will be influenced by the area over which it is calculated and, therefore, it is susceptible to start and end point decisions as well as detection processes. The authors suggest that in UL-only configurations, a positive (i.e., above body weight) take-off would be a reliable start and end and would include eccentric and concentric force application without having to precisely identify those phases. If, on the other hand, a UL-LL configuration is available and phases are identified, the practitioner could specifically examine eccentric deceleration mean force or impulse and concentric mean force/impulse separately.

5. **Peak landing force:** As we described in a case study editorial (Ashworth & Cohen, 2019), asymmetries in this variable appear to be revealing of avoidance strategies following shoulder injury and bilateral (total) peak landing can quantify impact load during upper limb X-PU exercises.

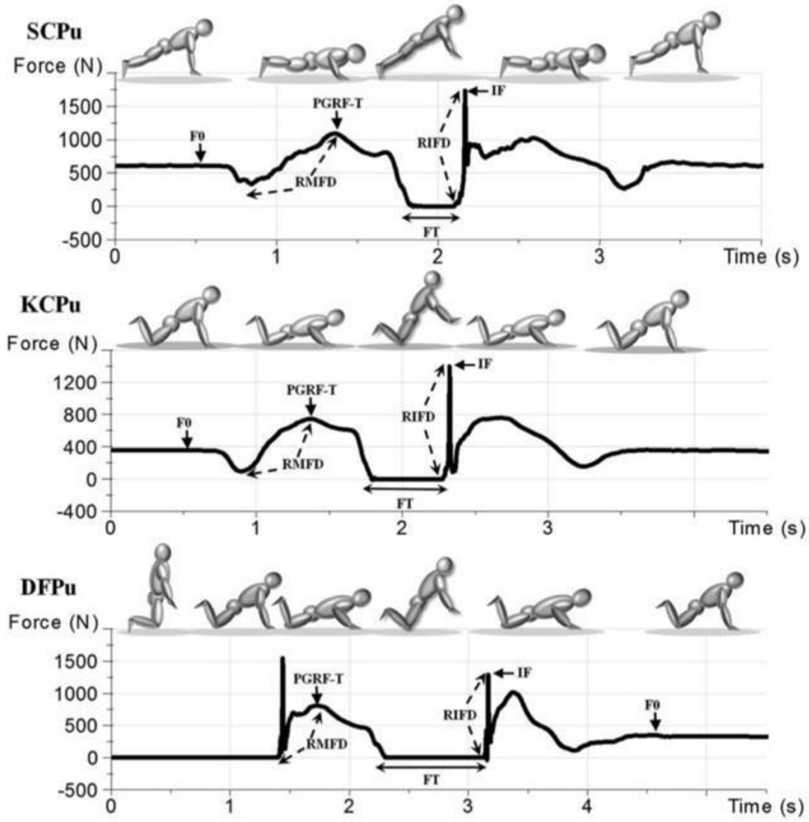
- **Limitations**

As for all neuromuscular assessments, familiarisation is key to obtaining reliable and representative data from plyometric upper body tests, until technique is stabilised/learnt, measures may improve without any true change in underlying neuromuscular characteristics. Similarly, standardisation of cueing and aspects highlighted above, if not between them, within athletes, are critical. In addition, not all athletes are capable of performing a X-PU due to either technical or physical limitations.

Modified X-PUSH-UP derivatives

The lower limb force platform kinetic analysis is used both as a neuromuscular assessment tool in periodic or frequent monitoring and as a means to provide immediate feedback on performance of variants such as loaded squats, jumps, or drop jumps at different heights: the same applies in the X-PU literature. Force platform evaluation of upper body neuromuscular performance, with the PPU as a core test, and its variants as a potential “Bosco” equivalent, is not restricted to the examples outlined above. Derivatives/progressions (e.g., added load/drop land from increasing heights), regressions (i.e., unloading by using bent knee – which reduces UL from load 64-67% during the 48-52% during the modified push-up–) of the X-PU are commonly used in training and rehabilitation programs, and vGRF derived kinetics allow quantification of load demands in propulsion (take-off) and impact (land) phases, and relative effects on velocity, durations, and load distribution. Selecting the appropriate intensity of plyometric training can be guided by vGRF data (Dhahbi et al., 2017); for example, peak vGRF and RFD during take-off were both higher ($P < .001$) in the PPU exercises than BPU (Dhahbi et al., 2017). This vGRF data can therefore help inform exercise prescription decisions in the healthy and rehabilitating athlete –such as in the selection of variants during early rehab to reduce demands. Loads can subsequently be progressively increased for propulsive or impact loading, or both – as part of optimal preparation to cope with the higher force and RFDs experienced in contact/impact. This also highlights the potential for exercise performance and assessment merging within rehabilitation to provide immediate feedback to the practitioner and athlete.

Figure 5: Vertical ground reaction force time profiles during performance of variants of the push up.



Vertical ground reaction force time recorded during the execution of countermovement push-up exercises (e.g., SCPu, KCPu, and DFPu). SCPu = standard countermovement push-up, KCPu = kneeling countermovement push-up, DFPu = drop-fall push-up; Fo = initial forece supported; PGRF-T = peak-GRF takeoff; RMFD = rate of force development during takeoff; FT = flight time; if = impact force; RIFD = rate of force development impact.

From *Explosive Push-ups: From Popular Simple Exercises to Valid Tests for Upper-Body Power*, by D. Zalleg et al., 2018, Journal of strength and conditioning research.

In general terms, there is not a large body of literature describing the force platform kinetics and/or the kinematics of alternative upper body plyometric exercises, and studies have been inconsistent. Initial work comparing “box drop” (BD) and “clap push-ups” (CPU) peak vGRF in military recruits familiar with plyometric training found no significant difference between CPU and BD push-ups from varied heights (Koch et al., 2012). In contrast, a study in subjects less familiar with regular plyometric upper body training observed a peak vGRF larger in the CPU than BD variation (Moore et al., 2012). This suggests a training history influence on the relative effect of alterations in external load –an important consideration in programming the incorporation of upper body plyometric training in athlete programs, and when analysing/interpreting results. This also highlights the importance for the practitioner to understand how their athletes produce and attenuate load across these variants, particularly in the context of data less extensively available than that for LL.

An interesting and useful addition to the body of published work, an online (non-peer reviewed) case study article, describes that force platform derived peak force values in a large number of X-PU variants during braking (descent/eccentric), propulsive (ascent/concentric), and landing –with the tests all performed by the author (Oakley, 2021). Selected data from this case describes differences in vGRF across a range of upper limb push-up and land derivatives to provide some guidance as to where an exercise (or assessment) sits along the loading continuum. The author also noted that, like in lower limb landings, push-up/upper limb drop landing technique and coaching of it also influence GRFs (Oakley, 2021); for example, cueing to absorb (elbow flexion on landing) rather than 'stick' (maintain extended elbows) the landing reduced peak landing force. As modifying GRFs and force absorption/attenuation strategies may be relevant from an injury risk perspective in the lower body, it also has potential value in terms of assessing shoulder injury risk associated with contact/falling (García-Massó et al., 2011) and is relevant to the accumulated loading if push-up/drop push-ups are being implemented as part of training.

For assessment purposes, standardising cues are not only critical to maintain data reliability across different test time points, but may also provide an opportunity to add constraints to strategies and consequent loading demands, thereby altering specific neuromuscular characteristics required for force production and absorption, and therefore demands and adaptive response. In alignment with the lower body literature, upper lib force-velocity profiles can be used to prescribe optimal loads for rate of force and peak force development. Upper body research using increments of 5% and 10% of body weight during a PPU in male and female athletes' parallel findings in the lower limb, showing increased ground reaction forces and decreased velocity with increased external load (Hinshaw et al., 2018). The authors also concluded that the relationship between external loading and peak power during the PPU is more aligned than the bench throw with the associations observed with weighted jumps. They also highlighted that when using the PPU to target development of upper body power, an external load may not be needed and, as for an increased emphasis on strength development, without significantly compromising power production, an external load of 5-10% of body weight is recommended. Nonetheless, if in an individual athlete's profile load-power profiling is going to be determined, if possible, this should be performed on a UL-LL configuration due to the issues around velocity inaccuracies highlighted above.

4.2 Other Upper Limb Neuromuscular Tests

While focused on kinetics for completeness, we provide a brief summary of some of the other more dynamic tests below.

Functional testing

Functional testing includes evaluations such as the Closed Kinetic Chain Upper Extremity Stability Test (CKCUEST) (Goldbeck & Davies, 2000) and the Unilateral Seated Shot Put test (Negrete et al., 2010). Justification behind the use of these tests is often due to their practicality (low cost, lack of need for equipment) and ease of interpretability (limited requirement for expert assessors, their ease of administration, and the provision of objective data) (Roush et al., 2007).

The CKCUEST starts in a push-up position, with participants reaching across to touch the opposite hand as many times as possible within the allotted 15 second timeframe. The number of touches is recorded. The test has good reliability (de Oliveira et al., 2017) and strong correlations between CKCUEST test performance and isokinetic internal and external shoulder rotator peak torque (r = 0.87–0.94) are reported. Despite this, the ability of these functional tests to define specific characteristics relating to performance at a particular time point or the contribution to changes observed is questionable. To illustrate this using a lower body example, with jump height or hop distance, we only have an external performance value with limited information on how that value is produced. Whether it is PF, RFD, or co-ordination in terms of muscle activity and recruitment, and which compensations or alternative strategies are utilised, it may be produced with evaluations of the neuromuscular contributions to force production, and subsequent programming can remain outcome driven using proven valid and reliable equipment to understand the decision-making process.

Inertial Sensors (Accelerometer/Gyroscope)

The use of inertial sensor technology is mainly driven by an interest in velocity-based training and evaluations –and therefore in quantifying and adapting training prescription in exercises. This wearable technology can provide valid and reliable information that can complement information gained from the tools described above. As an example, no difference was found between Smith machine bench press concentric movement velocity when measured using gold standard VICON motion capture or a wearable inertial sensor (PUSH Bands v.2.0) (Pelka et al., 2020). Such technology is also used and adapted to single arm exercises like the landmine press to quantify changes in velocity that may occur as a result of longer-term positive adaptations (athletic development), or acute within set performance decline (fatigue).

Conclusion

It is important for practitioners to identify tools capable of assessing an athlete's ability to rapidly produce upper-limb force. There is a growing body of evidence to support the use of upper limb plyometric testing (PPU and derivatives) using force platforms as a valid and reliable way of profiling and monitoring the healthy athlete, with additional applications in rehabilitation and return to sport (RTS) monitoring after injury or surgery. Isokinetic testing potentially provides valuable isolated joint torque-angle analyses that may generate different insights than those of isometric tests for the same action.

Low-cost functional tests provide a less detailed and objective alternative indicator of overall performance but may lack sensitivity to detect deficits expressed in strategy but not global performance. Overall, the limitations of these approaches and based on a combination of practical considerations (associations with previously established tests of interest and the potential to capture outputs and strategies/time constrained characteristics forces produced and absorbed and distribution thereof), practitioners working within the elite sport environment are recommended to consider integrate upper body dynamic tests such as the PPU and variants into upper athlete profiling, monitoring and RTS.

4.3 Isometric Testing

Hand Held Dynamometer (HHD) & Fixed Dynamometer (EFD)

Force Platform Isometric Test (ASH Test)

Upper body isometric tests are used to profile athletes' force production capacity/qualities and assess athletic development at regular intervals through a training cycle and as a tool in regular monitoring as a potential indicator of residual, or accumulated fatigue or positive adaptations to loading. Developing the neuromuscular system to enhance force production capabilities is one of the most important goals in athlete development and rehabilitation programmes. Isometric assessments can be routinely implemented on the recovery days following a game without impacting on training and performance (matchday (MD) +1 /24 hours or MD +2 / 48 hours), and can be deemed "safer" than eccentric tests with regard to minimising the potential for exercise-induced-muscle damage and lower load demands.

Furthermore, in parallel with the lower body tendon literature, upper body isometric training has been shown to improve pain scores, subjective function, and shoulder strength. This highlights the potential for an optimally programmed isometric exercise dose to improve shoulder joint tendon force capacity and elastic stiffness (Møller et al., 2017), and therefore to incorporate the assessment within training sessions. Additional benefits of isometric testing include the reduced likelihood of compensatory/ "pathological" movement patterns, when compared to more dynamic forms of testing. Besides, it is easier for patterns which do occur to be identified by the practitioner without the need for kinematics –gross shifts in trunk/scapular/shoulder positions during the application of maximal isometric force.

a. Isometric Tests - Hand Held Dynamometers and Fixed Dynamometers

While there is a widespread use of isometric testing and monitoring in elite athletes, there is a paucity of published evidence supporting applications. As with any S&P assessment tool, it is important to first consider the validity and reliability of these tests, depending on the methods utilised. Hand-held dynamometry (HHD) and externally fixed dynamometry (EFD) have both been shown to be reliable forms of assessing isometric shoulder internal and external rotation force production (Seroyer et al., 2010), with good to excellent reliability and strong correlations to ("gold standard") IKD isometric peak force (Sander et al., 2013). However, achieving these levels of reliability depends on consistent data collection, i.e., the same operator with adequate experience in applying the test. Furthermore, the operator must be stronger than the individual being tested or must use fixation such as a belt to help with stabilisation of the HHD (Seroyer et al., 2010; Fanning et al., 2021). It is this author's experience that adequate familiarisation with the test, adherence to standardised protocols, and quality assurance (e.g., inspection and possible removal of erroneously detected start of contraction trials) are important components of the data acquisition process. Couch et al.

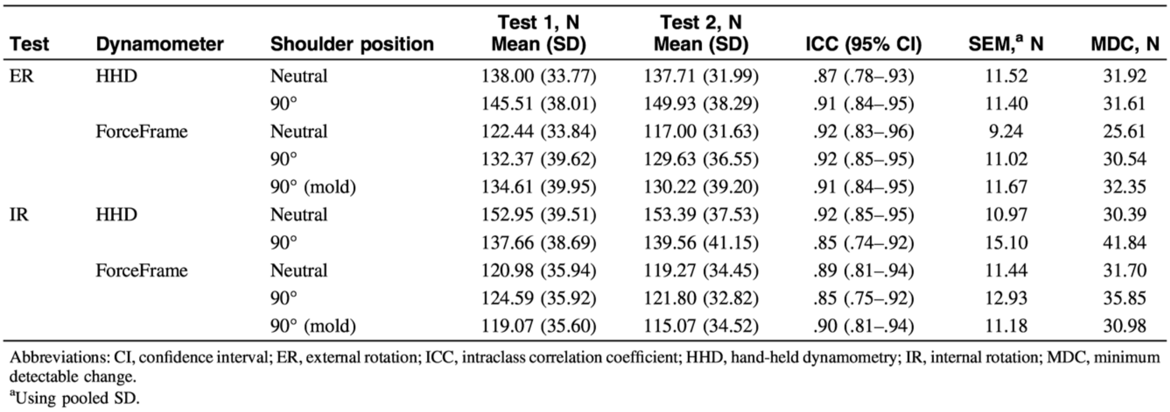
(2021) reported good to excellent test-retest reliability for all HHD and EFD (ForceFrame - VALD performance) shoulder-strength tests they evaluated and a slightly greater reliability of EFD than that of HHD across all testing conditions, except for neutral position IR. The EFD addresses the sources of measurement error and challenges to reliability of the HHD that are associated with sources of measurement error such as tester and subject position, shoulder position, tester strength, subject stabilisation, and equipment stabilisation. In addition, the use of a moulded elbow support in EFD (figure 6) improved reliability in ER but not IR. Both HHD and EFD detect changes in the athlete state due to fatigue or injury and are portable, quick, useful tools for field-based assessment of shoulder force production, enabling practitioners to collect meaningful information from a greater number of athletes in a shorter time frame.

Figure 6: Force Frame Isometric Shoulder test with moulded elbow support

Source: Vald Performance

- ***Data interpretation***

Table 3. Mean scores, test-retest reliability in ForceFrame and hand-held dynamometer



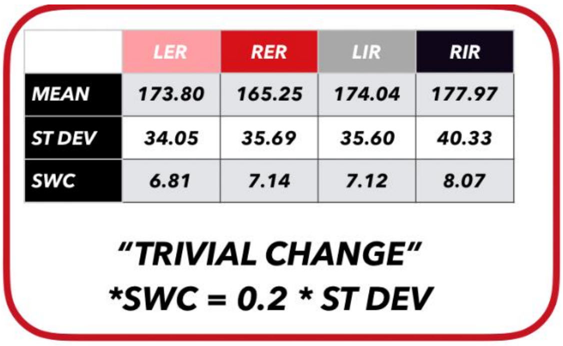
Test	Dynamometer	Shoulder position	Test 1, N Mean (SD)	Test 2, N Mean (SD)	ICC (95% CI)	SEM,^{a} N	MDC, N
ER	HHD	Neutral	138.00 (33.77)	137.71 (31.99)	.87 (.78–.93)	11.52	31.92
		90°	145.51 (38.01)	149.93 (38.29)	.91 (.84–.95)	11.40	31.61
	ForceFrame	Neutral	122.44 (33.84)	117.00 (31.63)	.92 (.83–.96)	9.24	25.61
		90°	132.37 (39.62)	129.63 (36.55)	.92 (.85–.95)	11.02	30.54
		90° (mold)	134.61 (39.95)	130.22 (39.20)	.91 (.84–.95)	11.67	32.35
IR	HHD	Neutral	152.95 (39.51)	153.39 (37.53)	.92 (.85–.95)	10.97	30.39
		90°	137.66 (38.69)	139.56 (41.15)	.85 (.74–.92)	15.10	41.84
	ForceFrame	Neutral	120.98 (35.94)	119.27 (34.45)	.89 (.81–.94)	11.44	31.70
		90°	124.59 (35.92)	121.80 (32.82)	.85 (.75–.92)	12.93	35.85
		90° (mold)	119.07 (35.60)	115.07 (34.52)	.90 (.81–.94)	11.18	30.98

Abbreviations: CI, confidence interval; ER, external rotation; ICC, intraclass correlation coefficient; HHD, hand-held dynamometry; IR, internal rotation; MDC, minimum detectable change.
^{a}Using pooled SD.

Source: Couch, J., Sayers, M., & Pizzari, T. (2021). Reliability of the ForceFrame with and Without a Fixed Upper-Limb Mould in Shoulder Rotation Strength Assessments Compared With Traditional Hand-Held Dynamometry. *Journal of sport rehabilitation*, *30*(8), 1246–1249. https://doi.org/10.1123/jsr.2020-0434

The reliability study above (table 4) reported the standard error of measurement SEM (9.24–15.10) and minimum detectable change MDC (25.61–41.84) values for HHD & ForceFrame. The MDC of 25.6 means that to say with 95% certainty that there has been an actual change in shoulder force production, we need to observe a greater than 25.6 change of a rotation strength. This value is relatively high in the context of the absolute mean values reported, but the authors suggest that this may be due to the heterogeneous nature of the participants. Another approach is to use a percentage value threshold, rather than absolute: for example, McLaine et al. (2016) concluded that a peak force change of more than 15% in any position can be considered meaningful. In the author's experience, and based on data acquired from pitchers and position players in baseball major league that used an EFD (ForceFrame) across a season, smallest worthwhile change values (SWC = 0.2 * SD) ranged from 6.81 N to 8.07 N across left and right shoulders for ER and IR force (figure 7). These data are confirmed in a recently published study, also showing higher force production in position players versus pitchers.

Figure 7: ForceFrame internal and external rotation peak force values and smallest worthwhile change in elite baseball players.



	LER	RER	LIR	RIR
MEAN	173.80	165.25	174.04	177.97
ST DEV	34.05	35.69	35.60	40.33
SWC	6.81	7.14	7.12	8.07

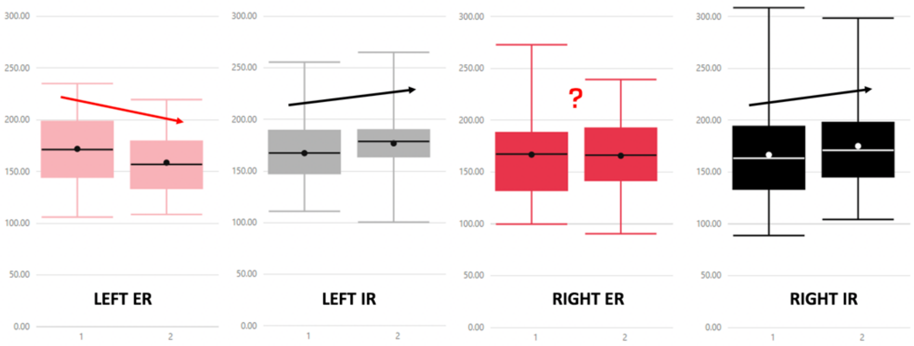
"TRIVIAL CHANGE"
****SWC = 0.2 * ST DEV***

LER=Left external rotation; RER=Right external rotation; LIR=Left internal rotation; RIR=Right internal rotation. SWC=smallest worthwhile change
Source: authors own elaboration.

- *Applications*

The observed improvement in IR peak force after spring training but no improvement (or decline) in ER suggests that targeted ER strength work is necessary to stimulate direction specific adaptation not obtained from throwing training/practice and traditional strength and conditioning as well as generalised arm care alone. This may have implications for injury risk: as in the overhead athlete, imbalance between internal (IR) and external rotation (ER) strength increases the risk of sustaining a shoulder injury (Johnston et al., 2016).

Figure 8. Internal and external rotation peak force trends in baseball players



ER=external rotation, IR=internal rotation. Box and whisker plot at 2 timepoints in 47 elite players at two timepoints; 1. Start of spring training 2. End of spring training. ForceFrame isometric shoulder peak force for left and right shoulders. Note an increase in IR force, a decrease in left ER and no improvement in right ER force. Source: authors own elaboration.

- ***ForceFrame Protocol(s)***

Figure 9: The force frame and positions for assessment of internal and external rotation strength

Source: Vald Performance

- ***Starting Position – 'Internal Rotation'***

- Supine 90° lying next to crossbar
- Crossbar height set so that the heel of the palm is resting on the pad
- Elbow bent 90°, raised out to side in-line with shoulder
- Elbow placed in moulded support to minimise compensation (support not fixed, as there is a tendency to use as a fulcrum to generate a large adduction component rather than a more focussed internal rotation torque)
- Heel of palm resting on pad (open palm used for volleyball as an example but may be more appropriate as a closed fist in gripping sports like judo), as long as the protocol is standardised and consistent for most reliable data (Couch 2021).

- ***Test protocol – 3 second isometric***

- Make contact with the pad.
- Once in contact, steadily increase force and hold for 3 seconds isometric.
- Don't take a "run up". Avoid rapid application of force.

- ***Starting Position – ‘External Rotation’***

- As above, except that the back of the wrist is resting against the pad.

Summary

In this author’s opinion, the use of isometrics allows practitioners to gather impactful information in a shorter time but does not replace the use of the isokinetic dynamometer, which is still considered as the gold standard to quantify dynamic force production in rotation, and the practitioner should aim to seek out this tool if a more in-depth evaluation is considered important. Using a fixed dynamometer with appropriate software (e.g., ForceFrame) makes it possible to monitor and translate doses into daily and weekly impulse values (useful for manipulating volume versus intensity) appropriate to manage daily changes in VAS scores, readiness, soreness, and session RPE, but this falls outside the scope of this module.

Practitioners should be aware that altering the test or subject position affecting mechanical advantage of muscles involved has a substantial impact on peak force values. Practitioners should always check methodology of papers providing reference data for position information to determine if it is comparable with their own data.

Figure 10: Prone isometric test using a ForceFrame.

Source: authors own elaboration.

b. ASH Test – Isometric test using a Force Platform

The Athletic Shoulder test (ASH test) was originally developed to enable the performance team in elite rugby to identify hidden deficits prior to returning players to contact. It was considered that the majority of existing upper limb kinetic assessments were typically short lever tests that did not mimic sports-specific actions or adequately assess higher shear forces experienced during competition (Hinshaw et al., 2018). Players were able to "pass" these short lever tests, but would still break down on returning to contact. A long lever isometric test was considered to be a more appropriate means to replicate the shoulder muscle contraction required, based on its correspondence to the demands of the tackle. Since then, relationships have been demonstrated with throwing performance and associated mechanisms of throwing shoulder injury.

Figure 11: ASH test positions (A) I-test (B) Y-test (C) T-test.

Source: Ashworth, B., Hogben, P., Singh, N., Tulloch, L., & Cohen, D. D. (2018). The Athletic Shoulder (ASH) test: reliability of a novel upper body isometric strength test in elite rugby players. BMJ open sport & exercise medicine, 4(1), e000365. https://doi.org/10.1136/bmjsem-2018-000365

The ASH test demonstrated excellent reliability supporting its use as a trustful tool to quantify the ability to produce and transfer force across the shoulder girdle using long levers (Hinshaw et al., 2018). This relatively new test has potential use in quantifying the recovery of muscle function after training or game exposure on a weekly basis, or return to performance after injury, when compared with a player's normal values. The ASH test can be integrated with other measures of mobility, force production, wellness, and performance metrics to provide a comprehensive overview of all of the components relevant to the maintenance of shoulder health and performance (Cronin & Owen, 2004).

The higher forces produced by more elite athletic populations are considered more likely to reduce HHD test reliability, which suggests that a stable force platform is more appropriate for these populations, eliminating the negative influence of tester-athlete strength imbalances on reliability, particularly in stronger athletes.

- ***ASH test protocol***

- **IYT tests:** All tests are performed in prone on the floor with neck position standardised (4 cm foam block) on which the forehead is rested.

- **I-test:** The shoulder is positioned in full abduction (in line with the body), the forearm in pronation, and the heel of the hand acts as the main contact point with the force platform.

- In **Y-test and T-test, t**he arm is positioned in 135° and 90° abduction shoulder abduction. And in all tests, a fully extended elbow.

- A standardised warm-up is recommended - 2 submax 80%-90% efforts in IYT positions.

- Test 3 trials in each of the positions on the same limb.

- Rest period of 20 s is optimal for full recovery between trials. Shorter time periods may restrict inter-trial recovery, which may be more appropriate when assessing decrements in repeated maximal isometric test outputs as a measure of an athlete's ability to cope under fatigue (this may also be of interest). If trend monitoring is performed and there is a need to reduce rest due to time constraints, it is important to ensure that this modified rest period is standardised across testing timepoints.

- Subjects are required to maintain their scapula in a natural position relative to the elevated arm (avoiding excessive scapula upward rotation/elevation or anterior tilt). Whilst we advise coaching this during familiarization, observing unconstrained scapula movement during testing can provide insights on individual movement strategies. Same force: different strategy, not the same outcome.

- Subject position has to be checked prior to each trial to remove visible compensations. The contralateral arm is placed behind the back so that the elbow is unable to fix on the floor and provide anti-rotation trunk stability for the Y and T test. However, in an I-test, the arm is allowed to remain by the subject's side due to lower trunk rotational forces encountered.

- During performance of the test, the subject is required to stabilise their trunk against rotation without using the contralateral arm and push down from the shoulder through the heel of their hand.

- In the instance of a failure to perform the test according to the instructions, the specific trial results should be discarded, and an additional trial should be performed after 20 s recovery.

- Tests have to be performed in the following order: I, Y, T. Completion of all three test positions for dominant and non-dominant limbs is estimated to take under 6 mins including recovery periods (each individual test position for one limb; for example, the dominant arm T-position, takes approximately 50 s).

- Subjects should be coached to push as “fast and hard” as possible to generate maximal force (aiming to achieve maximum force as fast as possible) and sustain it for the full 3-s test duration (Ashworth & Cohen, 2019).

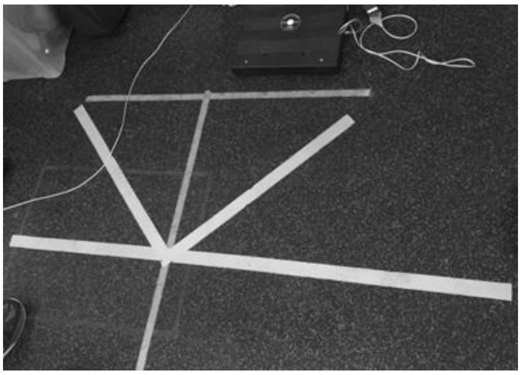
- **Compensations:** The practitioner should note compensatory strategies used by the athlete to ensure both a qualitative and a quantitative analysis of the test outcomes. Videoing each test is of value later, when quality assuring the force time curves. Tests are excluded if there is a loss of elbow extension, excessive scapular anterior tilting, excessive pelvic rotation, movement of the feet during the repetition or hand countermovement (i.e., lifting of the hand off the force platform prior to force application), or if the subject does not perform the test correctly.

- The feet and pelvis must be maintained in starting positions during each contraction. Failure to maintain body position changes joint angles, relative contributions of individual muscle groups, and muscle length-tension relationships, thus potentially impacting both peak and rate of force development.

- To ensure consistency, it is recommended that assessment of joint angles prior to initiating each test position is performed, and using a standardised taped testing surface to aid identification of unwanted movement (figure 12).

- The hand is placed in the centre of the force platform with no contact between wrist and platform.

Figure 12: Standardised taped testing surfaces for ASH test positioning



Source: authors own elaboration.

- ***ASH Test Data Interpretation***

The force platform IYT tests are reliable in detecting between subject and within subject difference. Measurement error was below 10% in all test positions (CV 5.0–9.9) in elite rugby players (Hinshaw et al., 2018). High reliability does not necessarily mean that a test has the sensitivity to detect a real change. Minimum detectable change (MDC) is useful in a monitoring context to establish how far "the needle needs to move" before a change can be considered meaningful. ASH test, IYT MDC90 values were 13.3–25.9 N (MDC% ranged from 10.7 to 20.1), meaning that a change of >13.3 N in a dominant arm T-test would be considered meaningful with a confidence level of 90% (Hinshaw et al., 2018). In this study, players were familiarised with the test by performing it on 3-5 separate occasions prior to the reliability study commenced.

- ***Applications***

1. **Rugby Data**

The initial purpose of the IYT tests was to quantify force production and potential interlimb or postinjury deficits in rugby-specific shoulder positions. The T-position is similar to the arm tackle position while the I-position closely represents the 'try-scorer' injury mechanism (Nichols & Szivak, 2021). It was our preliminary observation from pilot testing that the long lever test demonstrated unilateral deficits that were not evident in short lever testing using HHD (Hogben –verbal correspondence).

2. ASH test normative data

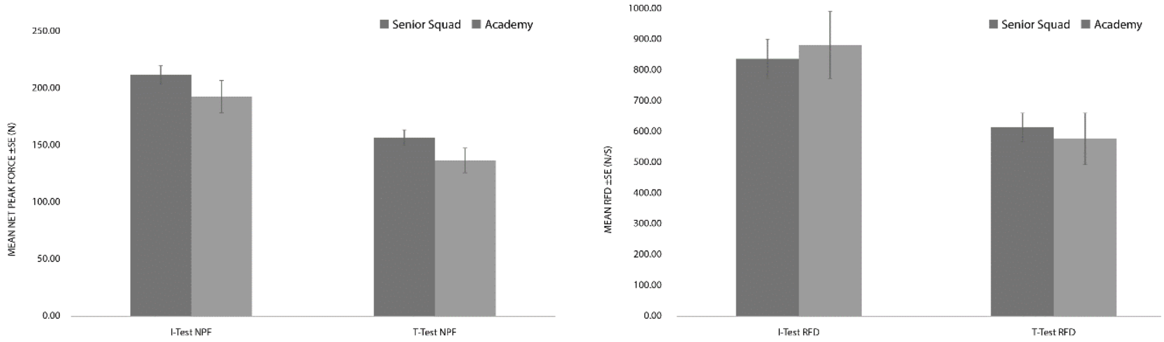
Peak Force (PF)

Peak force in senior squad players from an international rugby squad was 10.0% higher in the I-test, and in the T-test it was 14.0% higher than in academy players (figure 13). Mean relative I-test net peak force (NPF) was 202.8 N, 37.8% higher than T-test NPF (147.2 N). Peak force values in a larger sample of elite Rugby players are shown in Table 7 below.

Rate of Force Development (RFD)

The rate of force development is a measure of explosive strength and can be defined as the speed at which the contractile elements of the muscle can develop force (Aagaard et al., 2002). Mean RFD-100 in senior squad players was 5.5% higher in the I-test whilst T-test RFD was 5.9% higher in academy players. Mean RFD was 860.5 N/s in the I-Test and 597.5 N/s in the T-Test (the 44% higher RFD in the I-Test may be due to the T-position requiring greater trunk anti-rotation to stabilise the trunk proximally prior to transfer of force across the shoulder girdle and through the arm into the platform). In contrast, Del Águila Sánchez et al (2022), reported a mean I test RFD-100 of 480 N/s in elite volleyball players.

Figure 13: Rugby senior squad and academy players ASH I and T test data



NPF=Net peak force (peak vertical force - mass of limb at start of contraction). RFD=rate of force development 0-100 ms.
Source: Aagaard et al., 2002

To date, there is little ASH test RFD data published in athletes. Mean values in academy rugby players (543.67 N/s on the dominant side and 543.4 N/s on the non-dominant limb in the T-test). Senior squad players mean RFD was 12.1% higher in the T-test, with a maximum score of 1,566N/s reported in the dominant limb of one player, while the I-test averaged 44% greater RFD than the T-position.

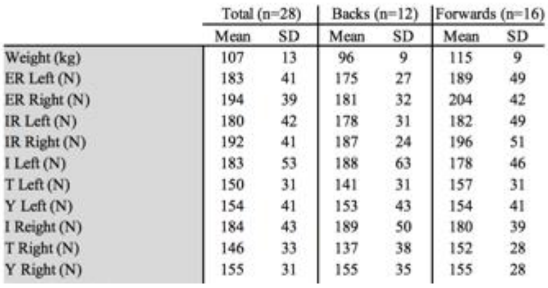
Table 4. Absolute and bodyweight relative ASH test performance in elite rugby players

	FORWARDS		BACKS	
ASH TEST	**PEAK FORCE**	**N/kg**	**PEAK FORCE**	**N/kg**
I TEST	335	2.83	252	3.25
Y TEST	365	2.96	235	3.03
T TEST	240	1.94	224	2.71

Data from five northern hemisphere rugby union teams (+200 players).
Source: authors own elaboration

Kadlec et al (2020) reported ASH tests, ForceFrame isometric ER and IR tests, and other measures of upper-extremity performance in rugby players (n=28). Mean adjusted net peak force for each test position; I-test (183.5 N) was greater than Y-test (154.5 N) and the lowest in the T-test (148 N) (see table 7). There was no significant correlation between peak force in the different tests (and positions), suggesting that each test provided useful information to add to the overall picture of the athlete's upper extremity performance.

Table 5. Upper body force profiles in Rugby players



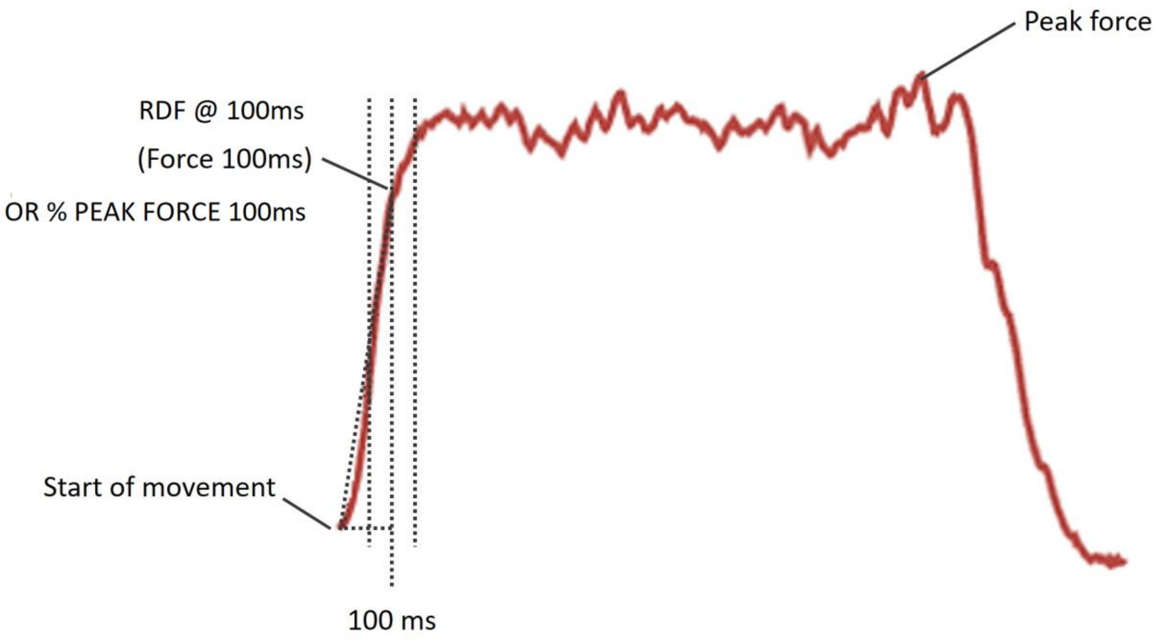
	Total (n=28)		Backs (n=12)		Forwards (n=16)	
	Mean	SD	Mean	SD	Mean	SD
Weight (kg)	107	13	96	9	115	9
ER Left (N)	183	41	175	27	189	49
ER Right (N)	194	39	181	32	204	42
IR Left (N)	180	42	178	31	182	49
IR Right (N)	192	41	187	24	196	51
I Left (N)	183	53	188	63	178	46
T Left (N)	150	31	141	31	157	31
Y Left (N)	154	41	153	43	154	41
I Reight (N)	184	43	189	50	180	39
T Right (N)	146	33	137	38	152	28
Y Right (N)	155	31	155	35	155	28

ER=External rotation; IR=Internal rotation; I=ASH test I position; Y=ASH Y position; T=ASH test T position. Bodyweight normalised values for full group (total): I Test (184/107) = 1.72 N/kg, Y Test (155/107) = 1.45 N/kg, T-test (146/107) = 1.36. Force Frame ER (183-194 N) and IR (180-192). Approximate Ratio 1.01 ER:IR and Asymmetry L: R of 6%
Adapted from Kadlec et al., 2020

- ***The Rate of Force Development***

RFD is typically obtained during the performance of a standard 3-s strength test, which may provide clinicians with a reasonable measure of both Peak Force and RFD. Nonetheless, if time permits and RFD is considered important to your performance/injury-related questions, RFD should ideally be recorded in a separate test that can be used to assess peak force. The recommended approach is to use a 1-s contraction or less, to minimise the effect of fatigue or discomfort in participants and with coaching cues to punch the hand through the floor. Objectively quantifying the ability to rapidly produce maximal forces across the shoulder and tolerate long lever stress is valuable to performance and return-to-sport (RTS) discussions in various settings. While peak force is never achieved within the first 100-150ms, it is important to define how much of their peak force athletes can apply in a short time window in relation to meaningful actions of injury/tackling/collision or throwing (figure 14).

Figure 14: Sample ASH test force-time profile: Peak force and RFD



Source: Authors own elaboration

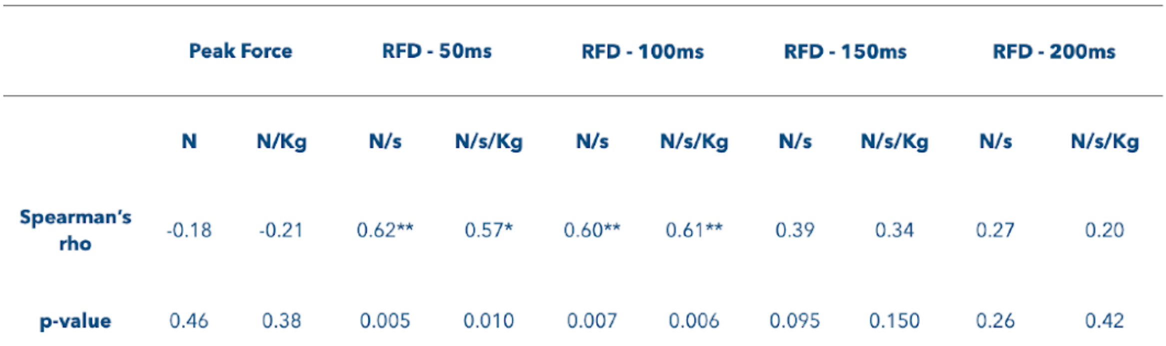
- ***Other ASH Test Applications – "Session Cost"***

Session cost can be defined as a drop in a component of performance as quantified by the change in a specific variable, determined by subtracting performance in a pre-session test from that achieved immediately after the session. It can also be a subjectively assessed rate of perceived exertion. Joseph Coyne evaluated session cost of a grappling/striking session in a small cohort of MMA fighters dichotomised as stronger or weaker in an ASH test. Session cost (in this case, defined as the decline in ASH test peak force) was larger in the weaker athletes, who also showed more variability in ASH test trials performance in the post-session test. Paula Timpson, first team physiotherapist at London Irish, has explored upper limb session cost in elite rugby players returning from shoulder injury. In RTS players, session cost (as defined as a decline in ASH test peak force immediately after performing a standardised return to tackling protocol) was approximately 20% in the healthy shoulder but often double in the injured (post-surgical) shoulder (~40%). This asymmetry in cost for the same load suggests an inability to cope with the demands of the session at that time point in the players return to performance pathway, thus representing a potential indicator to monitor for progress during rehabilitation.

- ***Relationship to Performance***

The relationship between volleyball spike velocity and ASH test RFD was evaluated in a professional team, and significant correlations noted for RFD at 50 and 100ms (Del Águila Sánchez et al., 2022). Peak force and RFD over longer time periods such as 200 ms was not correlated with velocity (table 10). Unpublished data in elite baseball demonstrated a similar relationship between pitching velocity and measures of RFD from ASH testing.

Table 6. Correlations between spike velocity and peak force and RFD measures in professional male volleyball players.



	Peak Force		RFD - 50ms		RFD - 100ms		RFD - 150ms		RFD - 200ms	
	N	**N/Kg**	**N/s**	**N/s/Kg**	**N/s**	**N/s/Kg**	**N/s**	**N/s/Kg**	**N/s**	**N/s/Kg**
Spearman's rho	-0.18	-0.21	0.62**	0.57*	0.60**	0.61**	0.39	0.34	0.27	0.20
p-value	0.46	0.38	0.005	0.010	0.007	0.006	0.095	0.150	0.26	0.42

N or N/s=absolute value; N/kg or N/s/kg=body weight relative values. Value for spike velocity and force were the highest achieved across trials.

From **Del Águila Sánchez, A., Ashworth, B., & Cohen, D. D.** (2022). Relationship Between Service Velocity and ASH test performance in Professional Volleyball Players. *Sports,* 10,93:12

Summary

Upper-extremity Isometric force platform testing is a relatively new and rapidly developing area of research and application. The use of the ASH test in addition to HHD and EFD measures is currently adopted in a variety of sports where upper-extremity demands are highest. Peak force data has already shown excellent reliability, and ongoing work into the reliability of RFD is promising and compares well to lower extremity testing protocols. In addition to providing additional information on the neuromuscular characteristics of athletes, there are an increasing number of examples of the link between ASH test data (PF and RFD) and measures of performance (e.g., volleyball spike & baseball pitching velocity) and injury.

References

Ashworth, B., & Cohen, D. D. (2019). Force awakens: a new hope for athletic shoulder strength testing. *British Journal of Sports Medicine*, *53*(9). http://dx.doi.org/10.1136/bjsports-2018-099457

Ashworth, B., Hogben, P., Singh, N., Tulloch, L., & Cohen, D. D. (2018). The Athletic Shoulder (ASH) test: reliability of a novel upper body isometric strength test in elite rugby players. *BMJ open sport & exercise medicine*, *4*(1), e000365. https://doi.org/10.1136/bmjsem-2018-000365

Bartolomei S, Nigro F, Ruggeri S, Malagoli Lanzoni I, Ciacci S, Merni F, Sadres E, Hoffman JR, Semprini G. (2018). Comparison Between Bench Press Throw and Ballistic Push-up Tests to Assess Upper-Body Power in Trained Individuals. *J Strength Cond Res*, Jun;32(6):1503-1510. doi: 10.1519/JSC.0000000000002571.

Bonello, C., Girdwood, M., De Souza, K., Trinder, N. K., Lewis, J., Lazarczuk, S. L., Gaida, J. E., Docking, S. I., & Rio, E. K. (2021). Does isometric exercise result in exercise induced hypoalgesia in people with local musculoskeletal pain? A systematic review. *Physical therapy in sport*, *49*, 51–61. https://doi.org/10.1016/j.ptsp.2020.09.008

Cools, A. M., De Wilde, L., Van Tongel, A., Ceyssens, C., Ryckewaert, R., & Cambier, D. C. (2014). Measuring shoulder external and internal rotation strength and range of motion: comprehensive intra-rater and inter-rater reliability study of several testing protocols. *Journal of shoulder and elbow surgery*, *23*(10), 1454–1461. https://doi.org/10.1016/j.jse.2014.01.006

Cormack, S. J., Newton, R. U., McGuigan, M. R., & Doyle, T. L. (2008). Reliability of measures obtained during single and repeated countermovement jumps. *International journal of sports physiology and performance*, *3*(2), 131–144. https://doi.org/10.1123/ijspp.3.2.131

Couch, J., Sayers, M., & Pizzari, T. (2021). Reliability of the ForceFrame With and Without a Fixed Upper-Limb Mold in Shoulder Rotation Strength Assessments Compared With Traditional Hand-Held Dynamometry. *Journal of sport rehabilitation*, *30*(8), 1246–1249. https://doi.org/10.1123/jsr.2020-0434

Cronin, J. B., & Owen, G. J. (2004). Upper-body strength and power assessment in women using a chest pass. *Journal of strength and conditioning research*, *18*(3), 401–404. https://doi.org/10.1519/12072.1

Del Águila Sánchez, A., Ashworth, B., & Cohen, D. D. (2022). Relationship Between Service Velocity and ASH test performance in Professional Volleyball Players. *Sports,* 10,93:12

Del Balso, C., & Cafarelli, E. (2007). Adaptations in the activation of human skeletal muscle induced by short-term isometric resistance training. *Journal of applied physiology (Bethesda, Md. : 1985)*, *103*(1), 402–411. https://doi.org/10.1152/japplphysiol.00477.2006

Dempsey G. (2021) The acute impact of tackling on shoulder isometric strength and rate of force development in Rugby union. University of Bath

De Oliveira, V. M., Pitangui, A. C., Nascimento, V. Y., da Silva, H. A., Dos Passos, M. H., & de Araújo, R. C. (2017). Test-Retest Reliability of the Closed Kinetic Chain Upper Extremity Stability Test (CKCUEST) in Adolescents: Reliability of CKCUEST in Adolescents. *International journal of sports physical therapy*, *12*(1), 125–132.

Dhahbi, W., Chaouachi, A., Cochrane, J., Chèze, L., & Chamari, K. (2017). Methodological Issues Associated With the Use of Force Plates When Assessing Push-ups Power. *Journal of Strength and Conditioning Research, 31*(7).

Dhahbi, W., Chaouachi, A., Dhahbi, A. B., Cochrane, J., Chèze, L., Burnett, A., & Chamari, K. (2017). The Effect of Variation of Plyometric Push-Ups on Force-Application Kinetics and Perception of Intensity. *International journal of sports physiology and performance*, *12*(2), 190–197. https://doi.org/10.1123/ijspp.2016-0063

Fanning, E., Daniels, K., Cools, A., Miles, J. J., & Falvey, É. (2021). Biomechanical upper-extremity performance tests and isokinetic shoulder strength in collision and contact athletes. *Journal of sports sciences*, *39*(16), 1873–1881. https://doi.org/10.1080/02640414.2021.1904694

García-Massó, X., Colado, J. C., González, L. M., Salvá, P., Alves, J., Tella, V., & Triplett, N. T. (2011). Myoelectric activation and kinetics of different plyometric push-up exercises. *Journal of strength and conditioning research*, *25*(7), 2040–2047. https://doi.org/10.1519/JSC.0b013e3181e4f7ce

Goldbeck, T. G., & Davies, G. J. (2000). Test-Retest Reliability of the Closed Kinetic Chain Upper Extremity Stability Test: A Clinical Field Test. *Journal of Sport Rehabilitation, 9*(1), 35-45. https://doi.org/10.1123/jsr.9.1.35

Hams, A. H., Evans, K., Adams, R., Waddington, G., & Witchalls, J. (2019). Shoulder internal and external rotation strength and prediction of subsequent injury in water-polo players. *Scandinavian journal of medicine & science in sports*, *29*(9), 1414–1420. https://doi.org/10.1111/sms.13459

Hinshaw, T. J., Stephenson, M. L., Sha, Z., & Dai, B. (2018). Effect of External Loading on Force and Power Production During Plyometric Push-ups. *Journal of strength and conditioning research*, *32*(4), 1099–1108. https://doi.org/10.1519/JSC.0000000000001953

Hogarth, L., Deakin, G., & Sinclair, W. (2013) Are plyometric push-ups a reliable power assessment tool? *Journal Australian Strength and Conditioning, 21*(1), 67-69.

Holt, K. L., Raper, D. P., Boettcher, C. E., Waddington, G. S., & Drew, M. K. (2016). Hand-held dynamometry strength measures for internal and external rotation demonstrate superior reliability, lower minimal detectable change and higher correlation to isokinetic dynamometry than externally-fixed dynamometry of the shoulder. *er. Physical therapy in sport: official journal of the Association of Chartered Physiotherapists in Sports Medicine, 21, 75–81.* *https://doi.org/10.1016/j.ptsp.2016.07.001*

Johnston, R. D., Gabbett, T. J., Jenkins, D. G., & Speranza, M. J. (2016). The Effect of Different Repeated-High-Intensity-Effort Bouts on Subsequent Running, Skill Performance, and Neuromuscular Function. *International journal of sports physiology and performance*, *11*(3), 311–318. https://doi.org/10.1123/ijspp.2015-0243

Kadlec, D., Griffiths, K. M., Young, J. D., & Downes, P. (2020). The relationship of upper body multi-joint and single-joint strength and function in male Rugby athletes. *Sport performance and science reports 1*(82), 1-4.

Koch, J., Riemann, B. L., & Davies, G. J. (2012). Ground reaction force patterns in plyometric push-ups. *Journal of strength and conditioning research*, *26*(8), 2220–2227. https://doi.org/10.1519/JSC.0b013e318239f867

Kubo, K., Kanehisa, H., & Fukunaga, T. (2001). Effects of different duration isometric contractions on tendon elasticity in human quadriceps muscles. *The Journal of physiology, 536(Pt 2),* 649–655. https://doi.org/10.1111/j.1469-7793.2001.0649c.xd

Lee D-R Kim LJ. (2015). Reliability and validity of the closed kinetic chain upper extremity stability test. J PhysTher Sci. 2015;27(4):1071–3

Littlewood, C., Malliaras, P., Bateman, M., Stace, R., May, S., & Walters, S. (2013). The central nervous system - An additional consideration in `rotator cuff tendinopathy' and a potential basis for understanding response to loaded therapeutic exercise. *Manual Therapy 18*, 468-472. http://www.aulakinesica.com.ar/semioquirurgica/files/2013%20The%20central%20nervous.pdf

Lum, D., & Barbosa, T. M. (2019). Brief Review: Effects of Isometric Strength Training on Strength and Dynamic Performance. *International journal of sports medicine, 40(6), 363–375*. https://doi.org/10.1055/a-0863-4539

Maffiuletti, N. A., Aagaard, P., Blazevich, A. J., Folland, J., Tillin, N., & Duchateau, J. (2016). Rate of force development: physiological and methodological considerations. *European* *journal of applied physiology*, *116*(6), 1091–1116. https://doi.org/10.1007/s00421-016-3346-6

McLaine, S. J., Ginn, K. A., Kitic, C. M., Fell, J. W., & Bird, M. L. (2016). The Reliability of Strength Tests Performed In Elevated Shoulder Positions Using a Handheld Dynamometer. *Journal of sport rehabilitation*, *25*(2), 2015-0034. https://doi.org/10.1123/jsr.2015-0034

Michener, L. A., Barrack, A. J., Liebeskind, B. Y., Zerega, R. J., Sum, J. C., Crotin, R. L., & Plummer, H. A. (2021). Professional Baseball Player Type and Geographic Region of Origin Impacts Shoulder External and Internal Rotation Strength. *International journal of sports physical therapy*, *16*(4), 1126–1134. https://doi.org/10.26603/001c.25237

Mirkov, D. M., Knezevic, O. M., Maffiuletti, N. A., Kadija, M., Nedeljkovic, A., & Jaric, S. (2017). Contralateral limb deficit after ACL-reconstruction: an analysis of early and late phase of rate of force development. *Journal of sports sciences*, *35*(5), 435–440. https://doi.org/10.1080/02640414.2016.1168933

Moore, L. H., Tankovich, M. J., Riemann, B. L., & Davies, G. J. (2012). Kinematic Analysis of Four Plyometric Push-Up Variations. *International journal of exercise science*, *5*(4), 334–343.

Morrison, G., Ashworth, B., & Taylor-Kaveney, T. (2021). The validity of the sphygmomanometer for shoulder strength assessment in amateur rugby union players. *Physical therapy in sport : official journal of the Association of Chartered Physiotherapists in Sports Medicine*, *47*, 59–65. https://doi.org/10.1016/j.ptsp.2020.10.013

Møller, M., Nielsen, R. O., Attermann, J., Wedderkopp, N., Lind, M., Sørensen, H., & Myklebust, G. (2017). Handball load and shoulder injury rate: a 31-week cohort study of 679 elite youth handball players. *British journal of sports medicine*, *51*(4), 231–237. https://doi.org/10.1136/bjsports-2016-096927

Myers N. L., Toonstra, J. L., Smith, J. S., Padgett, C. A., & Uhl, T. L. (2015). Sustained Isometric Shoulder Contraction on Muscular Strength and Endurance: a Randomized Clinical Trial. *International journal of sports physical therapy*, *10*(7), 1015–1025.

Negrete, R. J., Hanney, W. J., Kolber, M. J., Davies, G. J., Ansley, M. K., McBride, A. B., & Overstreet, A. L. (2010). Reliability, minimal detectable change, and normative values for tests of upper extremity function and power. *Journal of strength and conditioning research*, *24*(12), 3318–3325. https://doi.org/10.1519/JSC.0b013e3181e7259c

Nichols, I. A., & Szivak, T. K. (2021). Effects of Different Hand Widths on Plyometric Push-up Performance. *Journal of strength and conditioning research*, *35*(1), 80-83. https://doi.org/10.1519/JSC.0000000000003155

Oakley, A. (2021). Upper Body Return to Sport Testing in Collision Athletes – Exploring the Continuum. *Rehab in Sport*. Retrieved from https://rehabinsport.com/2021/01/08/upper-body-return-to-sport-testing-in-a-collision-athletes-exploring-the-continuum/

Parry, G. N., Herrington, L. C., & Horsley, I. G. (2020). The Test-Retest Reliability of Force Plate-Derived Parameters of the Countermovement Push-Up as a Power Assessment Tool. Journal of sport rehabilitation, *29*(3), 381–383. https://doi.org/10.1123/jsr.2018-0419

Pelka, E., Williams, A., McLaughlin, D., Gadola, C., Slattery, E., & Claytor, R. (2020). Comparison of Concentric Movement Velocity with Push Band 2.0 and Vicon Motion Capture During Resistance Exercises. *International Society of Biomechanics in Sports, 38*(1), 252.

Popchak, A., Poploski, K., Patterson-Lynch, B., Nigolian, J., & Lin, A. (2021). Reliability and validity of a return to sports testing battery for the shoulder. *Physical therapy in sport : official journal of the Association of Chartered Physiotherapists in Sports Medicine*, *48*, 1–11. https://doi.org/10.1016/j.ptsp.2020.12.003

Poploski KM, Picha KJ, Winters JD, Royer SD, Heebner NR, Lambert B, Lephart SM, Abt JP. (2020). Influence of Limb Dominance and shoulder injury on Strength and explosive force in US Marines. Int J Sports Phys Ther. 2020 Dec;15(6):1129-1140. doi: 10.26603/ijspt20201129.

Portlock, C., Browne, M., Jhala, P., & Fuller, J. (2019). Is the inter-rater reliability of hip and shoulder strength testing different between hand-held and portable fixed dynamometers? Sports Medicine Australia Conference. *Journal of science and medicine in sport, 22*(2), S103-S104. https://doi.org/10.1016/j.jsams.2019.08.136

Roe, G., Darrall-Jones, J., Till, K., Phibbs, P., Read, D., Weakley, J., & Jones, B. (2016). Between-Days Reliability and Sensitivity of Common Fatigue Measures in Rugby Players. *International journal of sports physiology and performance*, *11*(5), 581–586. https://doi.org/10.1123/ijspp.2015-0413

Roush, J. R., Kitamura, J., & Waits, M. C. (2007). Reference Values for the Closed Kinetic Chain Upper Extremity Stability Test (CKCUEST) for Collegiate Baseball Players. *North American journal of sports physical therapy*, *2*(3), 159–163.

Sander, A., Keiner, M., Wirth, K., & Schmidtbleicher, D. (2013). Influence of a 2-year strength training programme on power performance in elite youth soccer players. European journal of sport science, 13(5), 445–451. https://doi.org/10.1080/17461391.2012.742572

Seroyer, S. T., Nho, S. J., Bach, B. R., Bush-Joseph, C. A., Nicholson, G. P., & Romeo, A. A. (2010). The kinetic chain in overhand pitching: its potential role for performance enhancement and injury prevention. *Sports health*, *2*(2), 135–146. https://doi.org/10.1177/1941738110362656

Sha, Z., & Dai, B. (2021). The validity of using one force platform to quantify whole-body forces, velocities, and power during a plyometric push-up. *BMC Sports Science Medicine and Rehabil*itation, 13(103), 1-9. https://doi.org/10.1186/s13102-021-00330-z

Suprak DN, Dawes J, Stephenson MD. (2011). The effect of position on the percentage of body mass supported during traditional and modified push-up variants. *J Strength Cond Res*. Feb;25(2):497-503. doi: 10.1519/JSC.0b013e3181bde2cf.

Taberner, M., & Cohen, D. D. (2018). Physical preparation of the football player with an intramuscular hamstring tendon tear: clinical perspective with video demonstrations. *British journal of sports medicine*, *52*(19), 1275–1278. https://doi.org/10.1136/bjsports-2017-098817

Tulloch, L. (host). (2019, March 8). The use of force plates in return-to-play following shoulder injuries (No. 371). [Audio podcast episode]. In BJSM. Apple Podcasts. https://poddtoppen.se/podcast/330966919/bjsm/the-use-of-force-plates-in-return-to-play-following-shoulder-injuries-episode-371

Zalleg, D., Ben Dhahbi, A., Dhahbi, W., Sellami, M., Padulo, J., Souaifi, M., Bešlija, T., & Chamari, K. (2020). Explosive Push-ups: From Popular Simple Exercises to Valid Tests for Upper-Body Power. *Journal of strength and conditioning research*, *34*(10), 2877–2885. https://doi.org/10.1519/JSC.0000000000002774

Zebis, M. K., Andersen, L. L., Ellingsgaard, H., & Aagaard, P. (2011). Rapid hamstring/quadriceps force capacity in male vs. female elite soccer players. *Journal of strength and conditioning research*, *25*(7), 1989–1993. https://doi.org/10.1519/JSC.0b013e3181e501a6