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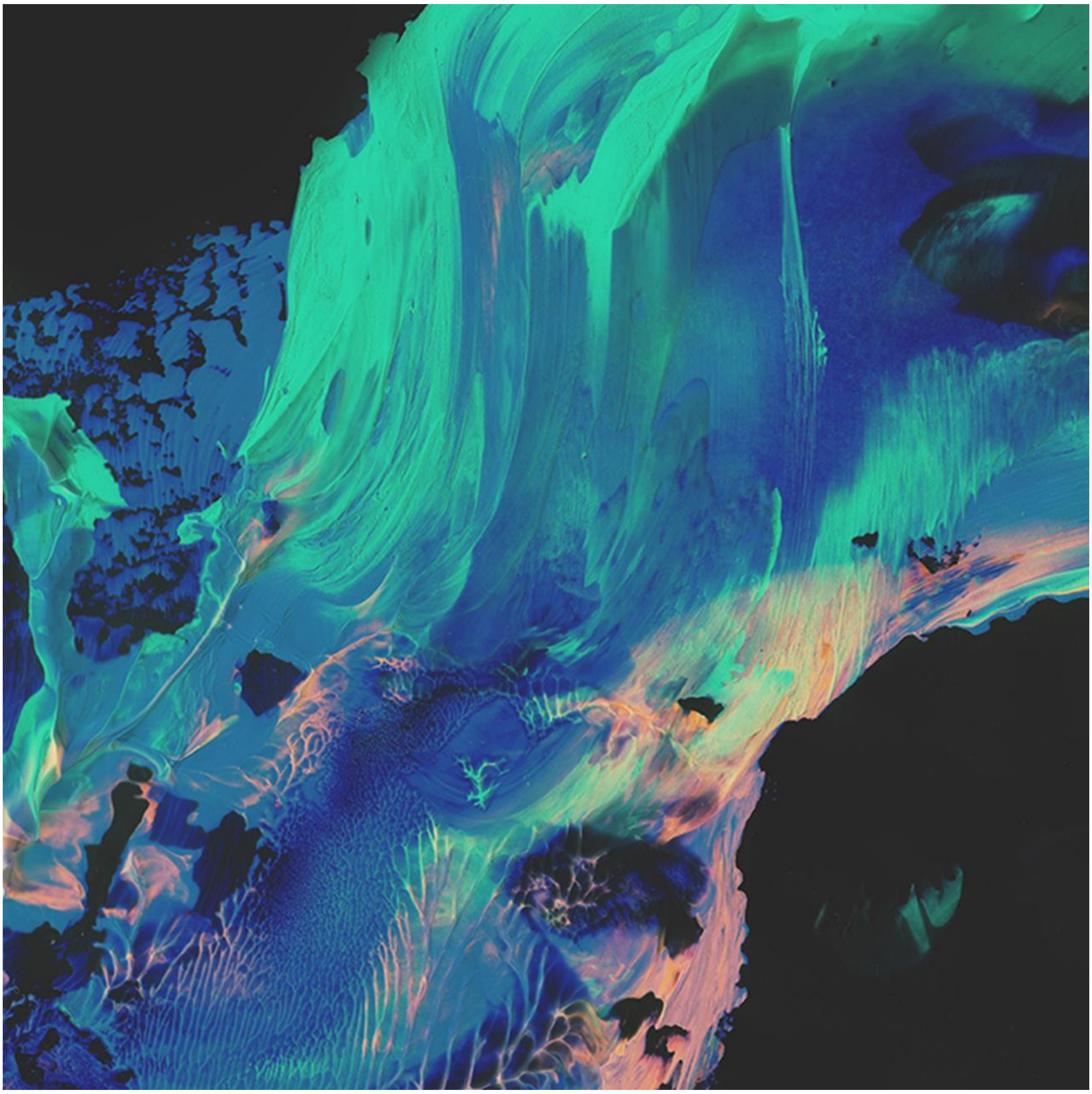
Concurrent validity of an inertial sensor for measuring muscle mechanical properties

Elias Olovsson Ståhl & Pontus Öhrner



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Abstract

Background: The usage of the Force-Velocity relationship for individualizing training regimes for athletes has increased in popularity. This can be done through measurements of muscle mechanical properties and creating individual force-velocity profiles. To do this, one must use valid and reliable test equipment. These types of equipment are often expensive and impractical, which limits the usage to a small population with the right financial means. Therefore, the purpose of this study was to examine the concurrent validity of the inertial sensor Vmaxpro for measuring muscle mechanical properties.

Method: 52 male ice-hockey players (age:17.9 ± 2.2 years, body weight: 77.7 ± 10.6 kg, height: 180.3 ± 6.2 cm) participated in this study and performed two jumps each on four different loading conditions (unloaded, 25, 50 and 75% of BW). The jumps were recorded simultaneously with an inertial sensor and a linear transducer. Three different variables were analyzed: peak velocity (pV), average velocity (avgV) and average power (avgP). Pearson's correlation coefficient (r), linear regression analysis, Bland-Altman analysis, and standard error of estimate (SEE) was used to examine the concurrent validity.

Results: The results showed a strong correlation, agreement and small SEE for pV: r=0.98, bias = -0.12, SEE = 0.08, for avgV: r = 0.98, bias = 0.01, SEE = 0.04 and for avgP: r = 0.97, bias = 30.94, SEE = 73.47.

Practical application: The results from the present study indicate that the Vmaxpro can be used for assessing muscle mechanical properties. Furthermore, since the Vmaxpro is both cheap and portable, it can potentially expand the usage of test equipment to clubs and associations with limited budgets.

Key words: Vmaxpro, accelerometer, linear encoder, test equipment, force-velocity profiling.

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1 Introduction

Sports performance can be considered multifactorial. Meaning, there are several factors that independently and dependently of each other influence sports performance (e.g. Brughelli et al., 2008; Carlsson, et al. 2016; Erculj, Blas & Bracic, 2010; Harper, Carling & Kiely, 2019; Krustrup, Mohr, Ellingsgaard & Bangsbo, 2005; Newton & Kraemer, 1994; Sundberg & Fitts, 2019; Taylor, Wright, Dischiavi, Townsend & Marmon, 2017). How important each factor is and how much it contributes to athletic performance may vary depending on the sport. Examples of performance factors that can be considered as universally important for most sports are VO_2 kinetics, aerobic capacity, anaerobic threshold, anaerobic capacity, movement economy, strength, speed and agility (Carlsson, et al. 2016; Drust, Atkinson & Reilly, 2007; Gabbett, King & Jenkins, 2008; Hausswirth & Lehénaff, 2001; Hoffman, 2008; Sundberg & Fitts, 2019). Another factor that has been proposed as universally important for sports performance is muscular power and more specifically peak power output (e.g. Cormie, McGuigan & Newton, 2011; Haff, Whitley & Potteiger, 2001; Kraemer & Newton, 2000; Sleivert & Taingahue, 2004; Stone et al., 2002).

Power (W) is equal to Force (F) x Velocity (V), Power = F x V (Knuttgen & Kraemer, 1987) and the mechanical definition of power is often referred to as “the rate of doing work” (Josephson, 1999; Knudson, 2009). The equation for power consists of two interdependently factors that influence power, the force a muscle can generate (F), and at which rate the force can be applied i.e. the velocity (V).

According to Cormie, McGuigan & Newton (2011), there is a wide array of muscle mechanical properties (e.g. force-velocity relationship, length-tension relationship, type of muscle action, storage and utilization of elastic energy, interactions of contractile and elastic elements, potentiation of contractile and elastic filaments and stretch reflexes), morphological factors (e.g. muscle fiber type, muscle architecture, and tendon properties) and neural factors (e.g. motor unit recruitment, firing frequency, motor unit synchronization, inter-muscular coordination) that influence power output. Even though all these muscle and neural characteristics influence power output, one’s ability to generate maximal power output is defined by the force-velocity relationship.

1.1 Force-velocity relationship

The force-velocity relationship is an inverse relationship between force and velocity (Gülch, 1994; Hill, 1938; Katz, 1939). When one of the two factors (force and velocity) gets larger or increases, the other one gets smaller or decreases.

The theory about sliding filaments is one explanation for this phenomenon (Huxley, 1957). When muscle contracts, actin, and myosin filaments attach and form cross-bridges. The more cross-bridges made, the more force a muscle can produce. However, this is limited by the velocity at which the muscle contracts. If the contraction is of higher velocity, fewer cross-bridges are made and thus limits the amount of force the muscle can produce.

The F-V relationship has previously been proposed as both linear (Figure 1), hyperbolic (Figure 2) and double-hyperbolic (Figure 3) (Alcazar, Csapo, Ara & Alegre, 2019). It has been suggested that the shape of the force-velocity relationship can differ depending on if the skeletal muscle action is single- or multi-jointed. A double hyperbolic relationship has been seen during single-joint movements (Yeadon, King & Wilson, 2006) whereas a linear relationship has been seen during multi-joint muscle actions (Bobbert, 2012).

The discrepancy in the literature can be explained by the fact that studies reporting a linear or hyperbolic relationship failed to accurately measure either both or one of the extremes of the F-V relationship (Alcazar, Csapo, Ara & Alegre, 2019). Furthermore, previous studies by Edman (1993) and Piazzesi et al. (2007) have shown an inflection point where an increase in attached cross-bridges is accompanied by a decrease in force production per cross-bridge made, making the F-V relationship double-hyperbolic.

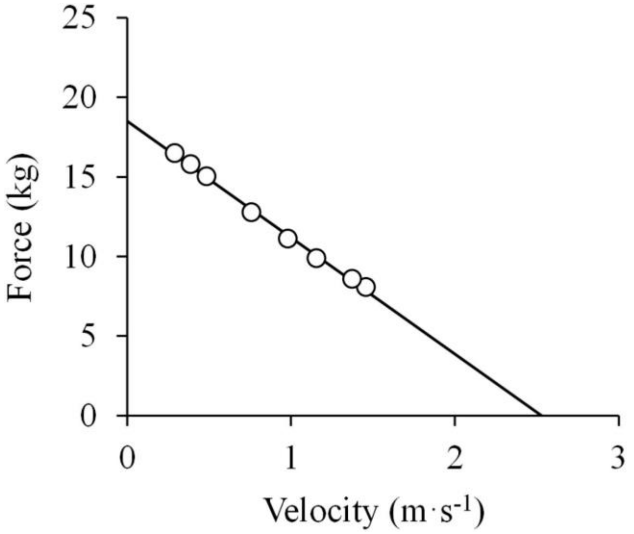

Figure 1. Linear force-velocity relationship. Obtained from *On the Shape of the Force-Velocity Relationship in Skeletal Muscles: The Linear, the Hyperbolic, and the Double-Hyperbolic. By Alcazar, Csapo, Ara & Alegre, 2019.*

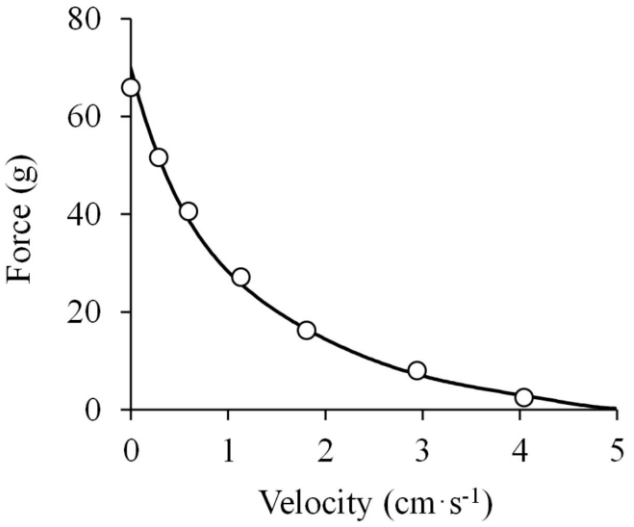

Figure 2. Hyperbolic force-velocity relationship. Obtained from *On the Shape of the Force-Velocity Relationship in Skeletal Muscles: The Linear, the Hyperbolic, and the Double-Hyperbolic. By Alcazar, Csapo, Ara & Alegre, 2019.*

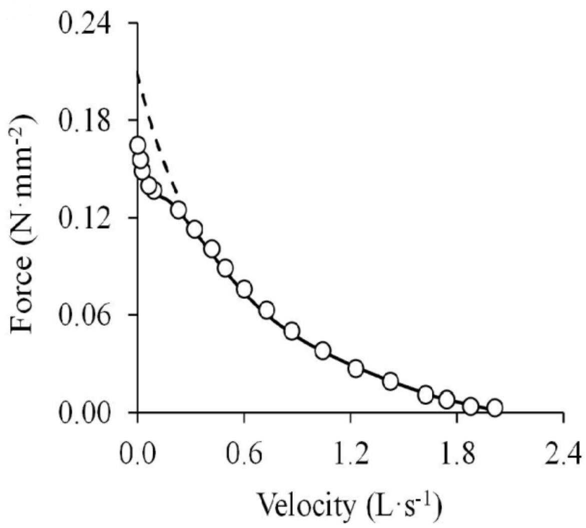

Figure 3. Double-hyperbolic force-velocity relationship. Obtained from *On the Shape of the Force-Velocity Relationship in Skeletal Muscles: The Linear, the Hyperbolic, and the Double-Hyperbolic. By Alcazar, Csapo, Ara & Alegre, 2019.*

1.2 Force-velocity profiling

Since maximal power output in skeletal muscle is associated with the curvature of the F-V relationship (Gordon & Julian, 1966), the usage of the F-V relationship for designing individualized training regimes and developing the desired trait on the F-V spectrum is increasingly intriguing (Morin & Samozino, 2016; Samozino et al., 2014)

Theoretically, an athlete may be more reliant on either strength (force) or speed (velocity) capabilities (Jiménez-Reyes, Samozino, Brughelly & Morin, 2017; Ramos, Castilla & Slobodan, 2018; Samozino et al. 2014) and different individuals can share the same power output but differ in force-velocity properties. A method for identifying these capabilities can be done through force-velocity profiling (Morin & Samozino, 2016). During this procedure, it's necessary to address both ends of the force-velocity spectrum to access athletes' force-velocity capabilities. Commonly, a procedure for this consists of 4-9 loads set to range from the low force - high velocity to the high force - low velocity. By assessing these profiles, the reliance on which properties an athlete is leaning towards can be identified. A commonly used method to assess the F-V relationship and create F-V profiles in athletes is through vertical jumping, and most commonly through the countermovement jump (Contreras-Diaz, Jerez-Mayorga, Delgado-Floody & Arias-Poblete, 2018).

1.3 Countermovement jump

The countermovement jump consists of 6 different phases (stance, unweighting, braking, propulsion, flight, and landing, respectively) (McMahon et al., 2018). Depending on the muscle mechanical properties of the athlete, one might perform better on some of the phases and worse on another. For example, an athlete's ability to relax the agonist muscle in the unweighting phase affects both the rate and the amount of force production that is required in the breaking phase (Kibele, 1998). Also, an athlete's ability to quickly decelerate in the breaking phase and transition fast into the propulsion phase can be used as an indicator of the athlete's rate of force development (Mizuguchi, Sands, Wassinger, Lamont & Stone, 2015). Previous research has shown a significant correlation between lower body power output and CMJ performance (Canavan & Vescovi, 2004; Nuzzo, Mcbride, Cormie & McCaulley, 2008; Peterson, Alvar & Rhea, 2006). However, the measurement of power output through vertical jumping has been criticized for not being the most suitable method (Adamson & Whitney, 1971; Knudson, 2009). Since the different phases of the CMJ are defined by different characteristics of the muscle mechanical properties, it is of the essence that the testing device must be able to identify the start and end of each phase as precisely as possible. This ensures that the information gathered from the device yields correct information on the muscle mechanical properties of the athletes.

1.4 Test equipment

To assess the mechanical properties of the muscles through F-V profiling, there are several test equipment from different brands available. These brands are often using different methods e.g. linear encoders, accelerometers, IR mats, force plates, contact-mat (Assess2perform.com; Ergotest.com; Gymaware.com; Optojump.com; Performbetter.com; Simplifaster.com; Thisisbeast.com; trainwithpush.com). These are often expensive and, in some cases, non-portable, which limits the usage of these products to teams and other associations with the right financial means. The prices can vary from 200-1,000$ for the cheaper equipment e.g. accelerometers & contact mats to 2,000-40.000$+ for the more expensive products e.g. Linear encoder, IR mats & Force plates. These different methods have previously been tested for their reliability and concurrent validity when measuring muscle mechanical properties with varying results (Beckham et al., 2019; Hilmersson, Edvardsson & Tornberg 2015; Pérez-Castilla, Piepoli, Delgado-García, Garrido-Blanca & García-Ramos, 2019; Pueo et al. 2018; Pueo, Lipinska, Jimenez-Olmedo, Zmijewski & Hopkins, 2016; Weakley et al., 2020). It seems like the more expensive products tend to be able to collect more accurate data. Furthermore, previous research on inertial sensors has examined the concurrent validity with non-ballistic exercises e.g. bench-press, push-ups and barbell back squat with an emphasis on velocity based training and not as test equipment (Beckham et al., 2019; Pérez-Castilla, Piepoli, Delgado-García, Garrido-Blanca & García-Ramos, 2019). Therefore, the potential practicality of a cheap and portable device being valid and reliable as test equipment for measuring muscle mechanical properties through vertical jumps could provide a measurement option for strength coaches and sports clubs with limited budgets.

The purpose of this study was to examine the concurrent validity of the inertial sensor Vmaxpro, and its ability to assess the mechanical properties of the lower extremities when performing countermovement jump with various loading.

1.5 Hypotheses

Peak velocity from the inertial sensor Vmaxpro will show a strong agreement and correlate significantly with the reference device.

Average velocity from the inertial sensor Vmaxpro will show a strong agreement and correlate significantly with the reference device.

Average power from the inertial sensor Vmaxpro will show a strong agreement and correlate significantly with the reference device.

2 Method

2.1 Experimental approach to the problem

To investigate the validity of the proposed device when measuring muscle mechanical properties, a validation study design was adopted. To assess the concurrent validity of a proposed device it is necessary to choose a reference device which has previously been validated. For the present study, the MuscleLab M-encoder was used as a reference device.

For the evaluation of the concurrent validity of the Vmaxpro, CMJ was chosen for the testing procedure. There are several reasons why CMJ was chosen in this study. The CMJ requires little to no familiarization, is non-fatiguing, and easy to conduct on a large sample. To this date, the majority of studies conducted on the evaluation of muscle mechanical properties with vertical jumps have CMJ as the preferred jump.
The 3 common variables between these two devices were peak velocity, average velocity, and power. Therefore, these variables were chosen to evaluate the concurrent validity of the inertial sensor.

As previously mentioned it's necessary to address both ends of the force-velocity spectrum to assess an athlete's force-velocity capabilities. Therefore, to test the proposed device capability to collect accurate data it was necessary to implement a loading scheme that included loads throughout this range.
To individualize the loading for each subject and address both ends of the force-velocity spectrum, a relative loading instead of a fixed was implemented. This scheme consisted of loads ranging from unloaded, 25%, 50%, and 75% of their body mass. Since the population consisted of mostly youth athletes the biological maturity, strength, and body mass differed considerably in some cases and if a fixed loading would be implemented it would be maladjusted for most subjects.

To minimize risk for injury and excessive bar displacement, the participants were instructed to hold the barbell tightly across their shoulders.
The wire from the M-encoder was attached to the velcro strap from Vmaxpro. This to ensure that both pieces of equipment were recording the data simultaneously from the same position.

2.2 Subjects

Fifty-two elite junior and senior male ice-hockey players participated in the present study (age:17.9 ± 2.2 years, bodyweight: 77.7 ± 10.6 kg, height: 180.3 ± 6.2 cm). Out of the 52 participants, two players were excluded from the data analysis since they were not able to perform all jumps.

The participants had no previous history of recent severe injury in the lower extremities or any medical condition that could potentially harm the subject or affect the performance during the testing procedure. Subjects were recruited from an ice-hockey club in the northern part of Sweden and were given both verbal and written information about the study (appendix 1). Written consent was obtained from all the subjects before any testing was conducted. Subjects under the age of 18 were required to have a parent or a legal guardian to sign their consent before the subject was allowed to participate.

According to the Helsinki declaration, all data regarding the subjects must be stored securely for as long as two years. To minimize the risk of spreading any personal information, all data regarding the participants were coded and stored in a separate passworded document.

The participants were informed that participation was voluntary and withdrawal from this study could be done without any specific reason.

The study design has been ethically reviewed and approved by the department's research council.

2.3 Procedures

A standardized warm-up was conducted for a total of approximately 20 minutes. This consisted of ten minutes of work on a stationary indoor bicycle set on 80RPM with an RPE of 3-4 on the Borg CR-10 scale (Borg, 1990). Following this, squats were performed 1x5 repetitions on 20kg, 1x3 repetitions on 40kg, and 1x1 repetitions on 60kg. Lastly, a vertical jump with maximal effort on both BW and with a 20kg barbell was performed with the purpose of both preparing and familiarize the subjects with the testing procedure. A rest period of five minutes was set between the warm-up and the beginning of the testing procedure. During the five-minute rest period, the subjects were given a recap of the testing protocol to ensure that there were no questions left unanswered.

After the warm-up, each subject was to perform a total of eight maximal countermovement jumps with an instructed turning point of a 90˚ knee angle. The testing procedure consisted of both unloaded jumps and jumps with additional loads of 25, 50, and 75% of their body mass in a randomized and balanced order. The subjects performed two jumps on each loading condition with a rest period of three to five minutes between each trial. For logistical reasons, every subject began with an unloaded condition. The unloaded condition was performed with a "wooden stick" as an attachment point for the Vmaxpro and MuscleLab. When the unloaded condition was completed, the wooden stick was replaced by a 15kg barbell from Eleiko (Eleiko Sport AB, Halmstad, Sweden). The subjects were instructed to jump with maximal intention and to land with the same position as they took off, i.e., extended leg in foot plantar flexion. Each trial was recorded simultaneously with the inertial sensor (Vmaxpro V2, Blaumann & Meyer - Sports Technology UG, Germany) and the linear encoder (MuscleLab, Ergotest Innovation, Langesund, Norway).

2.4 Equipment

2.4.1 MuscleLab Linear Encoder

The MuscleLab linear encoder or M-encoder (MuscleLab, x, Ergotest Innovation, Langesund, Norway) is a device consisting of a wire that can be attached to different objects. The M-encoder has a sample rate of 200hz (5ms) and a resolution of 0.019mm.
Multiple variables from both the concentric (C) and eccentric (E) phases can be provided through measurements and calculations from the software that comes along with the hardware (e.g. average power (W) C, average force (N) C, average velocity (m/s) C, peak velocity (m/s) C, time to peak velocity (s), distance (cm) C, time (s) C, average power (W) E, average force(N) E, average velocity(m/s) E, distance (cm) E, time (s), Total Power, frequency & reps)
According to the manufacturer the formula used for average power were P = F*V, and for average force were F = m*g + m*a (g=9.81 m/s^2), (m = mass kg, and a = acceleration m/s^2)

Previous research by Hilmersson, Edvardsson & Tornberg (2015) has evaluated the reliability of the M-encoder while performing countermovement jumps. The results of this study showed that the M-encoder has a high reproducibility when assessing CMJ performance among elite athletes. The M-encoder has also previously been used as a reference device when validating different types of testing equipment (Buscà & Font, 2011; Bosquet, Porta-Benache & Blais, 2010; Van den Tillaar & Ball, 2019).

2.4.2 Vmaxpro

Vmaxpro is a small inertial sensor (i.e accelerometer) that attaches to a barbell via magnets or a velcro strap for a more secure fit. The Vmaxpro has previously been tested by Blaumann & Meyer - Sports Technology UG when performing squats, bench press, deadlift, and snatch. According to the manufacturer, the inertial sensor has shown to be reliable and valid when measuring peak velocity (pV), average velocity (aV), and distance (d) (Vmaxpro V2, Blaumann & Meyer - Sports Technology UG, Germany).
The Vmaxpro can measure 11 different data points + bar path (Average velocity, Peak velocity, Power output, Distance, Movement duration, Duration between reps, Point of max. velocity, Point of max. acceleration, Minimum Velocity Threshold, Muscle Performance Threshold & 1 Repetition Maximum)
The calculations for the two variables peak and average power was, according to the manufacturer: (az [g] + 1.0) * 9.81 [m/s^2] * vz [m/s] * m [kg] for peak power and v [m/s] * (9.81 [m/s^2] + v [m/s] / t [s]) *m [kg] for average power.

2.5 Statistical analysis

Descriptive statistics were used for the statistical analysis. All data were normally distributed according to Kolmogorov-Smirnov test.
A T-test was performed between the Vmaxpro and M-encoder on all three variables.
Pearson’s correlation coefficient (r), linear regression analysis (R2), and standard error of estimate (SEE) were used to calculate the validity for the Vmaxpro on all three variables (Hopkins, Marshall, Batterham & Hanin, 2009).
For the interpretation of the Pearson correlation of coefficient, the values from Mukaka (2012) "Rule of thumb for interpreting the size of a correlation coefficient" were used.

A Bland-Altman analysis was performed on all three variables measured with both pieces of equipment (Bland & Altman, 1986).
All statistical analyses were performed on Microsoft Office Excel 2016 (Microsoft Corporation, Redmond, WA, USA).
Data are presented as Mean ± Standard deviation (SD).
The level of significance was set to $\alpha = 0.05$.

3 Results

Out of the 52 subjects, 50 performed all eight jumps. Two subjects were excluded from the data analysis since they were not able to perform jumps at 75%BW in a safe manner.
The mean values, standard deviation, T-test, and Pearson's correlation coefficient (r) for pV, avgV and avgP on both devices are presented in table 1,2,3 respectively. The results from the T-test showed a significant difference ($p<0.05$) between the two devices on all loading conditions for all three variables.
A significant correlation was found between the two devices on all jumps for all three variables (pV r = 0.98, avgV r = 0.98, avgP r = 0.97). The standard error of estimate (SEE) between the two devices were pV = 0.08, avgV = 0.04 & avgP = 73.47.
The linear regression analysis (R2) with the regression equation for pV, avgV and avgP are presented in Figures 1, 2, 3 respectively.
The results from the Bland-Altman analysis showed all recorded data points within both upper and lower LOA. The Bland-Altman plots for pV, avgV and avgP are presented in Figures 4, 5, 6.
Values for the Bland-Altman analysis on pV, avgV and avgP were, Bias = -0.12, Lower LOA = -0.99, Upper LOA = 0.75, Bias = 0.01, Lower LOA = -0.45, Upper LOA = 0.47 and Bias = 30.94, Lower LOA = -546.08, Upper LOA = 607.95 respectively.

Table 1. Mean ± SD, T-test, and Pearson's correlation (r) values for pV for each loading condition.

	pV (m/s)			
	Vmaxpro	**M-encoder**	**r**	**T-test**
Unloaded	2.93 ± 0.30	3.11 ± 0.31	0.92*	p<0.001**
25%	2.66 ± 0.65	2.79 ± 0.23	0.96*	p<0.001**
50%	2.28 ± 0.21	2.38 ± 0.20	0.97*	p<0.001**
75%	1.98 ± 0.19	2.06 ± 0.18	0.96*	p<0.001**

pV = peak velocity
* = significant correlation
** = significant difference

Table 2. Mean ± SD, T-test, and Pearson's correlation (r) values for avgV for each loading condition.

	avgV (m/s)			
	Vmaxpro	**M-encoder**	**r**	**T-test**
Unloaded	1.60 ± 0.13	1.63 ± 0.15	0.90*	p<0.001**
25%	1.43 ± 0.12	1.41 ± 0.12	0.96*	p<0.001**
50%	1.23 ± 0.11	1.20 ± 0.10	0.96*	p<0.001**
75%	1.09 ± 0.10	1.07 ± 0.10	0.97*	p<0.001**

avgV = average velocity
* = significant correlation
** = significant difference

Table 3. Mean ± SD, T-test, and Pearson's correlation (r) values for avgP for each loading condition.

	avgP (W)			
	Vmaxpro	**M-encoder**	**r**	**T-test**
Unloaded	1614.69 ± 292.03	1644.63 ± 318.69	0.96*	p<0.01**
25%	1739.08 ± 288.48	1701.59 ± 277.25	0.96*	p<0.001**
50%	1737.84 ± 300.70	1679.86 ± 278.70	0.98*	p<0.001**
75%	1753.18 ± 309.13	1694.97 ± 290.21	0.99*	p<0.001**

avgP = average power
* = significant correlation
** = significant difference

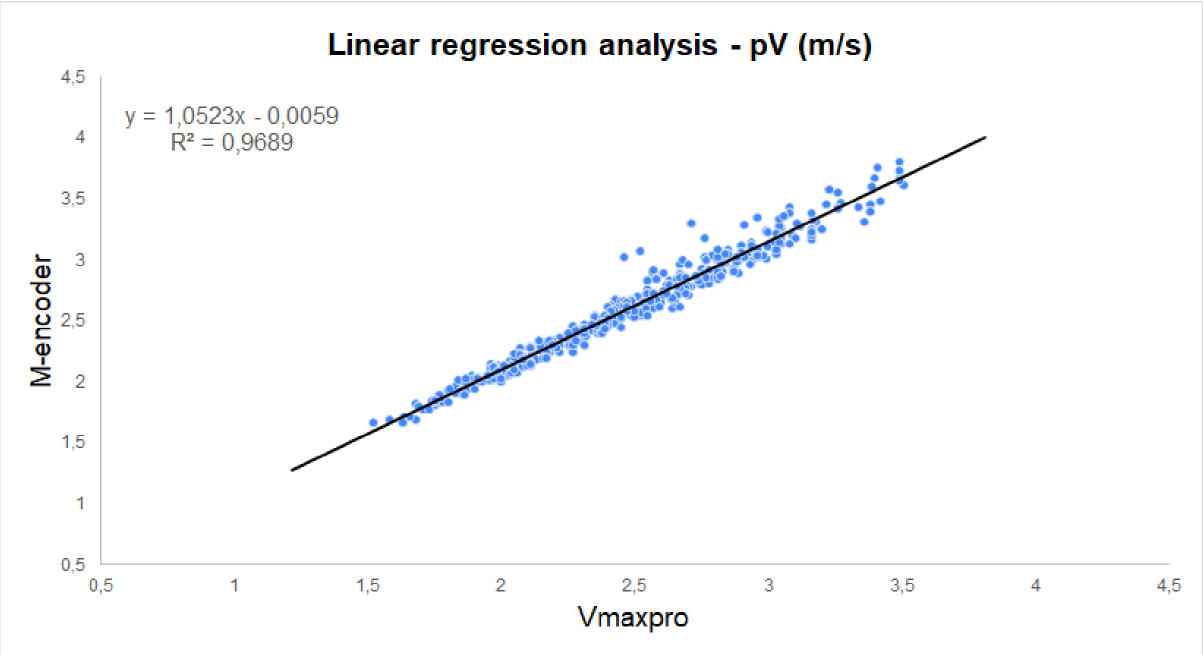

Figure 4. Linear regression analysis (R^2) for peak velocity (pV) between the Vmaxpro and the M-encoder. R^2 = 0.97, y = 1.0523x - 0.00059.

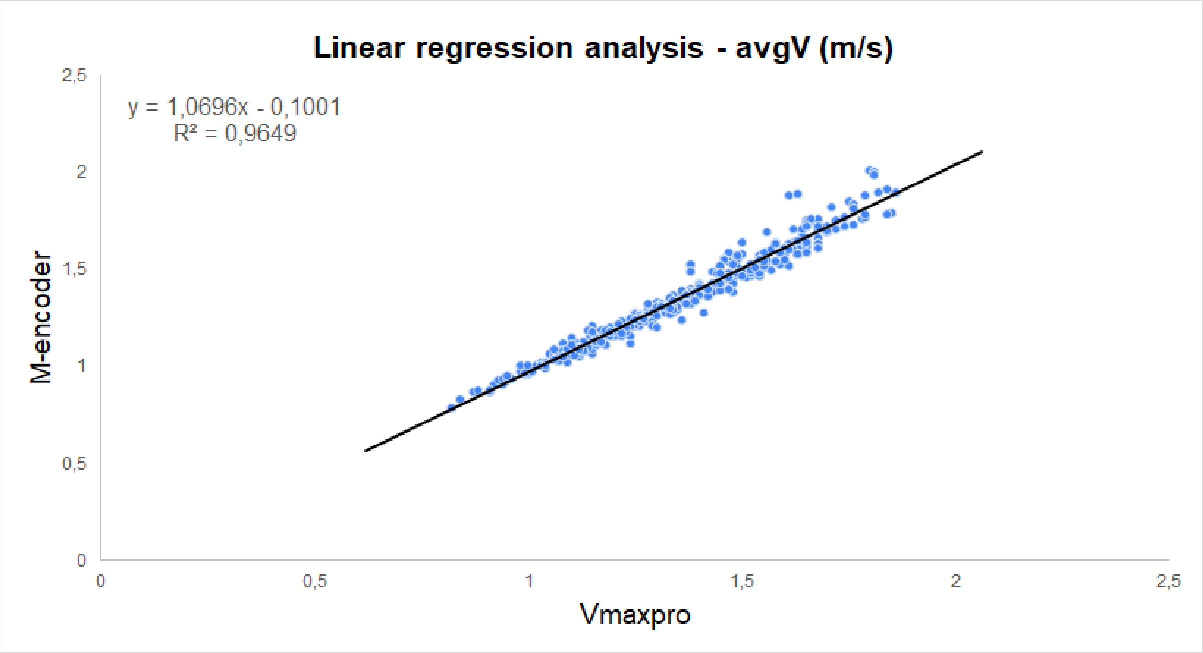

Figure 5. Linear regression analysis (R^2) for average velocity (avgV) between the Vmaxpro and the M-encoder. R^2 = 0.96, y = 1,0696x - 0.1001.

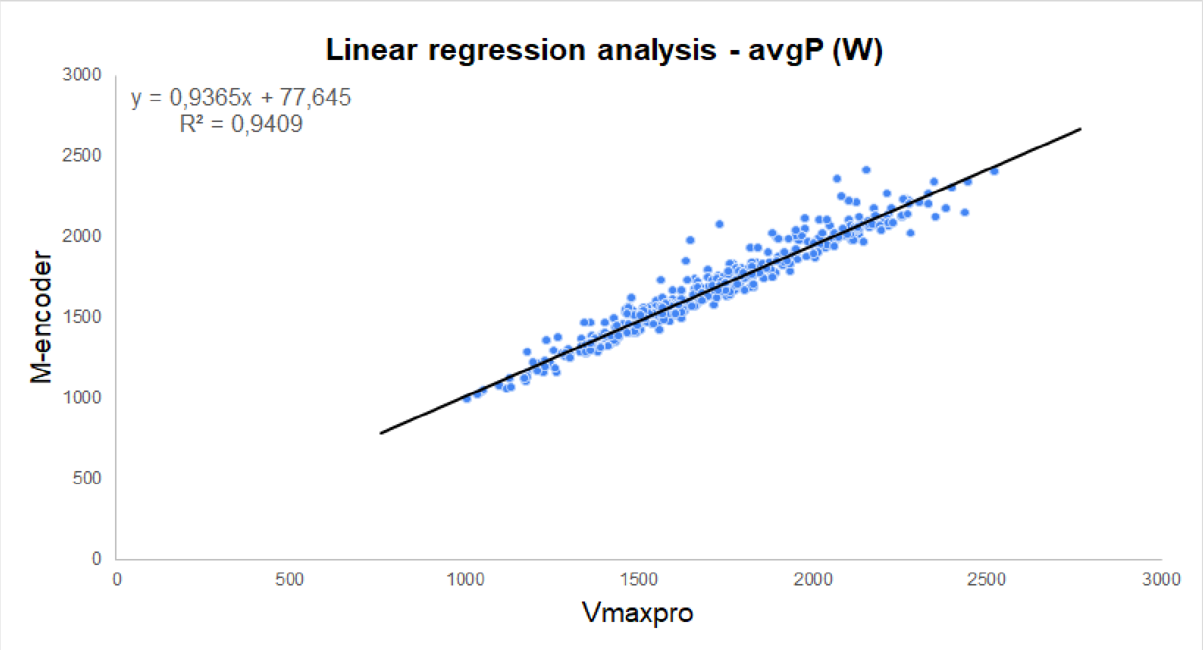

Figure 6. Linear regression analysis (R^2) for average power (avgP) between the Vmaxpro and the M-encoder. R^2 = 0.94, y = 0.9365x + 77.645.

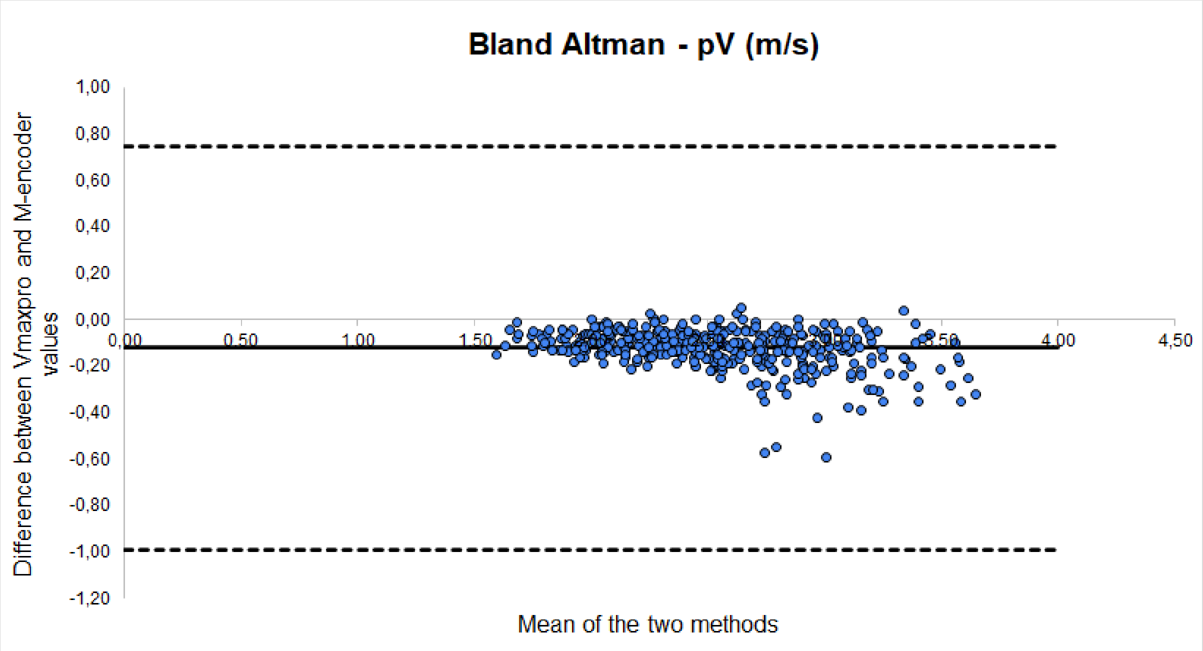

Figure 7. Bland Altman analysis for peak velocity (pV) between the Vmaxpro and the M-encoder. - Bias = -0.12, Lower LOA = -0.99, Upper LOA = 0.75.

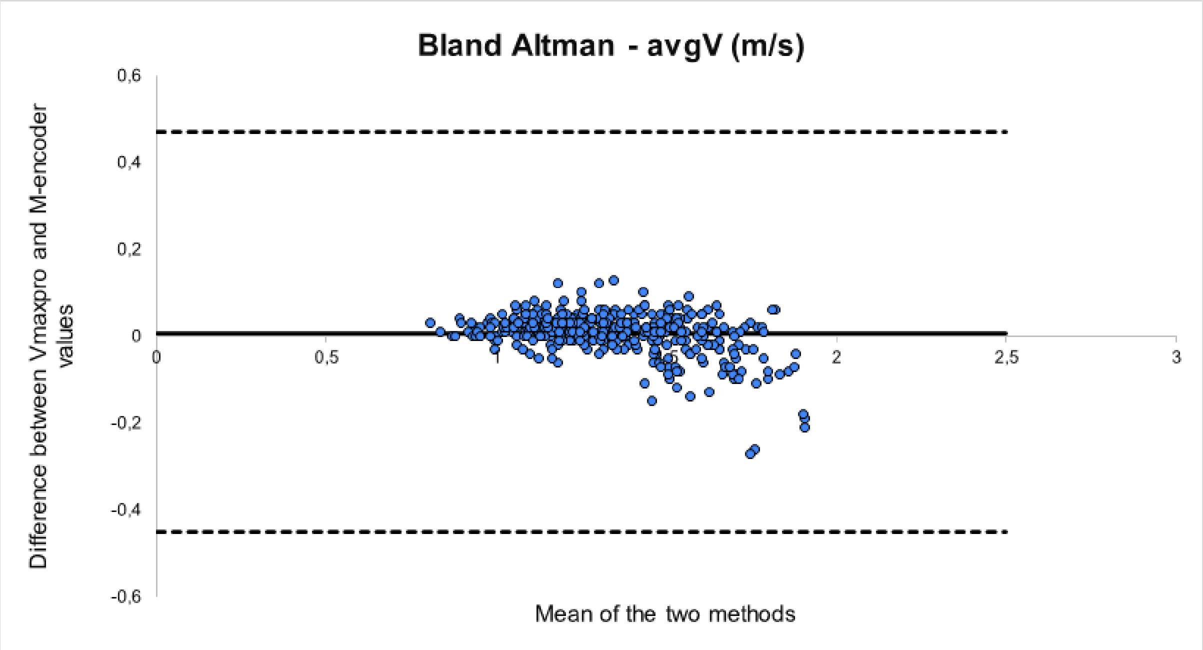

Figure 8. Bland Altman analysis for average velocity (avgV) between the Vmaxpro and the M-encoder - Bias = 0.01, Lower LOA = -0.45, Upper LOA = 0.47

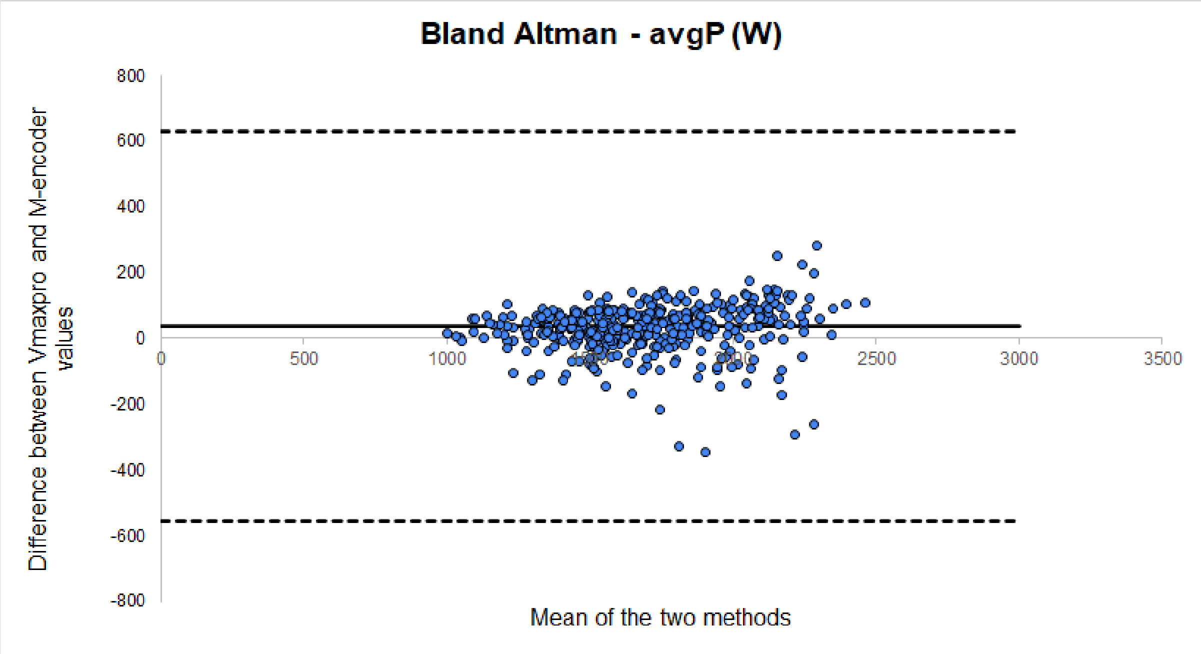

Figure 9. Bland Altman analysis for average power (avgP) between the Vmaxpro and the M-encoder - Bias = 30.94, Lower LOA = -546.08, Upper LOA = 607.95.

4 Discussion

The purpose of the present study was to examine the concurrent validity of the inertial sensor Vmaxpro, and its ability to assess the mechanical properties of the lower extremities when performing countermovement jump with various loading. The main findings from the present study indicated a strong correlation, agreement, and a relatively small SEE for the values recorded from the Vmaxpro and the M-encoder.

The Bland-Altman analysis indicated a strong agreement for all variables measured, with all data-points within both upper and lower LOA as shown in figure 7, 8, 9. The Bland-Altman analysis also indicated a low systematic bias for the Vmaxpro.

The results from the T-test showed a significant difference ($p<0.01$) for all measured variables between the two devices, on all loading conditions. However, interpretation of the results from the T-test must be done with caution. The significant results might be since all measures done between the two devices are of high correlation and a low standard deviation. Meaning, almost all the recorded values are within a small range of one another. This can make a small deviation from the mean a "significant difference" and thus make the devices seem to differ more than they are. The SEE values for pV, avgV and avgP were 0.08 m/s, 0.04 m/s and

73.47 W respectively. One might interpret 73.47 W as a large number, but relative to what has been measured, it is similar to the other two SEE values in percentage of the mean (<4.3%).

The slope and intercept of the regression analyses for pV, avgV and avgP were y = 1,0523x - 0,0059, y = 1,0696x - 0,1001 and y = 0,9365x + 77,645 respectively. To clarify the meaning of these metrics, the intercept represents the cutting point on the y-axis when x is 0. And the slope represents the constant change between the two variables and is a ratio of change in Y per change in X. This means that for a unit increased on the Vmaxpro, a decrease of 0.0059 for pV, 0.1001 for avgV, and an increase of 77,645 for avgP can be expected on the M-encoder. This is of importance since it may assist in the estimation of how data points could present themselves in relation to the regression line if they were to be either of higher or lower values than those presented in this study.

Almost all athletes had their highest recorded watt or close to their highest on the lighter loads with the highest velocities. As seen in both the regression analysis and the Bland-Altman plots (Fig 4, 5, 6, and Fig. 7, 8, 9), the correlation and agreement between the Vmaxpro and M-encoder are of a slight trend towards stronger for the lower velocities and watts. Interestingly enough, this might be explained by the fact that on the lighter conditions with higher velocities (i.e unloaded & 25% BW), the athletes are more prone to do some form of excessive movements. Considering the differences in the construction of the devices, this could potentially explain why the correlation and agreement are of a slight trend for stronger on lower velocities and watts. The Vmaxpro is an inertial sensor which measures velocities and movement through an accelerometer and a gyroscope. This makes the Vmaxpro able to record movement in both the x-, y- and z-axises, making it sensitive to excessive movements in either direction. Since the M-encoder is a linear encoder and measures the distance and velocity at which the wire is being pulled out. One might argue that the Vmaxpro is more prone to misreadings if excessive movement is present. Furthermore, the slight trend towards stronger agreement and correlation on the lower watts might also be explained by the possible “misreadings” due to excessive movement on the lighter loads. This does not necessarily mean that the highest recorded watt always occurred on the lighter jumps with the highest velocities due to excessive movements and “misreadings” but could be an explanation for the trends shown in both the regression analyses and the Bland-Altman plots.

The two devices could on some occasions show the same measurement in velocity but differ in power. Power = F*V and since the velocity measures were identical it should be something off with the force part of the equation. Force = mass * acceleration and since the mass was manually put in the software for the devices this eliminates that part of the equation as well. This leaves us with acceleration which is the product of the change in velocity over the change in time. The devices have different characteristics which make it improbable that they would measure every variable the same but it's still relevant to try to identify these differences. Given the fact that the velocity measure and mass were the same, it ought to be some discrepancies in the devices' ability to measure acceleration. Another potential factor that could explain why the devices differed would be if the equation programmed by the manufacturers differed as well. Therefore, both manufacturers were asked to specify which equations used in their products, however, the equations for all variables were not provided by them.

The results from the present study, showing strong concurrent validity for measuring muscle mechanical properties, which contradicts previous research done on inertial sensors, where the results indicate both poor, moderate and good validity and reliability (Beckham et al., 2019; Van den Tillaar & Ball, 2019; Pérez-Castilla, Piepoli, Delgado-García, Garrido-Blanca & García-Ramos, 2019). Besides differences in attachment points depending on which inertial sensor that is used (e.g. Vmaxpro attaches to the barbell and PUSH-band is attached to the arm of the athlete). One explanation for the contradicting results might be the differences in movements when examining the concurrent validity of the inertial sensors. To our knowledge, this is the first study to examine the concurrent validity of an inertial sensor when performing vertical jumps. Previous research has used other multi-joint exercises e.g. push-ups, bench press, barbell squat (Beckham et al., 2019; Van den Tillaar & Ball, 2019; Pérez-Castilla, Piepoli, Delgado-García, Garrido-Blanca & García-Ramos, 2019). The bar displacement is larger when performing vertical jumps when compared to some other multi-joint exercises (e.g. push-ups and bench-press). This might increase the probability that the inertial sensor accurately measures the recorded values.

4.1 Methodological reflections

Instructions for the jumping technique was for the subjects to use a voluntary stance with a barbell held tightly across their shoulders. The reason for these instructions was because of the ballistic nature of a countermovement jump, it's possible that the barbell could leave the subjects' shoulders after the push-off phase. This could both lead to risk for injury since it would eventually fall back on the subject, and also potentially lead to misreadings from the devices attached due to excessive displacement of the bar.
To minimize bias, we attached both devices at the same position (i.e the wire from the M-encoder attached to the velcro strap from the Vmaxpro). If both devices were attached in different positions e.g. one on the left side and one on the right side, it could lead to discrepancies in readings due to unsymmetrical movement in either the x-, y-, z-axis.

Since both devices must be attached to something, a wooden-stick was used for the unloaded condition. The weight of the wooden stick was approximately 200-300g + the weight of the two devices. This makes the unloaded condition not truly unloaded, but for logistical reasons, it could not have been done any other way. For this study, the external weight from the wooden-stick does not interfere with the measurements from the devices.

The reason for implementing four loads instead of more was because of the argument that it's less time consuming and that the participants are less prone to fatigue. It has also been shown that procedures consisting of fewer loads instead of multiple provide similar results when assessing force-velocity properties through vertical jumps (Garcia-Ramos et al. 2018).
If the difference between the first and the second trial on a given load differed more than 15% in watts on both pieces of equipment, the subjects were to perform a third jump on the same load. This increases the probability that the difference between the two jumps most likely was due to performance and not that it fell within the variation of the devices. The reason for the cut-off value being 15% was because previous research on accelerometers has not evaluated the coefficient of variance % (CV%) on watt but has shown a CV% range from 5.9-13.3% (Van den Tillaar & Ball, 2019).

Previous research has criticized the usage of vertical jumps as a predictor of power output (Adamson & Whitney, 1971; Knudson, 2009). This critique stems from the notion that the interpretation of power as a short, high-intensity variable for muscular power is theoretically wrong, and peak and average mechanical power does not always correlate well with jump height. The mechanical definition of power is, according to Knudson (2009) “the rate of doing work”. This makes the definition of power more of a variable, steady-state, cyclic movement. Since the nature of vertical jumps (e.g. CMJ) is more of a short and impulsive movement (McMahon et al., 2018), the velocity at take-off and the preceding vertical net impulse has, according to Newton's second law of motion, a perfect correlation (i.e $r = 1$) with jump height, which power values do not. However, despite that impulse might be a better measurement than power when performing vertical jumps. It does not take away the fact that measuring some form of power value or jump height with cheap and valid equipment to evaluate training adaptations, is still of relevance due to its potential practicality.

The MuscleLab linear encoder called M-encoder was used as a reference device. As mentioned earlier it has previously been used for measuring muscle mechanical properties (Hilmersson et al. 2015) as well as a reference device for other concurrent validity studies (Buscà & Font, 2011; Bosquet, Porta-Benache & Blais, 2010; Van den Tillaar & Ball, 2019). However, other devices can be considered as more appropriate and therefore the usage of the M-encoder can be questioned (Buckthorpe, Matthew, Morris & Folland, 2011) The results of the present study might have been different if another reference device was chosen.

4.2 Ethical and societal considerations

Paragraph 13 of the declaration of Helsinki states that "Groups that are underrepresented in medical research should be provided appropriate access to participation in research". Is it ethically appropriate to limit the sample of the study to only one gender, when the research question per se is not dependent on gender? Which is the case in the present study.
The sample consists of only males, which is overrepresented in the field of sport studies. Given that we had a limited amount of time available to recruit participants to this study, the recruitment of the most easily accessible participants was done. Which in this case was limited to only males. If more time had been available, the inclusion of both genders and/or different athletes from different sports could have been made.

The recruitment process for the athletes to participate in this study was done through a separate company that handles all the strength and conditioning training and testing for the

athletes. The company had already planned testing weeks for the entire hockey club and loaded CMJ was included in their testing battery.
This makes it difficult for the participants to decline participation in the study since the testing is part of their test battery and "must" be done. The company and its staff are hired by the club to be in charge of the participants' strength and conditioning training and testing, this makes them in a position of power over the participants and can have an impact on their ability to decline participation. However, the participants were given thorough information about their rights and that withdrawal from the study could be done easily and without any specific reason. Since participants under the age of 18 also were required to have written consent from a parent or legal guardian, it could have made it easier for the younger participants to decline.

The participants in the present study had to perform maximal vertical jumps. One might argue that there is an increased injury risk when performing work with maximal intent instead of submaximal intent. To ensure the safety of the participants, a relative loading scheme (%BW) was used instead of a fixed to make it more individualized. Furthermore, the participants were given adequate warm-up, a thorough understanding of the testing protocol, and familiarization of the test itself. Safety equipment was also used when testing (i.e Safety bars and a "spotter").

As previously mentioned, testing equipment to this date is limited to a small population with the right financial means. There is currently a gap in the market for cheap, portable, and valid test equipment when measuring muscle mechanical properties. The main findings in this study might contribute to filling this gap, and thus along with further research potentially be able to expand the usage of test equipment.

4.3 Future research

For logistical reasons this study only examines the concurrent validity of the Vmaxpro and not its reliability. This would be necessary for a more complete evaluation of the Vmaxpro. In a scenario where the device would be shown to be unreliable, its usage would be limited. Therefore, a similar study with a focus on variables regarding reliability would complement our findings and provide a more thorough evaluation and make the conclusion whether it is a relevant product for practical use.

Another contribution that could be made through further research is by widening the population that is being tested. In this study, the subjects consisted of purely ice-hockey players on a certain level which makes the results non-applicable for individuals performing work on either lower or higher velocities and power values. The Vmaxpro may or may not provide accurate data for different populations but from the results of the present study, we can not conclude this. Further research is needed.

4.4 Practical application

The results from the present study indicate that the Vmaxpro can be used for assessing muscle mechanical properties. Furthermore, since the Vmaxpro is both cheap and portable, it can potentially expand the usage of test equipment to clubs and associations with limited resources.

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5.2 Appendices

5.2.1 Appendix 1:

Informationsbrev till forskningspersonerna

Vad är det för projekt och varför vill ni att jag ska delta?

Idrottsprestation är multifaktoriellt, dvs. det finns väldigt många faktorer som påverkar hur väl en atlet presterar. En faktor som däremot påstås vara av särskilt stor vikt för idrottsprestationer och ha stor betydelse för både individuella idrotter och lagidrotter, är en atlets förmåga att producera så mycket kraft på så kort tid som möjligt.

För att mäta detta finns det en rad olika mätverktyg. Dessa mätverktyg är allt ifrån infraröda lasrar, kraftmattor, linjär kodare till kameror och accelerometrar. För att mäta en atlets förmåga att producera kraft (Force) och med vilken hastighet (Velocity). Är det vanligt att man utför belastade hopp samtidigt som man använder någon av de ovannämnda typerna av mätverktyg. Efter testerna får man ut värden för varje atlet, en sorts "profil" som man senare kan lägga upp träningen efter.

Nackdelen med många utav dessa ovannämnda typer av mätverktyg är att de ofta är opraktiska och väldigt dyra. Detta gör att användningen för dessa mätverktyg ofta begränsas till elitidrottare/elitlag med god ekonomi.

Syftet med denna studie är att undersöka om en otestad accelerometer kan fungera som ett substitut för redan beprövad utrustning för att utvärdera Force-Velocity egenskaper hos atleter.

Hur går studien till?

Alla atleter som deltar i studien kommer att delta under minst ett testtillfälle. Vid testtillfället kommer varje atlet att genomföra maximalt 8-10 belastade hopp. Innan testtillfället kommer varje atlet att få genomföra ett standardiserat uppvärmningsprogram och bli instruerad i utförandet av hoppen. Testtillfället kommer som mest att ta 60 minuter. Förutom data som registreras av testutrustningen, kommer vi även att dokumentera din ålder, längd och vikt.

Vi vill fråga dig om du vill delta i ett forskningsprojekt. I det här dokumentet får du information om projektet och vad det innebär att delta.

Forskningshuvudman för projektet är Umeå Universitet. Med forskningshuvudman menas den organisation som är ansvarig för studien.

Möjliga fördel, följder och risker med att delta i studien

En medverkan i denna studie kommer att bidra till möjligheten att undersöka om en otestad och relativt billig accelerometer kan fungera som ett substitut för dyrare och mer beprövad utrustning. Detta skulle kunna innebära att dessa mätverktyg inte bara begränsas till elitlag eller föreningar med god ekonomi.

Utöver det kommer du även få information om dig själv och din egna fysiska kapacitet och hur du kan gå tillväga för att förbättra din prestation.

Då testerna innebär maximala hopptester, är det vanligt att man kan känna sig trött och öm i den arbetande muskulaturen efter testtillfället. Vid maximala tester finns det alltid en skaderisk som man bör vara medveten om. Skulle andra symtom uppstå efter testtillfället, ta kontakt med projektansvariga.

Vad händer med mina uppgifter?

Projektet kommer att samla in och registrera information om dig. Dina svar och dina resultat kommer att behandlas så att inte obehöriga kan ta del av dem. Vi kommer samla in information om dina force-velocity egenskaper, dvs. hur mycket kraft, hastighet och power du kan producera under ett hopp. Utöver detta även information om din vikt, längd och ålder. Informationen kommer sedan att hanteras med yttersta konfidentialitet och inga obehöriga kommer ha tillgång till den insamlade informationen. Varje individ kommer kodas vilket minskar risken för att information ska kunna härledas till en specifik individ. Endast vi som projektansvariga och huvudhandledaren kommer att ha tillgång till informationen som kommer finnas på en datafil som inte får kopieras eller delas med någon. Samtlig information som samlas in kommer att lagras till dess att studien är färdigställd. Informationen som samlas in kommer inte användas i något annat syfte än den som beskrivits tidigare. Samtliga resultat som redovisas kommer inte att kunna härledas till någon specifik individ och all data kommer presenteras på gruppnivå.

Ansvarig för dina personuppgifter är Umeå Universitet. Enligt EU:s dataskyddsförordning har du rätt att kostnadsfritt få ta del av de uppgifter om dig som hanteras i studien, och vid behov få eventuella fel rättade. Du kan också begära att uppgifter om dig raderas samt att behandlingen av dina personuppgifter begränsas. Om du vill ta del av uppgifterna ska du kontakta projektansvariga Pontus Öhrner, pontusohrner@gmail.com och Elias Olovsson Ståhl, elias.os@outlook.com. Telefonnummer: 070-3238914 & 0703934661 eller huvudhandledare Apostolos Theos, apostolos.theos@umu.se, 090-7866619. Om du är missnöjd med hur dina personuppgifter behandlas har du rätt att ge in klagomål till Datainspektionen, som är tillsynsmyndighet.

Hur får jag information om resultatet av studien?

Efter att du genomfört samtliga tester kommer du få ta del av dina individuella resultat från testerna. Du kommer även få tips och råd om hur du kan gå tillväga för att förbättra dessa egenskaper. När studien är genomförd kommer du kunna ta del av studiens resultat. Om du inte önskar att ta del av dessa resultat kan du ta kontakt med oss.

Deltagandet är frivilligt

Ditt deltagande är frivilligt och du kan när som helst välja att avbryta deltagandet. Om du väljer att inte delta eller vill avbryta ditt deltagande behöver du inte uppge varför. Om du vill avbryta ditt deltagande ska du kontakta den ansvariga för studien (se nedan).

Ansvariga för studien

Ansvarig för studien är:

Forskningshuvudman: Umeå universitet

Handledare: Apostolos Theos, apostolos.theos@umu.se, 090-7866619

Personuppgiftsansvarig: Umeå universitet

Projektledare: Pontus Öhrner, pontusohrner@gmail.com och Elias Olovsson Ståhl, elias.os@outlook.com. telefonnummer: 070-3238914 & 0703934661

Samtycke till att delta i studien

Jag har fått muntlig och skriftlig information om studien och har haft möjlighet att ställa frågor. Jag får behålla den skriftliga informationen.

☐ Jag samtycker till att delta i denna studie

☐ Jag samtycker till att uppgifter om mig behandlas på det sätt som beskrivs i forskningspersonsinformationen.

Plats och datum

Underskrift deltagare:

Underskrift målsman: