NORWEGIAN SCHOOL
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Jonas Torkildsen

Efficiency of Elastic Resistance Bands and Conventional Barbells

A Comparison of Force Profiles

Master thesis in Sports Science
Department of Sports Medicine
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Abstract

Exercising with elastic resistance bands (ERB) has gained popularity over the past 5-10 years, but there is little research on how muscles are utilized during ERB exercises compared to conventional weights. To provide a better understanding on how ERB training can be optimized, the **purpose** of this study was to measure and compare force output profiles between ERB standing press and -pull and barbell-based bench press and -pull. By employing a **cross-sectional, within-subjects study design**, we collected data from 19 healthy men (N=14) and women (N=5). Force profiles were generated in a purpose-built Smith machine during bench press - and pull, with isokinetic resistance (measuring maximum force output capabilities) and conventional weight plates (measuring 6 repetition maximum). 3D motion capture in combination with a load cell were used to measure 6RM standing press and -pull forces using ERBs. Data were processed and analysed using Matlab with the SPM1d package (Statistical Parametric Mapping 1d). Our **results** indicate that press exercises with ERBs has a comparable force profile, but lower force output throughout the exercise trajectory compared to the maximum force output capability for isokinetic bench press up to 80% of total exercise trajectory length. Conventional bench press does not follow the isokinetic force profile, and the force output is virtually constant through a large section of the exercise trajectory. For pull exercises, ERB force profiles match poorly the isokinetic force profile, because the ERB load increases, while the maximum force output capability drops from 30% up the end of the exercise. According to our data, the shape of the conventional bench pull profile correspond well with the isokinetic force output. No significant statistical differences were found between ERBs stretched to 100% and 200% for neither standing press nor -pull. We **conclude** that ERBs are a convenient, user-friendly and viable alternative to conventional press exercises, but less efficient as replacements for conventional pull exercises. ERB training may be optimized to better match the maximum force output capability profiles during press and pull exercises.

Sammendrag - abstract in Norwegian

Styrketrening anses som en effektiv og ikke-medisinsk metode for å redusere eller dempe negative helseproblemer forbundet med en stillesittende livsstil. Selv om trening med treningsstrikk har blitt mer populært de siste 5-10 år, er det forsket lite på hvor effektivt musklene brukes når man trener med strikk sammenlignet med konvensjonell vekttrening. **Formålet** med denne studien var å måle og sammenligne kraftprofiler fra stående press og -trekk med strikk, hvor strikken ble strukket hhv. 100% og 200%, og konvensjonell benkpress og -trekk med stang. Vi benyttet et **tverrsnitts, innengruppe design** og hentet inn data fra 19 friske menn (N=14) og kvinner (N=5). Kraftprofiler for konvensjonell benkpress/-trekk med både konvensjonelle vektskiver (for å måle 6 maksimum repetisjoner, 6RM) og med isokinetisk motstand (for å måle maksimal kraftoutput). 3D bevegelsesdeteksjon kombinert med en kraftcelle ble brukt til å måle lengden på bevegelsesbaner og kraftoutput ved 6RM ved stående press og -trekk med treningsstrikk. Data ble deretter prosessert og analysert i Matlab med SPM1d-pakken (Statistical Parametric Mapping 1d). Våre **resultater** tyder på at pressøvelser med treningsstrikk gir sammenlignbare profiler for kraftoutput gjennom hele bevegelsesbanen sammenlignet med kraftoutput ved isokinetisk press, men med lavere kraftoutput. Konvensjonell benkpress følger ikke isokinetisk kraftprofil, og kraftoutput er tilnærmet konstant gjennom store deler av bevegelsesbanen. Kraftprofilene for trekkøvelser med strikk viser lite samsvar med de isokinetiske kraftprofilene, fordi motstanden øker samtidig som muskelkraften blir svakere mot slutten av øvelsenes bevegelsesbane. Ifølge våre data er det godt samsvar mellom kurveformene til henholdsvis konvensjonell benktrekk og maksimal kraftoutput. Det var ingen statistisk signifikant forskjell når strikken ble strukket hhv. 100% og 200%. Vi **konkluderer** med at treningsstrikker er praktiske, brukervennlige og brukbare alternativ til konvensjonelle pressøvelser, men mindre effektive som erstatning for trekkøvelser. Det er rom for å optimalisere trening med strikk for å få bedre samsvar med profilene for maksimal kraftoutput.

Contents

List of tables

List of figures

List of abbreviations

CBP	conventional bench press
CBPU	conventional bench pull
ERB	elastic resistance bands
IBP	isokinetic bench press
IBPU	isokinetic bench pull
MFOC	maximum force output cabability
NIH	Norwegian School of Sport Sciences
PTTL	percentage of total trajectory length
RM	repetition maximum
RT	resistance training
SP100	standing press at 100% elongation
SP200	standing press at 200% elongation
SPU100	standing pull at 100% elongation
SPU200	standing pull at 200% elongation

Acknowledgement

During my full-time job as a head teacher, I decided to give my growing wish to pursue a master's degree in sports science a chance by applying to the Norwegian School of Sport Sciences (NIH) in the spring of 2020. Even though it has been hard and challenging at times to juggle my thesis work, teaching job and family life, it now feels like I started this project only yesterday. I sincerely want to thank everyone simultaneously, however, I do need several paragraphs. The order is by no means a ranking of contribution.

To all **participants**, I will always be grateful for your willingness to dedicate time and effort contributing to this study. Without you there would not be data to analyse, understand and discuss. Your contribution means a whole lot more than what you might think. This also includes **Silje T. Bolin**, **Stian Christiansen**, **Aurora Jørnsdatter Kojen** and **Kristian Solem** who helped me during test trials, thank you! I also want to thank **Jonas Eivik Østensen** for his valuable contribution to the modelling of the exercise variations used in this study.

My sincerest gratitude goes to my supervisor Professor **Tron Krosshaug**; for your exceptional hands-on help and guidance, especially during piloting and data collection. I am truly grateful that you wanted to develop this study together with me and your continued support through the delayed months finishing spurt. You are a great professional and a superb human. I truly enjoyed our conversations about strength training, personal stuff and everything in between. I hope there will be more to come!

Thank you to Associate professor **Ola Eriksrud** and Researcher **Øyvind Gløersen** for help and guidance with the equipment used in this study.

To my fellow students, thanks to all of you for making the studies pleasant for a somewhat ageing student. A special thank you goes to **Silje Kittilsen** for collaboration and friendly discussions. Great things await you!

My **parents** also deserve appreciation for supporting me pursuing my second master's

degree even though you have none of your own. I hope I make you proud.

Last but not least I would like to thank my partner (in crime) **Sigbjørn** for your invaluable help and support. Your mere presence means the world to me; I am ever so grateful. You are truly the most exceptional individual I have ever met. Your knowledge goes above and beyond. Finishing off I wish to thank **Bodil**. For always being happy to see me when I get home from work and for "forcing" me to get outside for hikes when I need to clear my head the most. We both love you!

Hopefully, engaged readings.

Jonas Torkildsen
Graz, June 2023

Part I

Extended background

1.1 Introduction

An overarching **aim** of this study was to investigate the efficiency of a selection of press- and pull exercises. More specifically, force output profiles for standing press and -pull with elastic resistance bands (ERB) and conventional bench press and -pull were measured, analysed and compared. Data were sampled from recreational strength-trained individuals.

Part I is an extended background section and conforms to recommendations defined by the Norwegian School of Sport Sciences (NIH) for article-based masters' theses. **Part II** is written as a scientific article adhering to the format and guidelines set forth by *Frontiers in Sports and Active Living* journal. For the purpose of readability and presenting a coherent structure, part I and II are written with the same Vancouver referencing style (National Library of Medicine [NLM]). Furthermore, I have endeavoured to keep overlapping information to a minimum between the two parts.

1.2 Resistance training: definitions and concepts

Resistance training (RT) can be defined as "All exercises aimed at developing or maintaining our ability to generate as much force as possible at different shortening velocities" (translated from Norwegian) [1, p. 82]. Muscle strength is defined as "the capability to produce an external force, where force may be regarded as an action that maintains or changes the motion of a physical object" [2]. Forces are commonly represented as vectors, i.e. having both magnitude and direction.

Biomechanics distinguishes between *internal* and *external* forces. A force generated by one body part exerted on another body part is considered to be internal, whereas a force generated by a body(part) exerted on an object outside to the body is regarded as external. This implies that only external forces may be used to measure muscle strength [3]. Muscle activation/contraction can either be *isometric* (static) or *isotonic* (dynamic). During isometric contraction, muscles exert a force to maintain the same length, whereas isotonic contraction can either be *concentric* (miometric) when a muscle shortens, or *eccentric* (plyometric) if the muscle lengthens [3, pp. 18-19]. An illustration of an isotonic contraction could be e.g. the biceps curl movement; the lift phase is the concentric movement due to muscle tension during contraction of biceps and conversely, lowering the dumbbell is an eccentric movement, because it elicits muscle tension during volitional lengthening of the biceps. *Isokinetic* training is a third category of muscle activation and requires a device which provides variable resistance to impose a constant velocity of movement when the force output varies throughout the motion range of an exercise [4]. Exercise equipment for isokinetic training is typically more complicated and expensive to operate, and is predominately used in specialized facilities and cases. Resistance training can use all these three forms of muscle activation; isometric and isotonic are the most common variants.

Anaerobic energy conversion exercise are described by Vorvick and Zieve as activities which are usually hard, short in duration and hence intense [5]. RT is one such form of anaerobic exercise; other variants are high-intensity interval training, sprinting and weightlifting (Olympic sport). There is a substantial amount of research related to the short- and long term benefits of RT, e.g. on muscles strength and -hypertrophy [6, 7, 8], endurance and physical performance [9, 10, 11, 12], functioning in older adults [13] and lowering risk for injuries [14]. RT has been meticulously practised by elite athletes for optimization of sport performances for decades; it has also become increasingly popular with the general population as a leisure activity for maintaining and improving health, personal well-being and physical characteristics. RT is typically performed indoors at commercial fitness centres with purpose-built machines (e.g. Smith machine, seated leg extension and leg press equipment) and free weights (e.g. barbell and dumbbells). However, recreational RT performed with one's own bodyweight and resistance bands has gained increased popularity in both professional contexts, e.g. physiotherapists, personal trainers, rehabilitation, sports injury prevention and in-home scenarios, offering an attractive alternative for people not visiting fitness centres.

1.3 Exercise efficiency and optimal exercise loading

Muscle force output is the force generated by one or several muscles exerted on an object to either change its position, e.g. a barbell or its shape, e.g. an ERB. The force output varies along exercise trajectory due to biomechanical factors, i.e. the applied force will not be constant [15]. We define *exercise efficiency* as 'the amount of muscular effort a given exercise elicits throughout the movement trajectory compared to the individual maximum force output capability along the same trajectory'. An efficient exercise should be executed under *optimal loading*, which we define as 'the situation where the external load varies dynamically to match the force output capability at all positions of the exercise movement'. Our definition of optimal loading addresses other aspects of muscle training efficiency than e.g. the concept of “time under load/tension”, which is discussed extensively in other studies [16, 17, 18]. In short, "time under load/tension" addresses primarily the duration of an exercise and implications for the activation of muscle fibres.

The concept of optimal loading involves several biomechanical principles applicable to human motion; the illustration in figure 1.1 on page 4 depicts a number of parameters involved in conventional bench press. Our focus is on the total force output generated during the exercise cycle (for both press- and pull exercises), and not the specific impacts of and contributions from joint angles, force vectors and moment arms. Nevertheless, when studying the kinetics of resistance training, an understanding of some biomechanical principles is required to measure, analyse and assess contributions from individual force components and how they interact during an exercise movement. By measuring external forces and moments, we can deduce and calculate the e.g. the magnitude of internal muscle forces produced at various stages of an exercise. Resistance training engages both muscles and joints; muscles create torque in the joints enabling them to rotate. The amount of torque necessary to rotate a joint is proportional to the product of the line of force caused by the

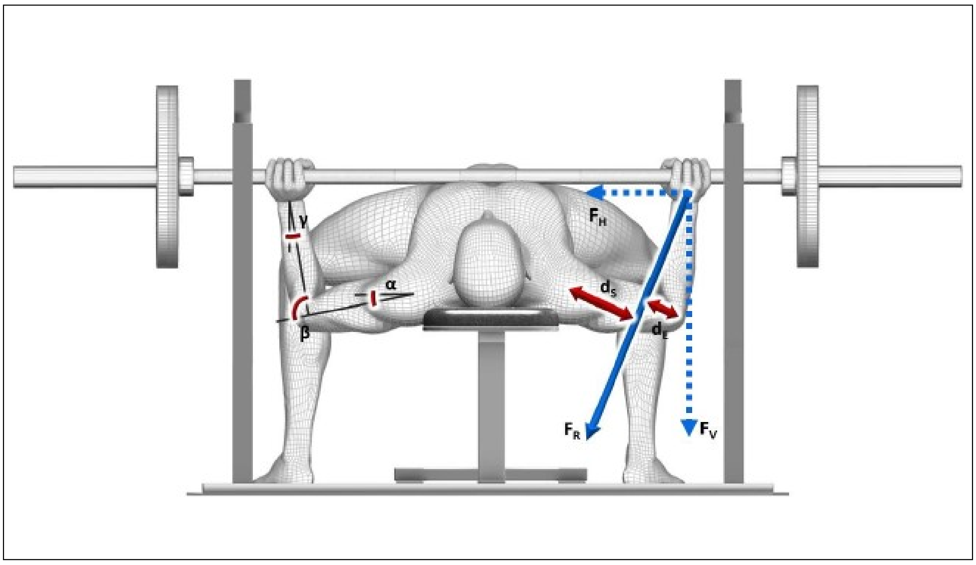


Figure 1.1: *Animated bench press figure of one representative subject at the bottom position of the bench press.* ***Greek letters*** *represent joint angles,* ***blue arrows*** *are forces and* ***red arrows*** *indicate moment arms. Produced by MuscleAnimations™.*

external load and the moment arm; the latter is defined as the perpendicular distance from the centre of the joint to the line of force [19, 20].

Moment arms for the elbow and shoulder joints at three stages of bench press are visualized in figure 1.2 and represented by the orange coloured arrows perpendicular to the line of force caused by the gravitational pull on the barbell (blue arrows). The relative lengths of the moment arm of the shoulder joint at the start and end positions indicate why muscles need to work harder in the start position than towards then end: the moment arm is longer in the start position than the end position. The elbow joint's moment arm is relatively longer in the mid position than the start and stop positions, and shorter than the moment arm on the should joint in the start position. Consequently, one is capable of generating larger muscle forces along the force line towards the end of the bench press, where the arms are almost fully extended, compared to the start position where arms are flexed. One should also note that a higher muscle force is required in the start position to set the barbell in motion from an inert state compared to lifting it with a fixed velocity [15, 20].

This brief analysis on the significance of moment arms can be extended to bench pull:

moment arms on shoulders and elbow joints are shortest in the start position when arms are fully extended and increase towards the stop position when arms are fully retracted towards the torso. In this thesis, we focus on a comparative analysis of combined muscle force output for bench press and-pull using and standing press and -pull exercises using resistance bands; we do not address the impact of specific parameters such as variations in width grips, joint angles or moment arms [21]; the latter are however useful to explain why test subjects are stronger when arms are almost fully extended compared when they are retracted.

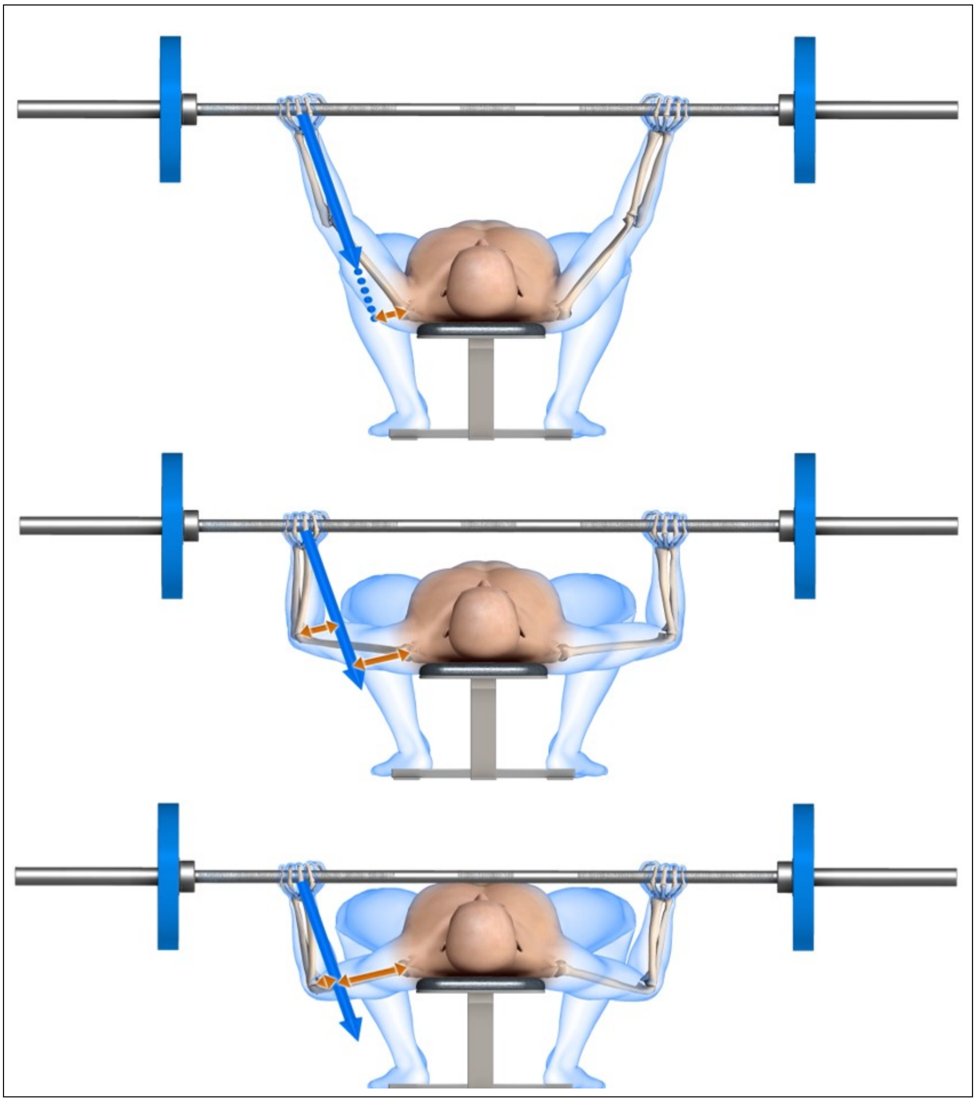


Figure 1.2: *Illustration of changes in moment arms (orange arrows) during bench press from start position (bottom) to end position (top).* ***Note****: The same moment arm principles apply in bench pull, but arms are fully extended in the start position; arms are retracted maximally towards the torso in the end position. Produced by MuscleAnimations™.*

1.4 Rationale and thesis aim

Typical aims of engaging in physical activity are to improve functions of the body. Thus, when doing RT which is one form of physical activity, the purpose of performing a particular exercise should be taken into consideration, i.e. what functions or parts of the body one wants to improve, such as cardiovascular functions, joint stability, strengthening of hamstring muscles to endure explosive sprint accelerations or raising muscle fatigue thresholds to name a few.

In the 1940s, DeLorme and Watkins argued that executing RT until neuromuscular volitional failure was the best way for optimizing muscle strength and hypertrophy [22]. Based on his work and subsequent studies, RT was considered to merit additional research, according to J. Todd, Shurley and T. Todd [23]. To date, exercise plans and programs commonly focus on either low repetition rates of a single exercise with high load (1-4 repetitions), moderate load (5-12) and low load (12+) for muscular- strength, hypertrophy and endurance, respectively[24] or a combination of these within a given time period. However, how to optimize RT outcome is still debated [8].

To our knowledge, there are no biomechanical studies comparing the efficiency of strength training exercises using resistance bands versus conventional barbells. To provide a better understanding of this subject, we set out two main aims for this study: **a**) comparison of force output profiles of exercises with ERBs and with barbells, and **b**) investigation of potential differences in load between ERBs with higher resistance stretched to double length (100%) compared to lower resistance ERBs stretched three times (200%).

Comparison of force profiles can provide new insight into how training efficiency with ERBs can be enhanced by optimally using force capabilities. In addition, force output profiles may also help interpret findings from other studies.

This thesis elaborates the research aim in four aspects by:

- employing isokinetic resistance to measure individual maximum force output capabilities of bench press and -pull exercises;
- measuring applied force output as a function of the movement trajectories of bench press and -pull;
- comparing the force profiles derived for the press- and pull exercises with those measured for ERBs;
- manipulating ERB characteristics (resistance and amount of extension) to examine if one can obtain matching resistance by stretching a high-resistance ERB 100% versus low-resistance ERB 200%.

Our methodological approach is presented in the subsequent chapter and describes strategies and methods for data collection, equipment and data processing. The purpose is to provide a transparent justification for the data which our analysis and discussion rely upon.

1.5 Methodological considerations

A dedicated test protocol (Figure 1.3 p. 9) was developed to give step-by-step descriptions on how to perform the the exercises in the lab, including practical aspects related to the set-up and information to test subjects. One of the main objectives of the test protocol was to ensure that all relevant steps of the test execution were sufficiently and properly documented to ascertain repeatability and reliability. In addition, we wanted to make sure that tests performed by different subjects were consistent and comparable, as well as to giving them a professional and targeted experience. Equally important, the test protocol should reduce the risk of measurement errors, glitches or anomalies during the exercises and serve as information preparing subjects. The verification steps included controls of proper functions of equipment and data capture.

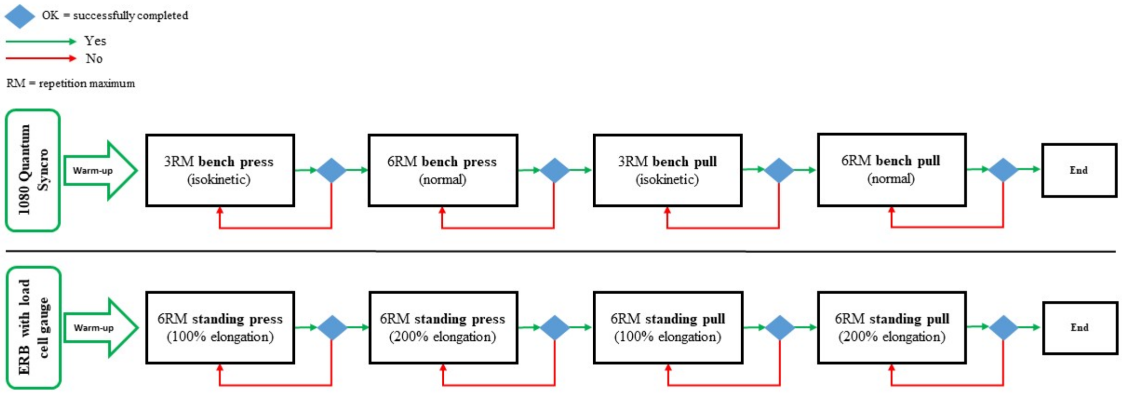
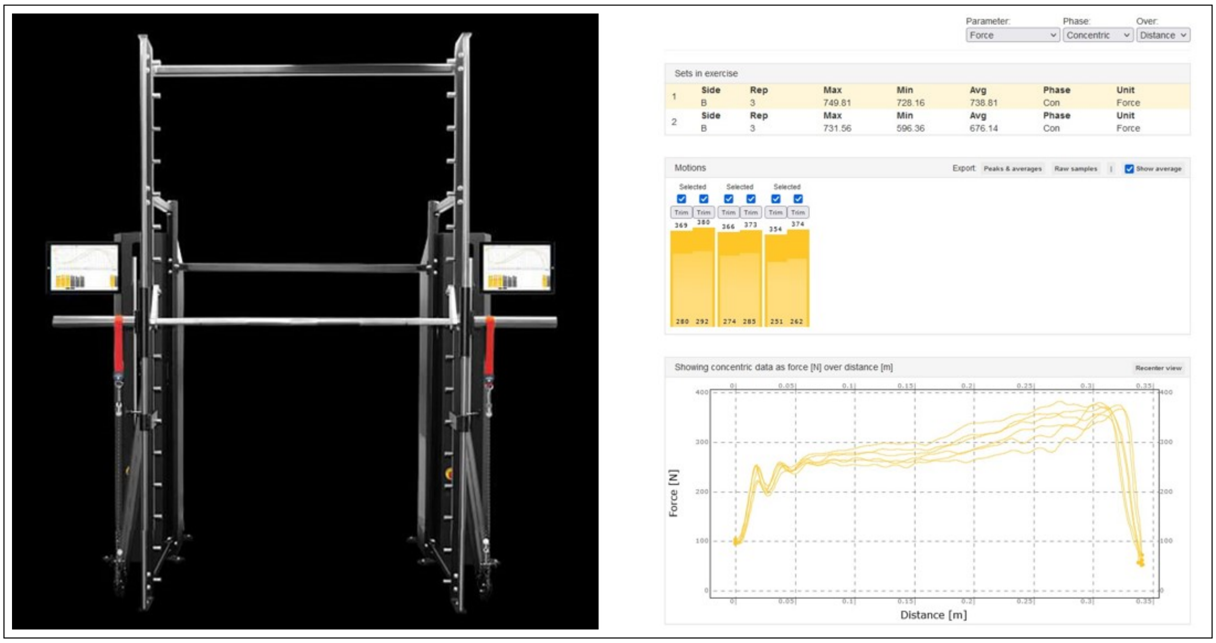


Figure 1.3: *The protocol depicts the two independent test session. Own illustration made with Microsoft® PowerPoint®.*

1.5.1 1080 Quantum Syncro

The 1080 Quantum Syncro (1080QS) (Figure 1.4, p. 10) is a multi-functional Smith machine supporting a range of different isokinetic (see section 1.2) and conventional exercises for upper- and lower body extremities (1080 Motion TM, Lidingö, Sweden). The 1080QS has two towers on each side and each sides can be connected to a tablet in order to control mode, load/resistance and speed for both the concentric and eccentric phases of exercise movements. A beam is connected to each tower; the beams can either be used together or independently supporting various uni- and bilateral movements. For this study, the 1080QS is used to capture the generated force when performing bench press and -pull with isokinetic resistance (i.e. imposing speed restriction on exercise movement) and for conventional bench press and -pull (respectively), which had no such speed restriction throughout the trajectory of the vertical displacement movement. With a fixed sampling rate of $f = 333Hz$, the measured force generation is transferred to the tablet app.

Helland et al. and Parker et al. tested the effects of isokinetic training with the 1080QS



Parameter: Force
Phase: Concentric
Over: Distance

Sets in exercise

	Side	Rep	Max	Min	Avg	Phase	Unit
1	B	3	749.81	728.16	738.81	Con	Force
2	B	3	731.56	596.36	676.14	Con	Force

Motions

Export: Peaks & averages | Raw samples

☑ Show average

Showing concentric data as force [N] over distance [m]

Figure 1.4: *Screenshots from:* ***left****: Quantum Syncro (www.1080motion.com),* ***right****: 1080 Motion™ online application of initial data output.*

on younger athletes and golfers; both studies indicate that isokinetic training with motorized equipment improve specific athletic tasks [25, 26]. With a medium effect size ($ES = 0.40 \pm 0.22$), the former study found that isokinetic intervention was superior to Olympic weightlifting on increased 1 repetition maximum (1RM) strength with [25, p. 742]. The latter study showed (compared to a control group) that isokinetic training programmes improved lead arm speed and acceleration with more than 80% compared to isotonic training [26], i.e. typical strength training. The reliability and validity of the 1080QS have been tested in two studies [27, 28]. One study compared the 1080QS (Co., 1080 Motion) with another device, K-toyo 333A (Co., Ltd., South Korea) [27]. The measuring reliability of the 1080QS was compared to reference levels of the K-toyo 333A. The average difference between measured peak values was calculated to be 2.08% ($SD = 0.017$) [27], which indicated high measuring reliability of the 1080QS. A second study compared the accuracy of both position and time measurements produced by the 1080QS and 1080 Sprint (1080 Motion TM, Lidingö, Sweden) [28]. Both devices were found to provide high accuracy in both time (±0.5%) and position ($\pm 5 mm/m$) measurements; the repeatability of force measurements was calculated to be 0.7% [28]. We therefore concluded that the 1080QS met our requirements for providing valid (i.e. measuring the true force production) and reliable (consistently measuring the true force) data for all subjects.

1.5.2 ERB force measurement device

The ERBs used in this study are manufactured by TheraBand® (Hygenic Corp., Akron, OH) (Figure 1.5, p. 12). Different resistance values are due to physical qualities of the rubber material and the cross-sectional areas of the resistance bands; a larger area gives higher resistance. An external force is required to stretch the ERB and the magnitude of this force is measured using a load cell (U2A 500 Hottinger Baldwin Messtechnik, Darmstadt, Germany) (Figure 1.5, p. 12).

The load cell produces an electrical resistance (measured in ohm (Ω)) which varies linearly with the applied force (Appendix A.4). The resistance is converted to a voltage (V) and sampled at a $1000Hz$ rate; the relationship should therefore be of the form $F = gm(aV + b)$, where F is the force, V is the load cell output voltage, g is the gravitational acceleration, m is the mass and a and b are constants. To determine a and b, assuming that since the load cell has a linear characteristic over the specified measurement range ($0 - 500kg$) (Appendix A.4), we derived the mapping from voltage to force by first attaching weight discs with known mass vertically to the load cell and then recording the output voltage. Ideally, we only needed two such calibration points due to the linear characteristic of the load cell. However, noise will invariably be present in physical measurements [29]; if we were to rely on two data points only when deriving the formula for load as function of output voltage, noise would impact the accuracy of those two calibration points negatively, resulting in an inaccurate formula. However, by using multiple data points and linear regression to fit a straight line through these points, the negative effect of electromagnetic noise in each individual measurement will be reduced significantly and make the conversion formula more accurate. As can be observed from figure 1.6 on page 13, our calibration points fit well on to a straight line; noise can be observed as some points not being centred perfectly on the extrapolated line.

Figure 1.5: *Left: load cell. Right: screenshot of elastic resistance bands (www.theraband.com/).*

A load cell with a lower L_{max} type rating would have higher resolution; we considered $L_{max} = 100kg$, which corresponds to an $F_{max} \approx 980N$, and we considered this to be possibly too low for some of our test subjects who were former competing powerlifters; we thus decided to use the $L_{max} = 500kg$ load cell. It could be argued that we should have chosen calibration disc masses covering a larger range of the load cell's dynamic range, e.g. weights up to the max values of $100kg$ or $500kg$. Unfortunately, we considered this not to be practical due to limitations of the physical lab setup; we also had concerns on how to attach heavy discs safely to the load cells. Finally, we did not consider that the lower resolution of the $L_{max} = 500kg$ had negative impact on our generation of force output profiles and subsequent analysis and comparison of exercise types.

1.5.3 Motion capture

In order to calculate force output profiles for ERB-based exercises, we attached reflective markers on test subjects and captured three-dimensional kinematic data from infrared cameras to determine the exercise trajectories. The corresponding forces were measured with a load cell attached to end of the ERB.

This type of optoelectronic measurement is regarded as optimal or reference benchmark for motion capture, although non-optical and/or marker-less systems gain popularity and

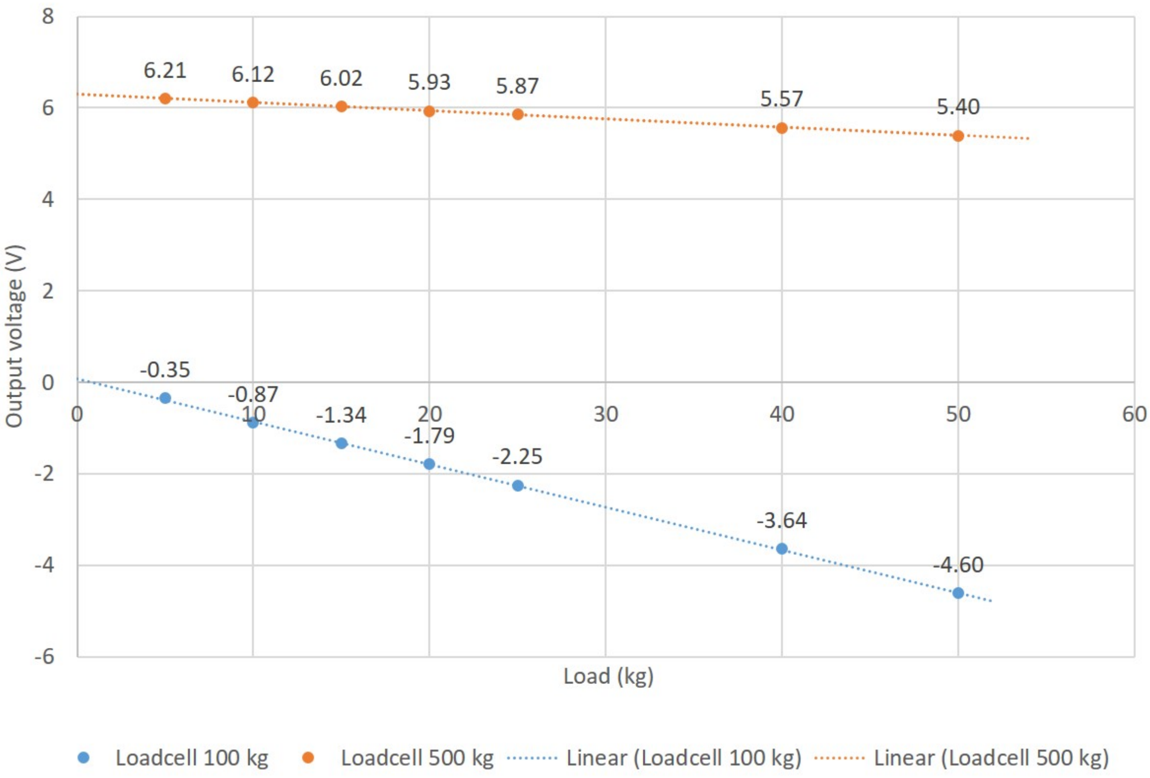


Figure 1.6: *Calibration data: output voltage as a function of load for 100kg and 500kg load cells. Plot generated in Microsoft® Excel®.*

continue to improve both large-scale research and smaller group analysis purposes [30, 31]. In this study we used the Qualisys Track Manager (QTM) (Qualisys AB, Gothenburg, Sweden), a reputable system for capturing digital imaging in three dimensions, which is useful when studying kinematics and kinetics of human biomechanics (e.g. gait analysis or functional assessments). The QTM is certified for technological assessment of movement (ISO 9001, 2015) and complies with laws and regulations for medical devices (93/42/EEC) by the Research Institutes of Sweden AB, RISE.

The kinematic data were recorded using 12 cameras (Oqus 400/700; Qualisys AB, Gothenburg, Sweden) at $200 Hz$ sampling rate, which is a common set-up for this kind of data collection [30, 32]. System calibration was carried out as specified by manufacturer with an accuracy of $< 1.2 mm$ (standard deviation of the calibrating wand length) (Figure 1.7, p. 15).

10 reflective markers were attached to the subject's body on the following anatomical landmarks [33, 34]: acromion, lateral and medial epicondyle and carpus at dorsal and palmar position on both sides of the body; these marker positions were selected in order to derive the actual extension of the ERB and correlate the position data with the force data recorded by the load cell.

The precision of marker positions is claimed by equipment producers to be about 1:3000 of the calibrated volume's diagonal and this resolution is considered adequate when analysing human movements [32, p. 201]. Moreover, it has been demonstrated that determining the exact spatial location of markers has less impact on the overall measurement accuracy; errors due to skin movement and marker positioning contribute more significantly [35]. Soft tissue artefacts (STA), i.e. displacement of markers relative to bone segments, frequently give rise to errors, in particular when estimating joint angles [36, 37, 38]. Lavaill et al. demonstrated that shoulder kinematic and kinetic data varied with between 3% to 7% and 11% to 28%, respectively [39]. In order to minimize these variations, they propose focusing on STA (soft tissue artefacts) reduction rather than marker misplacement. Hence, we could have employed rigid marker-clusters in an attempt to compensate for such deviations, as proposed by Cappozzo et al. [40]. However, the efficiency of such clusters in mitigating STA is questioned [41]. An easier strategy to compensate for STA issues is to place markers at positions where STA is considered to be at a minimum, i.e. where bone structures are easily palpable [42]; an approach which we also adopted, since we positioned markers at acromion, lateral and medial epicondyle, and dorsal and palmar carpus. The exact location of acromion was the most challenging to palpate on individual test subjects. Due to the ERB touching elbows and wrists, and the relative simplicity of the exercise trajectories, i.e. no rotational movements of joints, we assessed the given anatomical landmark placements to suffice, in accordance with proposed recommendations [33]. In case marker readings are missing, temporal interpolation may be used [32]; however, we opted for manual corrections in QTM as part of a visual inspection and quality assurance of measurements. It is not fully understood how kinematic and kinetic variable sensitivity is affected by marker placement; it depends on position, type of variable(s) being measured, type of marker, scale of displacement and movement phase [43]. These kinematic recordings enabled comparison between data from the ERB force measurement device (the load cell); data sampled from isokinetic and conventional press- and pull exercises; trajectory lengths were automatically recorded by the 1080QS.

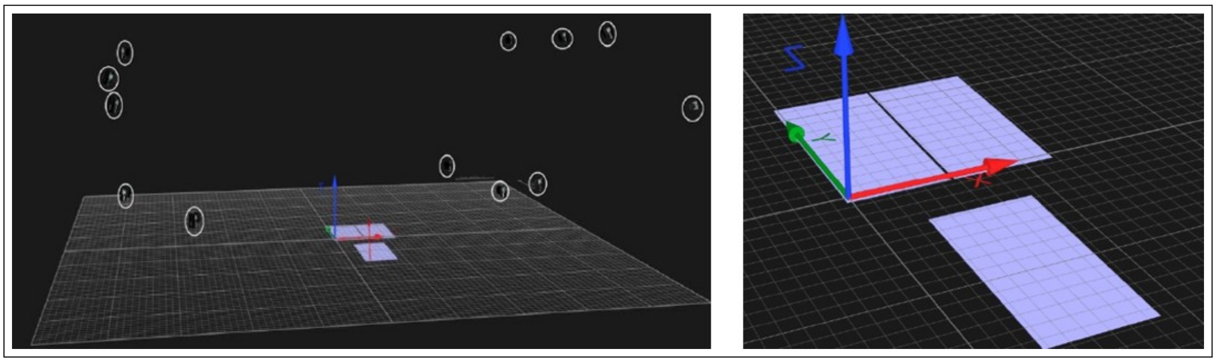


Figure 1.7: ***Left***: *12 cameras surrounding the capture volume in the middle. Picture is edited from QTM with white circles to highlight the cameras, courtesy of M.Sc. Helena Mo.* ***Right***: *global coordinate system in the biomechanical lab and the capture volume of motion capture recordings. These global coordinates needed to be calibrated before individual test trails. The pictures are screenshots from the QTM system.*

1.5.4 Ethical consideration

It is emphasized by the World Medical Association (2013) that "It is the duty of the physician to promote and safeguard the health, well-being and rights of patients" [44, p. 2191 (section 4)]. As a consequence, we found it imperative to secure, to the extent possible, the safety of our volunteers by adhering to applicable Health, Safety and Environment (HSE) protocols (see section 1.5.4). In addition, three other measures have been taken to comply with the WMAs guidelines [44, pp. 2191–2194]: Firstly, guaranteeing the anonymity of subjects at the time of publication (section 24); secondly, transparency of methods and procedures used for repeatability (i.e. a question of reliability) and finally, to the extent possible, unbiased reporting of findings (sections 35–36). All data registered for this project assumes the written consent of participants, based on information highlighting the voluntary participation and possibility for withdrawal at any time prior to publication without any negative consequences (Appendix A.1).

All Person Identifiable Information (e.g. signature, e-mail, anthropometric registration and data collection) was stored separate from the data and the subjects were assigned a unique identifier in agreement with applicable guidelines set forth by the Norwegian Agency for Shared Services in Education and Research/Norwegian Social Science Data Services (former NSD, now Sikt) (Appendix A.2). The study is also approved by NIH's ethical committee (Appendix A.3). Therefore, in our judgment, our study complies with the guidelines defined by the World Medical Association i.e. Declaration of Helsinki [44].

HSE precautions

In a worst-case scenario, maximum bench press weight might have caused tension or tear of the chest muscle [45]. However, the likelihood of such injuries is in general very low among healthy adults and often associated with the abuse of anabolic steroids [46]. We considered that kind of abuse unlikely among our participants. Another potential hazard might have been caused by incorrect use of the 1080QS, which could potentially have generated strong forces pressing volunteers hard on their chests. We mitigated this risk by employing strong physical metal stops, effectively preventing this from occurring in case of a software error or other unforeseen events.

There was also a small potential risk for ERB ruptures; to reduce the probability of such events, ERBs were thoroughly examined prior to each test session. For both test scenarios, sufficient warm-up was required to reduce the risk of muscle injuries; our test protocol specified and included a dedicated session to this effect prior to the actual test phase. NIH is a state owned educational institution and a self-insurer, hence insurance was covered.

1.5.5 Data reduction and processing

The exact duration of each repetition and the full set varied between subjects, which implied that sampled data had to be normalized and re-sampled before trends and tendencies across the data could be analysed. Each sample from the 1080QS contained data from a full bench press or -pull exercise set with three repetitions from the isokinetic sets and six repetitions from the conventional press and pull sets. Recording on the 1080QS started automatically on the first movement of the barbell and continued until it was placed in its final resting position latched on to the stop hooks. The duration of an exercise from start to finish were invariably unique for each subject due different techniques and muscle strength, i.e. start and stop positions for each repetition within a complete set varied.

To calculate e.g. an average force profile based on either 3 or 6 repetitions, we first had to identify the indices of the start and stop positions for each repetition. Since each sub-sample (representing one repetition) varied in length, both between individual repetitions of a subject's set(s) and between subjects, our first approach was to identify the shortest sample length for a specific exercise of an individual subject, and then re-sample by using the built-in resample function of Matlab (version R2022b, 9.13.0.2049777, The MathWorks Inc, Natick, MA) for all sub-samples to make sure they were of the same size before calculating average force profiles. This would then have to be repeated for all data from: standing press and -pull up to 100% and 200% elongation, isokinetic bench press and -pul, conventional bench press and -pull across the complete ensemble of subjects. However, this approach turned out to be both cumbersome, error-prone and time-consuming with additional steps needed to identify the shortest sample lengths and then resampling of all corresponding sub-samples. After developing Matlab scripts for this approach, we chose a simpler strategy; we set a fixed global sample length per exercise and resampled all sub-samples to this global value. In this way, the Matlab scripts became simpler and more efficient to run, and made comparisons across exercises and test subjects more directly comparable.

Resampling may affect accuracy and introduce errors at the extreme ends of sample intervals (R2022b, 9.13.0.2049777, The Mathworks Inc, Natick, MA); our objective was primarily to compare curve shapes and we did not see any adverse effects on force profile topologies before and after resampling. In the following, the resample length was set to 500 data points. Furthermore, we used linear approximation as resampling parameter, which had the positive effect of smoothing out noise in the load cell output voltage of the ERB exercise measurements.

Each subject's force profile is calculated as averages of three consecutive repetitions (out of a total of three or six repetitions) for the isokinetic, conventional and ERB exercise measurements. Visual inspection of the raw extension and force profiles from the QTM revealed that initial and final repetitions of a set sometimes were corrupted, probably due to unintentional pauses or uneven movements; as a consequence these repetitions had to be omitted. There were also issues with reflective markers sometimes falling off, rendering position values from a particular side (either left or right) of the body unavailable. In these cases, we found valid readings using the markers from the opposite side of the body. In sum, these anomalies required a manual inspection and verification of force and position values to determine which curve segments to base our subsequent analysis on. We applied this manual control procedure to data from both the 1080QS and the QTM.

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Part II

Article

Manuscript title: Comparison of Force Profiles from Elastic Resistance Bands and Conventional Barbells.

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Abstract

Exercising with elastic resistance bands (ERB) has gained popularity over the past 5-10 years, but there is little research on how muscles are utilized during ERB exercises compared to conventional weights. To provide a better understanding on how ERB training can be optimized, the **purpose** of this study was to measure and compare force output profiles between ERB standing press and -pull and barbell-based bench press and -pull. By employing a **cross-sectional, within-subjects study design**, we collected data from 19 healthy men (N=14) and women (N=5). Force profiles were generated in a purpose-built Smith machine during bench press - and pull, with isokinetic resistance (measuring maximum force output capabilities) and conventional weight plates (measuring 6 repetition maximum). 3D motion capture in combination with a load cell were used to measure 6RM standing press and -pull forces using ERBs. Data were processed and analysed using Matlab with the SPM1d package (Statistical Parametric Mapping 1d). Our **results** indicate that press exercises with ERBs has a comparable force profile, but lower force output throughout the exercise trajectory compared to the maximum force output capability for isokinetic bench press up to 80% of total exercise trajectory length. Conventional bench press does not follow the isokinetic force profile, and the force output is virtually constant through a large section of the exercise trajectory. For pull exercises, ERB force profiles match poorly the isokinetic force profile, because the ERB load increases, while the maximum force output capability drops from 30% up the end of the exercise. According to our data, the shape of the conventional bench pull profile correspond well with the isokinetic force output. No significant statistical differences were found between ERBs stretched to 100% and 200% for neither standing press nor -pull. We **conclude** that ERBs are a convenient, user-friendly and viable alternative to conventional press exercises, but less efficient as replacements for conventional pull exercises. ERB training may be optimized to better match the maximum force output capability profiles during press and pull exercises.

Keywords: *bench press, bench pull, force profiles, force output capability, isokinetic resistance*

2.1 Introduction

Current World Health Organization (WHO) recommendations for physical activity state that higher intensity gives more health benefits[2]. However, any non-sedentary behaviour is better than none [1, 2]. Some transnational large-scale epidemiological studies have shown that all-cause mortality (ACM) could be reduced by 7 – 10% if inactivity was eliminated [3, 4]. Findings from other studies support the claim that PA at moderate- to high intensity (MVPA) levels also reduce the risk of cardiovascular diseases and mortality [4, 5]. Furthermore, current national and international physical activity recommendations emphasize the importance of muscle-strengthening activities, e.g. resistance/strength training (RT) as part of our daily or weekly physical activities [1, 6]. The amount of research on RT (resistance/strength training) has increased rapidly during the last 20 years: more than 21,000 RT themed research articles according to the PubMed® webpage[3]. Common focal points for RT research have been e.g. development of strength, hypertrophy, power and endurance [7, 8, 9, 10] or a combination of these. RT is also used to develop sport-specific skills needed for e.g. football players and rowers [11, 12].

Squat [13, 14, 15, 16] and deadlift [17, 18, 19, 20, 21] are widely used in RT research. Even if bench press is a popular exercise to enhance upper body strength, power, hypertrophy [20, 22, 23, 24], injury prevention and rehabilitation [25, 26, 27], it is less investigated compared to squat and deadlift in both recreational and professional sport contexts. This may partly be explained by some difficulties associated with measuring forces applied during upper-body exercise/movements [28]. Typical for squat-, deadlift- and bench press studies is the use of electromyography (EMG) to measure muscle activity [16, 19, 28]. Even though electromyography data may provide relevant information, the magnitude of muscle activity does not provide a sufficient picture on the efficiency of an exercise [29]. In this context, 'efficiency' refers the amount of muscular effort a given exercise elicits throughout the movement trajectory compared to the individual maximum force output capability along

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[2] Relative to level of fitness, individual benefits tend to diminish at higher intensity [1].

[3] Using "strength training" OR "resistance training" as search-string in February 2023 seems to have increased almost exponentially from 2003.

the same trajectory.

Press vs pull exercises can be classified as antagonistic movements, i.e. a press exercise is a movement executed from a proximal-to-distal position relative to the torso and conversely for a pull exercise [30]. Seated- and standing row are frequently used exercises for strengthening the back. Bench pull though, is less used by recreational exercisers, but it is frequently used in studies and training programs for athletes who rely heavily on back strength, e.g. sailors, kayakers and ice sledge hockey players [31, 32, 33]. Additionally, bench pull is used in training interventions with an elderly population [34].

The use of elastic resistance bands (ERB) has increased among e.g. professional trainers, physiotherapist and the wider public. One main reason may be attributed to the user-friendly and portable nature of the equipment. There is a growing body of literature reporting on its efficiency for different training goal purposes [35, 36, 37]. The ERB (elastic resistance bands) exercise can be made more flexible by varying grip, position and length (by push/pull type of exercise), and thus, assessing the precise amount of muscle activation can be more challenging. Some studies indicate that ERBs enable similar workout results as machines or free weights [38, 39], whereas other research findings suggest that ERB training programs are not superior to general strength exercise [35, 40].

The amount of studies on ERBs in *combination* with traditional barbells when performing squats or deadlifts are increasing. Some of the current evidence suggest that the use of ERB in combination with barbell squat can produce a similar increase in 6RM load as squats *without* ERB. Both modalities showed roughly a 23-25% load performance improvement after a 10 week training intervention [41]. Additionally, barbell squat in conjunction with significant ERB load elicited $\approx$ 12% higher EMG measured muscle activation in the biceps femoris compared to barbell squat alone. Similar results are reported for deadlift by Andersen et al., who found an $\approx$ 8% overall increase in muscle activation when comparing barbell deadlift with heavy ERB load compared to lighter ERB load [42]. While the former study showed no significant differences between light- and heavy load ERB conditions [41], other scholars report no significant differences between exercises *with* ERB compared to those *without* [43, 44].

To our knowledge, there are no biomechanical studies comparing the efficiency of strength training exercises using ERBs versus conventional barbells. To provide a better understanding of this subject, we defined two main aims for this study : **a)** measure and compare force profiles of exercises with ERBs and conventional barbells, and **b)** investigation of potential differences in load between ERBs with higher resistance stretched to double length (100%) compared to lower resistance ERBs stretched three times (200%). Comparison of force profiles can provide new insight into how one may enhance training efficiency with ERBs by optimally using maximum force output capabilities (MFOC).

2.2 Materials and methods

To assess force profiles generated by a selection of press and pull exercises, we employed a cross-sectional, within-subjects design, which is in line with recommendations for biomechanical studies [45]. Subjects performed a set of workout exercises in a purpose-built Smith machine and with ERBs. The objective was to compare force profiles using ERBs versus conventional equipment.

Table 2.1: *Subject characteristics*

Description	Mean	St. Deviation	Min	Max
Age (yrs)	28.7	± 8.1	20	48
Height (cm)	177.1	± 6.2	160	186
Body mass (kg)	78.7	±12.5	52	104

2.2.1 Subjects and recruitment

We recruited 15 males and 5 females for this study; our analysis is based on data from 14 men and 5 women (i.e. one drop-out) (Table 2.1). We initially aimed for at least a 40% representation of either sex, but ended up with 26% women. All subjects were assessed to be physically capable of executing and completing all exercises and categorized as recreational strength-trained individuals; two were former powerlifters. All data registered for this project assumes the written consent of participants (Appendix A.1). The study was approved by the Norwegian Agency for Shared Services in Education and Research/Norwegian Social Science Data Services (former NSD, now Sikt) (Appendix A.2), the ethical committee of the Norwegian School of Sport Sciences (NIH) (Appendix A.3) and conformed to the latest revision of the Declaration of Helsinki [46].

2.2.2 Test procedures

Tests were organized in two independent sessions using the 1080 Quantum Syncro (1080QS) Smith machine (1080 Motion™, Lindingö, Sweden) and TheraBand® elastic resistance bands (Hygenic Corp., Akron, OH), respectively. All test subjects completed both test sessions either on the same day or on separate days to make study participation as little intrusive in their daily routines as possible. They were instructed to refrain from any heavy upper body resistance training for 24–48 hours prior to testing; all subjects reported that they had followed this protocol. 1080QS and ERB sessions were performed in random order based on available time-slots in the biomechanics laboratory at the NIH and also at the convenience of subjects. Anthropometric measurements (height and weight), gender and date of birth were registered for all subjects before testing commenced. Test sessions were supervised by a trained master student and an experienced researcher.

Isokinetic- and conventional bench press and bench pull

Four different press- and pull exercise types were executed using the 1080QS with isokinetic resistance/load and conventional weight plate loads. Both isokinetic and conventional bench press (IBP and CBP, respectively) were carried out in a supine position; conversely, bench pull (IBPU and CBPU) exercises were carried out in a prone position. For all four exercises, a specific shoulder width grip was recommended in order to resemble the corresponding press and pull movements with ERBs. Table 2.2 summarizes the number of maximum repetitions for each exercise type.

Table 2.2: *Overview of exercises and repetitions*

Repetitions	IBP/IBPU	CBP/CBPU	SP100/200	SPU100/200
3RM	V			
6RM		V	V	V

RM: repetition maximum, **IBP/IBPU**: isokinetic bench press and -pull

CBP/CBPU: conventional bench press and -pull, **SP100/200**: standing press with 100- and 200%

SPU100/200: standing pull with 100- and 200% elongation

By employing the isokinetic resistance mode (i.e. the speed with which the barbell could be lifted, was restricted to an adjustable, fixed value), of the 1080QS, during bench press and -pull we collected subjects' maximum force output capability (MFOC) profiles. We set speed restriction to 0.15 m/s (N=13) and 0.2 m/s (N=6). These profiles were then used as reference measurement when analysing and comparing force profiles of CBP and CBPU and ERB press- and pull exercises (see section 2.2.2). The terms 'maximum force output capability profile' and 'isokinetic force profile' (for bench press and -pull, respectively) are use interchangeably in the subsequent chapters.

Force profiles were recorded as functions of the barbell's position relative to the starting point for CBP and CBPU. We wanted our test subjects to apply maximum force throughout the whole trajectory of the exercises, hence the "No Flying Weight" (NFW) mode on the 1080QS was enabled to avoid slack in cables and maintain resistance throughout the movement. All force and position data were sampled at $f = 333Hz$.

Specific procedures Subjects started with 5–10 minutes of general warm-up on a treadmill followed by a bench press warm-up protocol: progressing from 10–20 repetitions with barbell load only, then adding weight discs to achieve 10 repetitions at 50% of their expected 1RM, followed by 4 repetitions at 70%, 2 repetitions at 80% and finally one repetition at 90% [47]. After warm-up, subjects performed dry-runs with 1–3 isokinetic repetitions, followed by data measurement at 3RM. Conventional exercises started with 3–6 repetitions dry-run, followed by data measurement at 6RM (5–7RM correspond to approximately 80–85% of 1RM) [28].

The purpose of the familiarization step was to estimate 6RM without subjects having to perform unnecessary sets, which might otherwise have resulted in fatigue. For the 6RM CBP and CBPU, five repetitions sufficed; if they managed less then five, load was reduced. If they felt that they could do more than 10 repetitions before reaching six, they were instructed to stop so that the load could be increased. In most cases 1–3 attempts were required to determine subjects' individual 6RM.

There was room for personal preference with respect to grip position, and subjects could also deviate from the number of repetitions prescribed by the warm-up protocol. However, it was clearly stated that after warm-up, subjects needed to be prepared to perform at their maximum capacity, in particular during the isokinetic sessions since this is considered an uncommon exercise for recreational trainers. Isokinetic sessions were always executed prior to conventional, whereas the order of bench press and bench pull exercises was arbitrary.

ERB standing press and standing pull

Subjects performed a total of four different standing press and -pull exercises with ERBs. For each press and pull exercise, ERBs were stretched to their double and triple length, i.e. 100% and 200% respectively (SP100/SP200 and SPU100/SPU200). ERBs were selected separately for each exercise to allow for 6RM, i.e. the load had to be tailored to each exercise and per subject (see also Table 2.2)

Ten spherical retro-reflective (passive) markers ($12.5 mm$ diameter) were used to record kinematic data along the exercise trajectory. These data were recorded using the Qualisys Track Manager (QTM) system consisting of 12 cameras (Oqus 400/700; Qualisys AB, Gothenburg, Sweden) at a $200 Hz$ sampling rate through a 16-bit analog-to-digital conversion board (USB-2533; Measurement Computing Corporation, Norton, MA, USA). The markers were positioned by palpation and visual inspection on each subject's anatomical landmark: acromion, lateral and medial epicondyle and carpus at dorsal and palmar positions to define anatomical segments [48, 49]. Previous studies have shown that skin-based markers may have some issues attached to it, e.g. movement of markers relative to the (representing) bone

Figure 2.1: ***Top left***: *isokinetic bench press.* ***Top right***: *isokinetic bench pull.* ***Middle left***: *conventional bench press.* ***Middle right***: *conventional bench pull.* ***Bottom left***: *standing press. Bottom right: standing pull.* ***Note***: *Both ERB modalities were carried out at 100- and 200% elongation.*

segments or misplacement of markers from the onset [50, 51]. To mitigate displacement of markers to the extent possible, the same person carried out the marker set-up for all participants as recommended [52]. Subjects wore their preferred clothing provided it did not cover any attached reflective marker.

To calculate force output profiles for ERB-based exercises, we combined the three-dimensional kinematic data for the movements with force measurements from a load cell (U2A 500 Hottinger Baldwin Mestechnik, Darmstadt, Germany) attached to end of the ERB. The load cell produced a resistance varying linearly with the applied force. The resistance was converted to a voltage (V) sampled at $1000 Hz$. The certified weight range of the load cell was 0–$500 kg$.

Specific procedures Subjects were instructed to stand firmly in a position which felt normal to them with their clenched hands (fists) positioned adjacent the torso, approximately below their chest. For the press exercises, their palms were to be in a supine position while for the press exercises, palms had to be in a medial position. Tests started with a general 5–10 minutes' warm-up on a stationary bike before a more targeted ERB warm-up. Standing press and -pull exercises at 100% and 200% band extensions were performed in a random order.

The resting time between sets was set to ca. 3 minutes, in accordance with applicable guidelines [53]. When switching between 100% and 200% extensions and between press and pull exercises, subjects were invited to do additional test trials with 1–3 repetitions to reduce the chance of unsuccessful attempts. The total duration of test sessions varied from 60 to 90 minutes.

2.2.3 Data reduction and processing

Data from both 1080QS and QTM test sessions were imported in Matlab (version R2022b, 9.13.0.2049777, The MathWorks Inc, Natick, MA) variations in exercise speeds, sample lengths varied between exercises, between individuals and also between repetitions of a single exercise set. To simplify the processing, all measurements were resampled to a fixed length of 500 data points. Employing the 'resample' function with linear approximation in Matlab had the added positive effect of smoothing curves due its built-in default poly-phase anti-aliasing filter.

To make comparison and statistical analysis of force profiles easier, both the dependent and independent variables were: We converted individual trajectory lengths (independent variable), measured in centimetres, to relative trajectory lengths, measured as a percentage of the total trajectory length (PTTL). Thus, mean forces are calculated as the average of normalized individual force profiles. All data points of each force profile were divided by the max isokinetic force for the test subject in question before calculating means, i.e. the highest forces along the profiles equal 1.0. Because max force is attained at different PTTL points for different test subjects, mean forces do not attain a maximum of 1.0. Since our analysis was primarily focused on force profile shapes, variations between individual absolute force output capabilities were out of scope.

During the initial test data sampling, significant spikes were observed in both start and stop positions of exercise trajectories. This spurious data were most likely caused by challenges with setting weights in motion in a smooth and controlled fashion from start positions, and possible difficulties in keeping weights and ERBs in a fixed position towards the end of the exercise when movement became gradually restricted until the final halt. The first and last 5% of the PTTL are therefore omitted in the subsequent analysis.

Specifics to 1080QS

Isokinetic and conventional force profiles were calculated as the average of three repetitions in one set for each type. Trajectory lengths were calculated as the difference between the start and stop positions measured by the 1080QS and then converted to percentage of total trajectory length (PTTL). This procedure was applied to all four modalities (i.e. IBP, CBP, IBPU and CBPU).

Specifics to QTM

ERB force profiles were calculated as the average of three consecutive repetitions selected from within a series of six after excluding the first set (set 1) and the last set (set 6), in accordance with common practice. ERB elongation was calculated as the difference in centimetres on the x-axis between the reflective markers attached to the shoulder and wrist, which was then converted to percentage of maximum extension recorded for each test subject. This procedure was applied independently to all four modalities (i.e. SP100/SP200 and SPU100/SPU200, respectively).

2.2.4 Statistical analysis

Statistical Parametric Mapping (SPM) [54] was employed to analyse forces generated during barbell- and resistance bands exercises. Exercises were then grouped in two main categories: press and pull. Normalized force profiles were compared pairwise using two-tailed paired t-tests to study the applied force as function of the percentage of total trajectory length (PTTL) of each exercise. The objective of t-tests was to determine if there were statistically significant difference(s) between force profiles over the full movement; α was set to 0.05, whereas the default null hypotheses claimed no statistical difference between variables. Main objective and interest of our analysis were the pairwise comparison of an ERB with a non-ERB exercise; hence ANOVA was not considered necessary. Tests and possible corrections for non-sphericity were considered not to be applicable, since there were no repeated measurements; also Bonferroni-corrections were deemed not relevant, because only one parameter, applied force, is measured as a function of PTTL. SPM analyses were implemented with the open-source spm1d code (version M.0.4.10 (2022.09.23), www.spm1d.org) in Matlab (version R2022b, 9.13.0.2049777, The Mathworks Inc, Natick, MA).

2.3 Results

2.3.1 Press exercises

ERB standing press 100% vs 200%

Whereas the force profiles of SP100 and SP200 were highly similar in shape throughout the exercise movement, mean applied force is somewhat lower for SP100 than for SP200 between 5% and 30% of the PTTL; however the t-test shows that this a non-significant difference. Furthermore, we observe that force profiles, for both modalities, are not linearly dependent on PTTL; the forces increases relatively more steeply between 30% and up to 60% of PTTL compared to the 5% to less than 30% and the above 60% to 95% intervals (Figure 2.2.(A) and .(B)). Since there is no significant difference between SP100 and SP200, the null hypothesis is kept. For the same reason, when contrasting ERB exercises with IBP and CBP respectively, we compared only SP200 to IBP and to CBP.

Isokinetic bench press vs ERB standing press 200%

From the force profiles of IBP vs SP200, it was observed that both are increasing for the majority of the PTTL (percentage of total trajectory length) (Figure 2.2.(C)); however two supra-threshold cluster (5% to 27% and 69% to 84%) exceeded the critical threshold of as the force profile of IBP was significantly higher than SP200 (Figure 2.2.(D)). The probability that a supra-threshold cluster of these sizes would be observed in repeated random samplings was $p = 0.002$ and $p = 0.011$ respectively; the null-hypothesis was thus rejected. It is worth noting that since ERB resistance increases continually when it is elongated, while force output capability profile from the IBP drops sharply towards the end of the PPTL, at one time point the the two force profiles intersect, resulting in a third supra-threshold cluster (92% to 95%, $t^* = -2.953, p = 0.049$).

Isokinetic bench press vs conventional bench press

The mean force profiles during IBP and CBP were different throughout the PTTL (Figure 2.2.(E)). Two supra-threshold cluster (5% to 12% and 66% to 90%) exceeded the critical threshold of $t^* = \pm 2.934$ with the force being significantly greater for CBP than for IBP between 5% to 12% of PTTL, corresponding to the beginning of the press movement. However, the second supra-threshold cluster confirm the visually observed difference in mean force profiles between IBP and CBP. The exact probability of a supra-threshold cluster of this size would be observed in repeated random samplings was $p = 0.038$ and $p = 0.001$, respectively (Figure 2.2.(F)). The null hypothesis was therefore rejected.

ERB standing press 200% vs conventional bench press

The recorded mean force profiles during SP200 and CBP displayed significant dissimilarities throughout the exercise movements (Figure 2.2.(G)). At $\alpha \leq 0.05$, two supra-threshold clusters exceeded the critical threshold of $t^* = \pm 2.934$ from 5% to 37% and at the end of the movement (91% to 95% of the total PTTL) (Figure 2.2.(H)). Consequently, the null hypothesis was rejected.

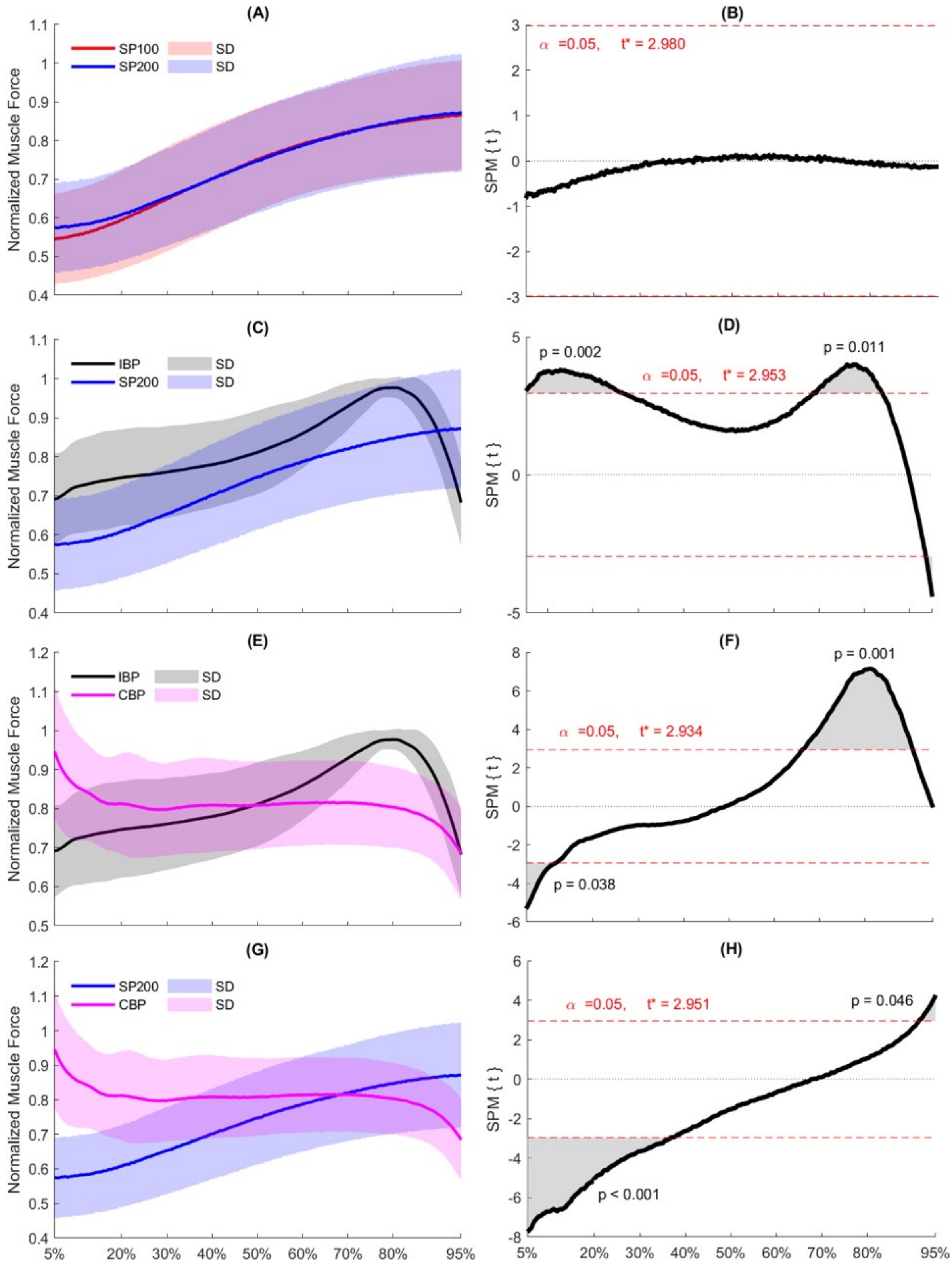

Figure 2.2: *Mean force vs standard deviation (SD) (left column) and paired samples t-test statistics SPMt (right column). From top to bottom:* ***A, B:*** *standing press 100% vs standing press 200%;* ***C, D:*** *isokinetic bench press vs standing press 200%;* ***E, F:*** *isokinetic bench press vs conventional bench press;* ***G, H:*** *standing press 200% vs conventional bench press.* ***Note:*** *Force profiles for standing press 100% and 200% and conventional bench press represent 6 repetition maximum performance. Force profile for isokinetic bench press represent subjects maximum force output capabilities (MFOC) i.e. the reference measurement. All force profiles are normalized.*

2.3.2 Pull exercises

ERB standing pull 100% vs 200%

The force profiles of SPU100 and SPU200 had comparable slopes (Figure 2.3.(A)). However, throughout the whole PTTL, the mean applied force is consistently higher during SPU200 than SPU100. There was a noticeable difference between the 30 to 40% and between 80 to 95% PTTL; however, *t*-tests showed that the differences were non-significant (Figure 2.3.(B)). We also observe that the force profiles, for both modalities, were not linearly dependent on PTTL; the force increased relatively more steeply between approximately 40% and 70% of PTTL compared to the 5% to 40% and 70% to 95% intervals. Since there is no significant difference between SPU100 and SPU200, the null hypothesis is kept. To simplify the subsequent analysis, also here, only SPU200 will be utilized for further comparisons (see section 2.4.1).

Isokinetic bench pull vs ERB standing pull 200%

The IBPU and SPU200 force profiles were dissimilar along the whole trajectory (Figure 2.3.(C)); the SPU200 resistance increases continuously when the ERB is stretched, the IBPU force profiles drops markedly from 30% to 95% of the PTTL. Two supra-threshold clusters (from 5% to 53% and from 71% to 95%) exceeded the critical threshold of $t^* = \pm 2.984$. Whereas the force profile of IBPU was significantly higher than SP200 for first half of the PTTL, the second cluster indicated that SPU200 elicited higher force production towards the end of the movement (Figure 2.3.(D)). The probability that a supra-threshold cluster of this size would be observed in repeated random samplings, was $p < 0.001$ for both clusters; the null-hypothesis was thus rejected.

Isokinetic bench pull vs conventional bench pull

The force profiles of IBPU and CBPU were highly different throughout the PTTL (Figure 2.3.(E)). One supra-threshold cluster (between 23% and 82%) exceeded the critical threshold of $t^* = \pm 2.815$, which means that the applied force in this interval was significantly higher during IBPU than CBPU; the interval corresponded to roughly the main part of the pull movement. The exact probability of a supra-threshold cluster of this size would be observed in repeated random samplings was $p < 0.001$ (Figure 2.3.(F)). The null hypothesis was thus discarded.

ERB standing pull 200% vs conventional bench pull

The recorded mean force profiles during SPU100 and CBPU displayed divergent features throughout the whole exercise movements (Figure 2.3.(G)). At $\alpha \leq 0.05$, two supra-threshold clusters exceeded the critical threshold of $t^* = \pm 2.876$ from 5% to 31% and from 60% to 95% of the total PTTL (Figure 2.3.(H)), and consequently, the null hypothesis was rejected.

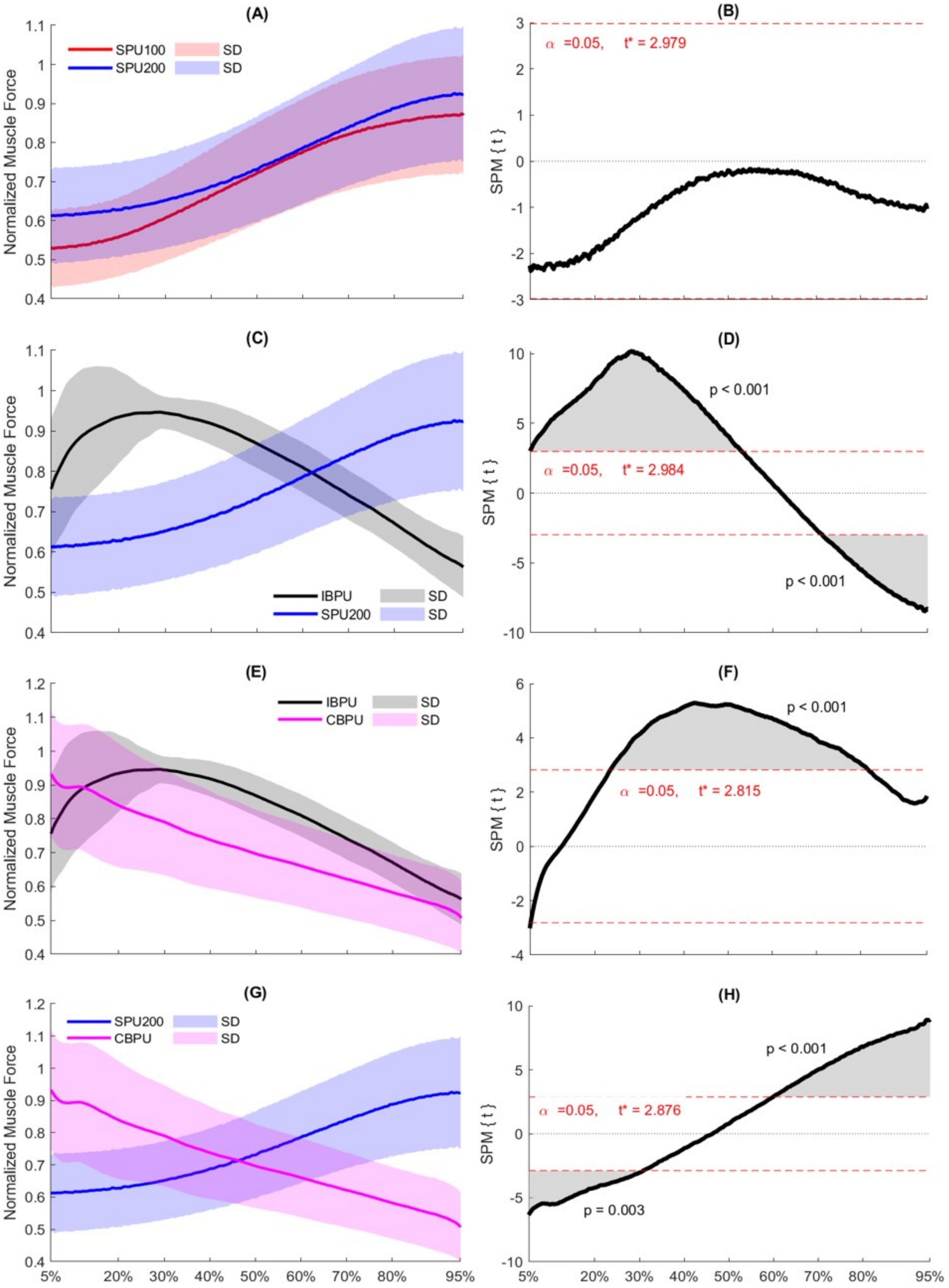

Figure 2.3: *Mean force vs standard deviation (SD) (left column) and paired samples t-test statistics SPMt (right column). From top to bottom:* ***A, B:*** *standing pull 100% vs standing pull 200%;* ***C, D:*** *isokinetic bench pull vs standing pull 200%;* ***E, F:*** *isokinetic bench pull vs conventional bench pull;* ***G, H:*** *standing pull 200% vs conventional bench pull.* ***Note:*** *Force profiles for standing pull 100% and 200% and conventional bench pull represent 6 repetition maximum performance. Force profile for isokinetic bench pull represent subjects' maximum force output capabilities (MFOC) i.e. the reference measurement. All force profiles are normalized.*

2.4 Discussion

To seek a better understanding on how ERB exercises can be optimised, we measured force output profiles of standing press and -pull using ERBs and compared them with conventional bench press and -pull using barbells. Differences in applied force when stretching low-resistance ERBs to 200% of its initial length versus high-resistance ERBs to 100% were also examined. To calculate subjects' maximum force output capabilities (force output reference levels), we sampled force profiles using isokinetic resistance during dedicated bench press and -pull exercises.

Our data indicate that the force profiles from standing press with ERBs (at 100% and 200% elongation) better matched the shape of subjects' maximum force output capability (MFOC) profiles for press, compared to conventional bench press (CBP). On the other hand, for pull exercises, the conventional bench pull (CBPU) force profile displayed the same shape as the MFOC profile for pull. Force profiles for both SPU100 and SPU200 went in opposite directions compared to CBPU and MFOC profiles. Finally, there were no significant statistical differences between SP100/SP200 and between SPU100/SPU200, respectively.

2.4.1 Press exercises

As previously stated, one aim was to investigate if a comparable force output could be attained by stretching an ERB with low-resistance 200% compared to stretching a high-resistance ERB 100%. Our data indicated that there was no statistically significant difference between force profiles of SP100 and SP200, i.e. they produced virtually the same load on muscles throughout the exercise (Figure 2.2.(A) and .(B)). As a consequence, we only compared SP200 with IBP and CBP in the subsequent discussion; i.e. we conjectured that SP100 would yield the same conclusions.

The force output profile during IBP increased from start at 5% and peaked around 80% of percentage of total trajectory length (PTTL). From 80%, the force output dropped sharply, since the arms approached maximum extension and the available force was used to keep the barbell in a locked position. The standard deviation of the IBP mean was higher during early phases of the lift than towards the peak at 80%. Our supposition was that highly experienced lifters were capable of producing more force output at lower PTTLs compared to less experienced subjects (Figure 2.2.(C) and .(D)).

Up to the peak force output of IBP at 80% PTTL, the SP200 profile had comparable gradient, but the force output generated during SP200 was between 8% and 18% lower than that of IBP; the highest difference is at 5% PTTL (18% deviation), followed by the difference at the IBP peak force output (14% deviation); the lowest difference occurred around 55% PTTL with an 8% deviation. This discrepancy could be explained by the observation that IBP used 1RM load, whereas SP200 resistance was determined by 6RM. Hence, while ERB load did match closely IBP load, it increased by almost the same factor as the increase in force output capability (Figure 2.2.(C) and .(D)). A similar result was observed by Wallace et al.; in their study on the efficacy of training with variable resistance, they concluded that "variable exercises more closely match the strength curve of ascending strength curve" [55, p. 1185]; bench press having ascending and bench pull descending strength curves, respectively. It should be noted that joint angles were the independent variables in their study, whereas we used PTTL; however, increasing joint angle translates to increasing PTTL, with force as the dependent variable.

CBP exhibited a topologically different force output profile compared to IBP. Maximum force output was used during the first part (up to ca. 25% of PTTL), which could be explained by the need to accelerate the barbell from its start position. Once it attained a steady velocity, only a constant force to counteract gravitational pull was required to continue the motion, which was also in line with biomechanical principles [56, p. 371]. From 80% PTTL, arm movement became more restricted, barbell motion falls and hence the force output dropped. CBP seemed to allow for more explosive use of force output during the initial phase compared to IBP; force output of CBP was statistically significantly higher below 12% PTTL 2.2.(F). We also observed that force output of CBP started to drop when the IBP force output attained its peak; there was a statistically significant difference from 66% to 90%

PTTL. This indicated that CBP was less efficient with respect to following the IBP profile and hence maximum force output capability (MFOC), which was not fully utilized during the last one third of the PTTL as opposed to IBP and SP200 (Figure 2.2.(C) and .(D)), where profiles exhibited good correspondence. Findings by Nyberg et al. underpins this observation, i.e. isokinetic and ERB measurements seem to agree quite well with respect to maximum force [57, p .110].

Force output profiles of CBP and SP200 deviated significantly from start and up to 37% PTTL. The load of CBP and SP200 were both determined by individual 6RM and should thus be comparable in load. The PTTL at which 6RM was defined differed between the two exercises; for CBP, 6RM was determined by the maximum force output during the initial phase of the lift; for SP200 on the other hand, 6RM load was limited by the force output maximum force output capabilities towards the final phase. It would therefore seem that CBP was more efficient during the initial 37% percent, because the force output was significantly higher than the force required during the same initial part of SP200 (Figure 2.2.(G) and .(H)).

Comparing the force profiles of IBP and CBP revealed an apparent anomaly: below 50% PTTL, subjects appeared stronger than their isokinetic force profiles suggested (Figure 2.2.(E)). This however could be explained by the instructions given to subjects during isokinetic lift: In order to prevent the built-in speed limiter of the 1080QS from being invoked too abruptly, test subjects were asked to start the press exercise using less force than they actually believed to be capable of. If the built-in speed limiter is triggered by a relatively high barbell velocity, a substantial force will be required to reduce and counteract the movement. This might lead to an almost full stop, causing a jerking barbell movement affecting measurements negatively and possibly also preventing subjects' ability to lift optimally. That in turn would possibly have resulted in the maximum force being attained somewhat later than what our results indicated; hence the first part of the maximum force output (MFOC) profile would have reached a higher value earlier in the lift, and levelled out more. Conventional press on the other hand had no speed limitation, and subjects could therefore use maximum force from the start, only limited by their force output capabilities. It was thus reasonable to assume that subjects in reality were stronger in the first part of the exercise movement than indicated by their measured isokinetic profiles.

2.4.2 Pull exercises

Similar to ERB standing press, there was no statistically significant difference between two ERBs stretched 100% versus 200% in terms of applied force[4]. However, the mean force output during SPU200 increased less steeply compared to SPU100 up to ca. 40% PTTL. However, the normalized force used in the start position of SPU200 was higher than by SPU100: 0.61 versus 0.53. We conjecture that this was due the ERB already being stretched 100% in the start position of SPU200, thus demanding a higher initial force and possibly less explosive application of power compared to SPU100, where the ERB was stretched only enough to keep it horizontal, which required less force (Figure 2.3.(A) and .(B)).

The force output of IBPU peaked around 30% PTTL and then dropped almost linearly towards the end of the movement. ERB resistance of SPU100/SPU200 on the other hand was at 0.65 of maximum force output when muscles had their highest force output capability. Maximum force output of IBPU versus SPU200 displayed a statistically significant deviation between 5% and 53%, and then between 71% to 95% PTTL. In addition, ERB resistance increased continuously while maximum force output capabilities fell. We thus conclude that ERB standing pull was less efficient when it came to matching maximum force output capability versus load. Finally, we presume that exercise technique played a role towards the final part of the PTTL; test subjects seemed capable of mustering a factor of 0.9 of maximum force output towards the end of the exercise trajectory. The applied force dropped continuously from a peak at 30% to the end at 95% PTTL, where only 0.57 force output (i.e. 57% of maximum force capability) was applied (Figure 2.3.(C) and .(D)).

The forces exerted in the start positions and the peaks of CBPU and IBPU were comparable, which seem plausible: The maximum force was required in the start position of the CBPU, and we did expect this to correspond to the maximum value of IBPU. Similar to IBP, test

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[4] Note: ERBs had different resistances and were selected to match 6RM at 100% and 200% stretch respectively.

subjects were encouraged to lift the barbell during IBPU both quickly, to use maximum force, but also smoothly at the same time to avoid invoking the speed limiter too abruptly (see also section 2.4.1). Force profiles for IBPU and CBPU had comparable gradients starting from 30% and up to 95% PTTL, but they were significantly different between 23% and 85%. We conjecture that this was caused by maximum IBPU being calibrated for 1RM, whereas maximum CBPU was determined by 6RM (Figure 2.3.(E) and .(F)).

Figure 2.3.(G) shows how force output of CBPU differed from SPU200. CBPU seemed better aligned with IBPU, whereas SPU200 poorly utilized force output capabilities; only in the interval between 30% and 60% PTTL were the differences statistically not significant. When muscles force capabilities were at their highest at the beginning of the exercise, a high force was required to start lifting the barbell. The ERB on the other hand presented the lowest load. Conversely, towards the end of the movement, ERB resistance was at its highest when at the same time muscle force output dropped.

Figures 2.3.(C) and .(D) display an apparent discrepancy between SPU200 and IBPU: from 60% PTTL and above, the applied force used during SPU200 was clearly significantly higher than during IBPU; the latter representing the maximum force capability for the pull movement. We conjectured that it was more difficult to finalize the full IBPU exercise range in a prone position on a bench compared to the upright position of SPU200. Also, we speculated that subjects invariably leaned ever so slightly backward, giving added force and making control of the movement easier compared to IBPU.

2.4.3 Additional observations

As stated in sections 2.3.1 and 2.3.2, the observed force output for both standing press and -pull exercises had a non-linear dependence of PTTL; the same behaviour is observed by e.g. McMaster et al. [58]. If ERB resistance was increased to make the gap between ERB standing press force profile(s) on the one hand and the isokinetic force profile on the other as small as possible, subjects would most likely not have had sufficient force to extend the ERB fully to 100%. Instead, they would have been able to reach about 85% extension, but not being able to perform six repetitions to 100% extension. This argument can be illustrated by imagining the ERB curve being shifted vertically upwards until it coincides with or overlaps the isokinetic force profile. Above 85%, the force required to continue the ERB standing press exercise would exceed the available force output. From a purely comparative standpoint, we could propose the following: by careful selection of band resistance, a standing ERB press exercise load can be calibrated to follow force output capabilities closely, offering near to optimal loading of muscles, provided arms are not extended beyond approximately 85%. This would imply close to optimal loading during the exercise and hence high efficiency. If on the other hand, the ambition is to utilize the full range of arm movement, ERB resistance has to be reduced to match the available force output, which according to our data drop significantly from 85% up to 100% extension.

In addition, it seemed physically more challenging to stretch ERBs to 200% than to 100%. The majority of test subjects also expressed some concerns that the ERB might rupture when stretched 200%. In a normal context, i.e. at a fitness centre or at home, it is less likely that ERBs will be stretched 200%. It could be interesting to investigate if other stretch strategies or -degrees could alleviate the fear of ERB rupture while at the same time increasing load and exercise efficiency. Also, ERB exercises seemed challenging for subjects, because they needed to maintain balance while at the same time applying high force. During conventional bench press and -pull on the other hand, the body was supported and hence no force was used to maintain a fixed and stable position.

Force output profiles for SPU100/SPU200 deviated significantly from IBPU and CBPU in the first half of PTTL. As a consequence, there would be benefits by adding more resistance to SPU and perform about half the movement (PTTL) rather than trying to continue up to maximum elongation. This would potentially elicit force production closer to both IBPU and especially CBPU, since both SPU and CBPU were performed at 6RM load. We also believe the same technique could be applied to SP100/200: By not extending arms beyond 80% of PTTL, a higher resistance ERB could be employed, thus loading muscles more optimally and hence increasing efficiency. Further research could shed light on possible downsides to this strategy, e.g. what would be the potential loss to efficiency by not elongating ERBs as far as arms permit biomechanically.

Overall, ERBs are considered a viable alternative to conventional weight training, reported in e.g. the systematic review and meta-analysis' by Lopes et al. [59] and Andersen et al. [60]. However, there seem to certain nuances to this conclusion: some exercises seem to be performed more efficiently with conventional weights than with ERBs and vice versa, which some of our results also suggest. For instance, Pearson et al. report that loads should be differentiated by bench press and bench pull to maximize muscle power [31, p. 252]. There are also studies which suggest that ERBs target different muscle groups; Bergquist et al. [61, pp. 11-12] reported that different muscle groups were activated differently using ERBs and dumbbells during flyes and reverse flyes. They concluded that dumbbells activated primary muscle groups somewhat more than ERBs, while ancillary muscle groups experienced a higher degree of activation with ERBs compared than with dumbbells.

2.4.4 Limitations

Some limitations should be acknowledged. Only healthy individuals were recruited and as a consequence, the shape of the force profiles might not be representative for other populations such as elderly or people with movement restrictions due to e.g. chronic pain issues; i.e. results may not necessarily be generalized. There are some difficulties to determine exact load (e.g. 6RM) with ERBs [39]; however, our approach of using progressive loading to find subjects' 6RM is a strategy similar to what other scholars have done [39, 62, 63]. It is worth noting that by using 1-4 repetitions as familiarisation and specific warm-up with the ERBs, all subjects found their individual 6RM load within three attempts. Furthermore, it would have been beneficial to our study to have had a larger sample size, especially a higher percentage of women. Initial calculations did not detect any sex differences regarding the shape of force profiles. As this is not a training intervention, results do not indicate possible strength gains over time. We have not considered potential issues caused by individual variations in sticking points/regions [64, 65, 66, 67], which might have affected subjects' maximum force output capability values. However, the exact peak force was not in focus, thus consequences of sticking points/regions would not impact our comparative analysis. Since we used a Smith machine (i.e. 1080QS) and not a true free-weight barbell bench, the trajectory is locked to vertical movement only for both press and pull exercises, which might have been unfamiliar to some individuals. However, according to Schick et al., there is no difference between free-weight and Smith machine bench press when activating primary movers (i.e. deltoid and pectoralis) [68]; thus we assumed that this applied to our study context as well.

2.5 Conclusion

This study set out to gain a better understanding of muscle force generation for a selection of strength training exercises using elastic resistance bands and conventional barbells. The maximum muscle force output was determined using isokinetic resistance during bench press and -pull (IBP and IBPU); force output profiles from standing press and -pull using ERBs, and bench press and -pull were then sampled, representing muscle force output as function of percentage of total exercise trajectory length.

The most significant findings are in our view as follows: firstly, the force profiles of standing ERB press followed the shape of the maximum force output capability profile (force profile of isokinetic bench press) better than that of conventional bench press up to 80% PTTL. Overall, ERBs seemed to provide more optimal loading with higher workout efficiency compared to conventional bench press. However, it is reasonable to assume that it is possible to lift more in conventional bench press than standing press, because the upper body rests firmly against a bench. We also conjecture that there is less to be gained in terms of exercise efficiency by performing SP100/SP200 to 100% PTTL. Stopping the exercise movement at 80% PTTL, additional resistance may be added, enhancing efficiency further.

On the other hand, standing pull with ERBs turned out to be inferior to conventional bench pull (CBPU) with respect to matching muscle force output throughout the exercise trajectory, because ERB resistance increased while muscle force output dropped as a function of trajectory length. However, CBPU allowed the barbell to be accelerated from the start position when muscle force output was at its highest, enabling completion of the exercise motion, even if maximum force output capabilities (force output profile for the isokinetic bench pull) dropped gradually towards the end. To make SPU100/SPU200 comparable to CBPU with respect to exercise efficiency, one possibility would be to increase ERB resistance and restrict the maximum trajectory to e.g. 50% PTTL.

Finally, we did not identify significant statistical differences in terms of muscle force output when using two ERBs with different resistance elongated to 100% (high-resistance) and 200% (low-resistance), respectively.

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Conflict of interest

The authors declare no conflict of interest with the equipments used in this study. No external funding was received for the present study and the results of this study do not constitute endorsement by the *Frontiers in Sports and Active Living.* The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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Appendices

A.1 Informed Consent Form

Vil du delta i forskningsprosjektet

”En biomekanisk sammenligning av styrketrening med strikk og belastet vektstang”?

Formål

Dette er et spørsmål til deg om du vil å delta i et mastergradsprosjekt hvor hovedformålet er å kartlegge i hvilken grad vi belaster musklene i to utvalgte øvelser (benkpress og -trekk). Dette kan hjelpe oss med å forstå hvordan man kan få maksimal effekt av trening med strikk. I dette skrivet gir vi deg informasjon om målene for prosjektet og hva deltakelse vil innebære for deg.

Forskningsspørsmålet vil bli belyst i tre trinn:

1) Beskrive evnen til å generere kraft i ulike deler av bevegelsesbanen til en kontraksjon (trekkøvelse) og ekstensjon (skyveøvelse).
2) Sammenligning av styrkeprofilene fra steg 1) med tilsvarende styrkeprofiler for tilsvarende øvelser utført med treningsstrikk.
3) I hvilken grad kan endring av egenskapene til treningsstrikken (motstand og graden av strekk) bidra til best utnyttelse av muskelkraften gjennom hele bevegelsesbanen til øvelsen?

Hvem er ansvarlig for forskningsprosjektet?

Norges idrettshøgskole og Institutt for idrettsmedisin er ansvarlig for prosjektet.

Hvorfor får du spørsmål om å delta?

Vi søker kvinner og menn som kan delta i studien. Du må være fylt 18 år og ha kjennskap til og erfaring med styrketrening fra tidligere.

Hva innebærer deltagelse i prosjektet?

I denne studien vil du gjennomføre isokinetisk benktrekk og benkpress, dvs. at du løfter med maksimal innsats ved en konstant hastighet. Dette gjøres for å måle hvor stor kraft du kan generer i ulike deler av bevegelsesbanen. Du vil også gjennomføre submaksimale løft i benkpress- og benktrekk med tradisjonell stang. I tillegg vil du gjøre stående trekk og press med treningsstrikk. Det vil også bli gjort bevegelsesmålinger for å kunne beregne og analysere bevegelsesbanen. Til dette vil vi bruke små refleksmarkører festet til hhv. skulder-, albue og håndleddene.

Det vil ta deg ca. 120 minutter å gjennomføre alle øvelsene, inkludert pauser. I forkant av testsituasjon må du ha sett fem korte instruksjonsvideoer med på ett minutt hver. I prosjektet vil alle testmålinger registreres og lagres elektronisk. I tillegg vil det bli registrert opplysninger om alder, kjønn, vekt, høyde og armlengde.

Mulige fordeler og ulemper ved deltagelse

Fordeler ved å delta i prosjektet er at du blant annet får et innblikk i noen biomekaniske forskningsmetoder og vil være med å bidra til ny kunnskap på et område som er lite undersøkt (biomekaniske studier som sammenlikner grunnleggende øvelser med stang og treningsstrikk).

Selv om maksimalkraft skal måles, vil det ikke være bruk av maksimale vekter siden vi benytter oss av 1080 Quantum-maskinen, som bruker elektromotorer som motstand. Dermed er risikoen for at stanga skal presse ukontrollert på brystet eliminert.

Det er frivillig å delta
Det er frivillig å delta i prosjektet. Hvis du velger å delta, kan du når som helst trekke samtykket tilbake uten å oppgi noen grunn. Det vil ikke ha noen negative konsekvenser for deg om du trekker samtykket og dine personopplysninger og testdata vil da bli slettet.

Ditt personvern – hvordan vi oppbevarer og bruker dine opplysninger
Vi vil bare bruke opplysningene om deg til formålene vi har fortalt om i dette skrivet. Vi behandler opplysningene konfidensielt og i samsvar med personvernregelverket.

- I dette prosjektet vil det kun være masterstudent, veileder og eventuelle prosjektmedarbeidere som vi ha tilgang til opplysningene om deg.
- Navnet og kontaktopplysningene dine vil vi erstatte med en forsøkspersonnummer i databehandlingen i tillegg vil egen navneliste som vil være adskilt fra øvrige data. Lagret data vil også ligge kryptert på NIHs forskningsserver.
- Ved publikasjon vil du som testdeltaker ikke kunne bli gjenkjent.

Hva skjer med opplysningene dine når vi avslutter forskningsprosjektet?
Opplysningene som registreres om deg skal kun brukes slik som beskrevet i hensikten med prosjektet. Data anonymiseres så snart datainnsamlingen er avsluttet (sannsynligvis innen 01.06.2022).

Dine rettigheter
Så lenge du kan identifiseres i datamaterialet, har du rett til:

- å få innsyn i hvilke opplysninger vi behandler om deg og å få utlevert en kopi av opplysningene,
- å få rettet opplysninger om deg som er feil eller misvisende,
- å få slettet personopplysninger om deg,
- å sende klage til Datatilsynet om behandlingen av dine personopplysninger.

Hva gir oss rett til å behandle personopplysninger om deg?
Vi behandler opplysninger om deg basert på ditt samtykke.

Prosjektet er godkjent av Norges idrettshøgskoles etiske komité, saksnr. 206 – 1410921 (19.10.2021).

På oppdrag fra Norges idrettshøgskole og institutt for idrettsmedisin har Norsk senter for forskningsdata AS vurdert at behandlingen av personopplysninger i dette prosjektet er i samsvar med personvernregelverket (02.11.2021).

Etter ny personopplysningslov har behandlingsansvarlig Norges idrettshøgskole og prosjektleder er professor Tron Krosshaug et selvstendig ansvar for å sikre at behandlingen av dine opplysninger har et lovlig grunnlag. Dette prosjektet har rettslig grunnlag i EUs personvernforordning artikkel 6 nr. 1a og artikkel 9 nr. 2a. Vi behandler opplysninger om deg basert på ditt samtykke.

Hvor kan jeg finne ut mer?
Hvis du har spørsmål til studien eller ønsker å vite mer om eller benytte deg av dine rettigheter, ta kontakt med:

- *Norges idrettshøgskole* ved masterstudent *Jonas J. S. Torkildsen* (jjs.torkildsen@gmail.com, tlf: +47 90 25 83 05) eller *veileder/prosjektleder* professor Tron Krosshaug (tron.krosshaug@nih.no, tlf: 456 60 046).
- Vårt personvernombud: Rolf Haavik (personvernombud@nih.no)

Hvis du har spørsmål knyttet til NSD sin vurdering av prosjektet, kan du ta kontakt med:

- NSD – Norsk senter for forskningsdata AS på epost (personverntjenester@nsd.no) eller på telefon: 55 58 21 17.

Med vennlig hilsen

Tron Krosshaug	*Jonas J. S. Torkildsen*
(Forsker/veileder)	(Masterstudent)

Samtykkeerklæring

Jeg har mottatt og forstått informasjon om prosjektet *En biomekanisk sammenligning av styrketrening med strikk og belastet vektstang* og har fått anledning til å stille spørsmål. Jeg samtykker til:

☐ å delta i prosjektet

☐ at mine testdata og personopplysninger behandles frem til projektslutt (01.06.2023) eller inntil 5 år i tråd med de retningslinjer som gjelder.

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Deltakers signatur Sted og dato

Deltakers navn med trykte bokstaver

Telefon

E-post

NORGES
IDRETTSHØGSKOLE

A.2 Norwegian Agency for Shared Services in Education and Research

Vurdering av behandling av personopplysninger

Referansenummer	**Vurderingstype**	**Dato**
615743	Standard	02.11.2021

Prosjekttittel
En biomekanisk sammenligning av styrketrening med strikk og belastet vektstang ([eng] A biomechanical comparison of strength training exercises performed with elastic resistance bands and weighted barbell)

Behandlingsansvarlig institusjon
Norges idrettshøgskole / Institutt for idrettsmedisinske fag

Prosjektansvarlig
Tron Krosshaug

Student
Jonas J. S. Torkildsen

Prosjektperiode
01.08.2021 - 01.06.2022

Kategorier personopplysninger
Alminnelige

Lovlig grunnlag
Samtykke (Personvernforordningen art. 6 nr. 1 bokstav a)

Behandlingen av personopplysningene er lovlig så fremt den gjennomføres som oppgitt i meldeskjemaet. Det lovlige grunnlaget gjelder til 01.06.2022.

Meldeskjema

Kommentar
Det er vår vurdering at behandlingen vil være i samsvar med personvernlovgivningen, så fremt den gjennomføres i tråd med det som er dokumentert i meldeskjemaet den 02.11.2021 med vedlegg, samt i meldingsdialogen mellom innmelder og NSD. Behandlingen kan starte.

TYPE OPPLYSNINGER OG VARIGHET
Prosjektet vil behandle alminnelige personopplysninger frem til 01.06.2022.

LOVLIG GRUNNLAG
Prosjektet vil innhente samtykke fra de registrerte til behandlingen av personopplysninger. Vår vurdering er at prosjektet legger opp til et samtykke i samsvar med kravene i art. 4 og 7, ved at det er en frivillig, spesifikk, informert og utvetydig bekreftelse som kan dokumenteres, og som den registrerte kan trekke tilbake.

Lovlig grunnlag for behandlingen vil dermed være den registrertes samtykke, jf. personvernforordningen art. 6 nr. 1 bokstav a.

PERSONVERNPRINSIPPER
NSD vurderer at den planlagte behandlingen av personopplysninger vil følge prinsippene i personvernforordningen:

- om lovlighet, rettferdighet og åpenhet (art. 5.1 a), ved at de registrerte får tilfredsstillende informasjon om og samtykker til behandlingen
- formålsbegrensning (art. 5.1 b), ved at personopplysninger samles inn for spesifikke, uttrykkelig angitte og berettigede formål, og ikke viderebehandles til nye uforenlige formål
- dataminimering (art. 5.1 c), ved at det kun behandles opplysninger som er adekvate, relevante og nødvendige for formålet med prosjektet

- lagringsbegrensning (art. 5.1 e), ved at personopplysningene ikke lagres lengre enn nødvendig for å oppfylle formålet.

DE REGISTRERTES RETTIGHETER

NSD vurderer at informasjonen om behandlingen som de registrerte vil motta oppfyller lovens krav til form og innhold, jf. art. 12.1 og art. 13.

Så lenge de registrerte kan identifiseres i datamaterialet vil de ha følgende rettigheter: innsyn (art. 15), retting (art. 16), sletting (art. 17), begrensning (art. 18) og dataportabilitet (art. 20).

Vi minner om at hvis en registrert tar kontakt om sine rettigheter, har behandlingsansvarlig institusjon plikt til å svare innen en måned.

FØLG DIN INSTITUSJONS RETNINGSLINJER
NSD legger til grunn at behandlingen oppfyller kravene i personvernforordningen om riktighet (art. 5.1 d), integritet og konfidensialitet (art. 5.1. f) og sikkerhet (art. 32).

For å forsikre dere om at kravene oppfylles, må prosjektansvarlig følge interne retningslinjer/rådføre dere med behandlingsansvarlig institusjon.

MELD VESENTLIGE ENDRINGER
Dersom det skjer vesentlige endringer i behandlingen av personopplysninger, kan det være nødvendig å melde dette til NSD ved å oppdatere meldeskjemaet. Før du melder inn en endring, oppfordrer vi deg til å lese om hvilken type endringer det er nødvendig å melde:
https://www.nsd.no/personverntjenester/fylle-ut-meldeskjema-for-personopplysninger/melde-endringer-i-meldeskjema
Du må vente på svar fra NSD før endringen gjennomføres.

OPPFØLGING AV PROSJEKTET
NSD vil følge opp planlagt avslutning for å avklare om behandlingen av personopplysningene er avsluttet.

Kontaktperson hos NSD: Markus Celiussen

Lykke til med prosjektet!

A.3 Ethical Committee of the Norwegian School of Sport Sciences

Tron Krosshaug
Institutt for idrettsmedisin

OSLO 19. oktober 2021

Søknad 206 – 1410921 - En biomekanisk sammenligning av styrketrening med strikk og belastet vektstang

Vi viser til søknad, prosjektbeskrivelse, informasjonsskriv og innsendt melding til NSD.

I henhold til retningslinjer for behandling av søknad til etisk komite for idrettsvitenskapelig forskning på mennesker, har komiteen i møte 14. oktober 2021 konkludert med følgende:

Vedtak

På bakgrunn av forelagte dokumentasjon finner komiteen at prosjektet er forsvarlig og at det kan gjennomføres innenfor rammene av anerkjente etiske forskningsetiske normer nedfelt i NIHs retningslinjer. Til vedtaket har komiteen lagt følgende forutsetning til grunn:

- *Vilkår fra NSD følges*

Komiteen forutsetter videre at prosjektet gjennomføres på en forsvarlig måte i tråd med de til enhver tid gjeldende tiltak ifbm Covid-19 pandemien.

Komiteen gjør oppmerksom på at vedtaket er avgrenset i tråd med fremlagte dokumentasjon. Dersom det gjøres vesentlige endringer i prosjektet som kan ha betydning for deltakernes helse og sikkerhet, skal dette legges fram for komiteen før eventuelle endringer kan iverksettes.

Med vennlig hilsen

Anne Marte Pensgaard

Professor Anne Marte Pensgaard
Leder, Etisk komite, Norges idrettshøgskole

A.4 Load Cell Data sheet

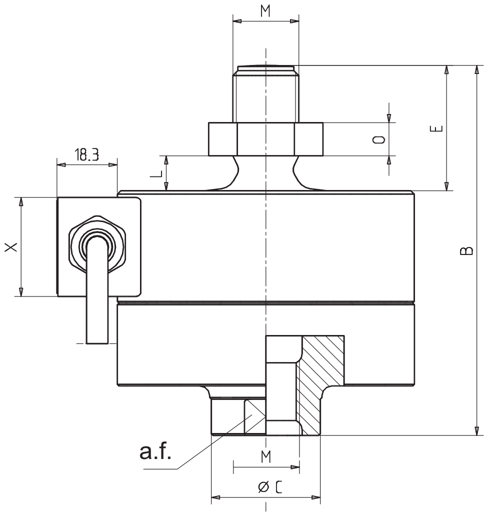
DATA SHEET

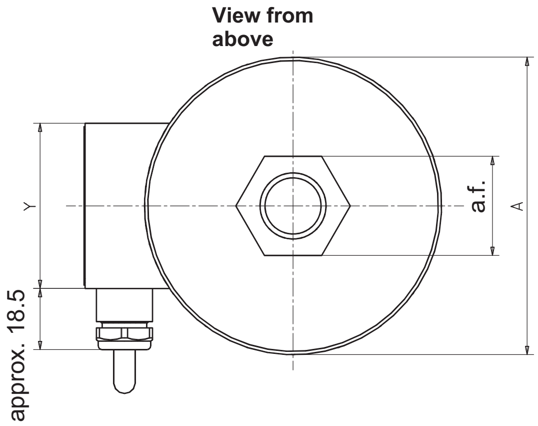
U2A...
Load cells

SPECIAL FEATURES

- Load cells made of stainless steel
- Max. capacities: 50 kg ... 20 t
- Suitable for scales according to OIML R60 up to 1000 d
- Six wire circuit
- Low profile
- For tensile loads
- Explosion proof version (optional)

DIMENSIONS





Dimensions in mm (1 mm= 0.03937 inches)

Max. capacity [t]	$A_{-0,2}$	B	C	E	L_{min}	M	O	a.f.	X	Y
0.05 ... 1	50	72	21	24	5[1]	M12	6	19	20	35
2	90	112	33	38	10.6	M20x1.5	10	30	30	50
5	100	141	40	47	13.2	M24x2	12	36	30	50
10	135	197	68	67	19	M39x2	19	60	30	50
20	155	232	82	85	24.2	M48x2	22	70	30	50

[1] With U2A/1 t: 7.4 mm

SPECIFICATIONS

Type			**U2A**		
Accuracy class			**0.2**	**0.1**	**D1**
Max. numbers of load cell verification interval	n_{LC}		-	-	1000
Max. capacity	E_{max}	kg t	50 -	100, 200, 500 10, 20	500 1, 2, 5
Minimum load cell verification interval	v_{min}	% from E_{max}	-	-	0.0286
Sensitivity	C_n	mV/V	2		
Tolerance on sensitivity With tensile loads		%	<±0.20		<±0.20
With compressive loads		%	<±1.50	<±0.50	<±0.50
Temperature effect on sensitivity[1] In nominal temperature range In service temperature range	TK_C	%/10 K %/10 K	<±0.05 <±0.10		<±0.05 <±0.10
Temperature effect on zero balance In nominal temperature range In operating temperature range	TK_0	%/10 K %/10 K	<±0.05 <±0.10		<±0.04 <±0.10
Hysteresis error[1]	d_{hy}	%	<±0.15		<±0.07
Non-linearity[1]	d_{lin}		<±0.20	<±0.10	<±0.05
Creep over 30 min.	d_{cr}		<±0.06		<±0.05
Input resistance	R_{LC}	Ω	340 ... 550		
Output resistance	R_0		356 ±0.2 (for cable lengths less than 20 m) 359 ±0.2 (for cable length 20 m)		
Insulation resistance	R_{iso}	GΩ	>5		
Reference excitation voltage	U_{ref}	V	5		
Nominal range of excitation voltage[4]	B_u		0.5 ... 10	0.5 ... 12	
Max. permissible excitation voltage[4]			12	18	
Nominal temperature range[4]	B_T	°C [°F]	-10 ... +40 [14 ... 104]		
Operating temperature range[4]	B_{tu}		-30 ... +85 (-30 ... +120) [-22 ... 185] [-22 ... 248]		
Storage temperature range	B_{tl}		-50 ... +85 [-58 ... 185]		
Safe load limit	E_L	% from E_{max}	130	150	
Breaking load	E_d		300		
Relative stat. lateral load limit	E_{lq}		25		
Permissible dynamic load (peak to peak according to DIN 50100)	F_{srel}		100	160	
Degree of protection (IP) to EN 60529 (IEC 529)			IP 67		
Material: Measuring body Cable gland Cable sheath			Stainless steel[3] Nickel plated brass, Silicone Thermoplast. elastomere		

[1] The data for Non-linearity, hysteresis error and temperature effect on sensitivity are typical values. The sum of these data meets the requirements according to OIML R60

[2] Optionally available with extended operating temperature range

[3] According to EN 10088-1

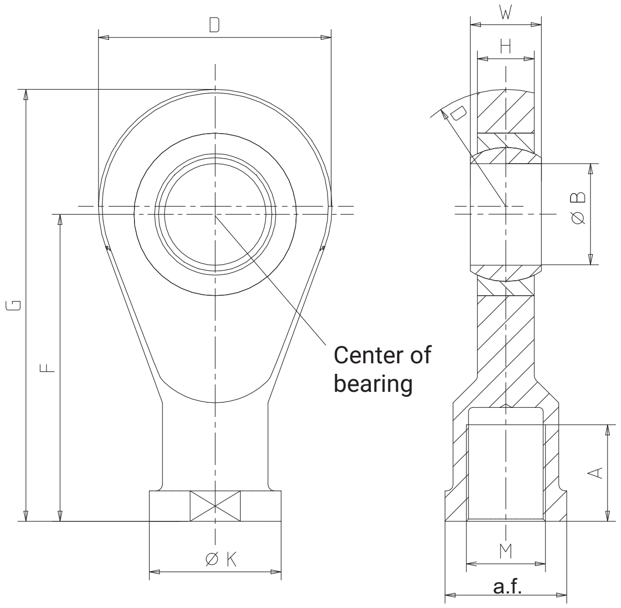
[4] Not for explosion protection, see Safety instructions

MECHANICAL VALUES

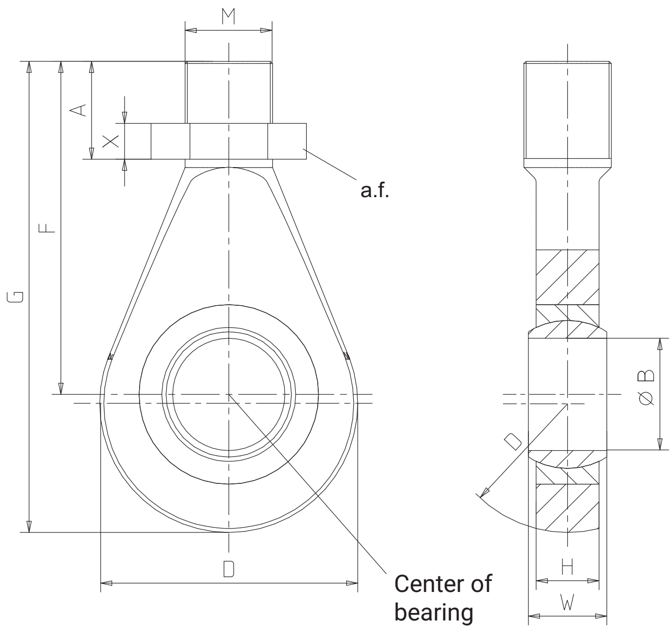
Max. capacity [t]	Deflection at max. capacity (s_{nom}), approx. [mm]	Weight (G), approx. [kg]	Cable length [m]
0.05	< 0.1	0.8	3
0.1	< 0.1	0.8	3
0.2	< 0.1	0.8	3
0.5	< 0.1	0.8	3
1	< 0.1	0.8	3
2	< 0.07	2.9	6
5	< 0.07	4.3	6
10	< 0.09	10.7	12
20	< 0.09	15.9	12

MOUNTING ACCESSORIES (IN MM; 1 MM = 0.03937 INCHES)

Knuckle eye ZGOW



Knuckle eye ZGUW



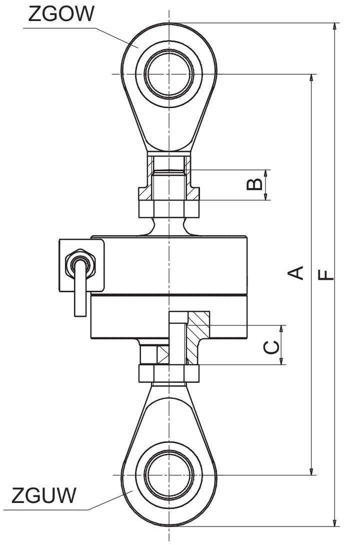
Max. capacity [t]	Knuckle eye ZGOW	Weight [kg]	A	ØB	D	F	G	H	ØK	M	a.f.	W
0.05 … 1	U2A/1T/ZGOW	0.2	22	12^{H7}	32	50	66	12	22	M12	19	16
2	U2A/2T/ZGOW	0.5	33	20^{H7}	50	77	102	18	34	M20x1.5	32	25
5	U2A/5T/ZGOW	0.8	42	25^{H7}	60	94	124	22	42	M24x2	36	31
10	U2A/10T/ZGOW	3.2	50	$50\,^{+0.002}_{-0.014}$	115	151	212,5	28	65	M39x2	60	35
20	U2A/20T/ZGOW	4.8	60	$60\,^{+0,003}_{-0,018}$	126	167	235	36	82	M48x2	70	44

Max. capacity [t]	Knuckle eye ZGUW	Weight [kg]	A	ØB	D	F	G	H	M	a.f.	W	X
0.05 … 1	U2A/1T/ZGUW	0.1	33	12^{H7}	32	54	70	12	M12	19	16	7
2	U2A/2T/ZGUW	0.2	47	20^{H7}	50	78	103	18	M20x1,5	32	25	9
5	U2A/5T/ZGUW	0.4	57	25^{H7}	60	94	124	22	M24x2	36	31	10
10	U2A/10T/ZGUW	1.1	65.5	$50\,^{+0.002}_{-0.014}$	115	148.5	210	28	M39x2	60	35	16
20	U2A/20T/ZGUW	3.2	80	$60\,^{+0.003}_{-0.018}$	126	168	236	36	M48x2	70	44	18

Load cell U2A with monted knuckle eyes ZGOW, ZGUW

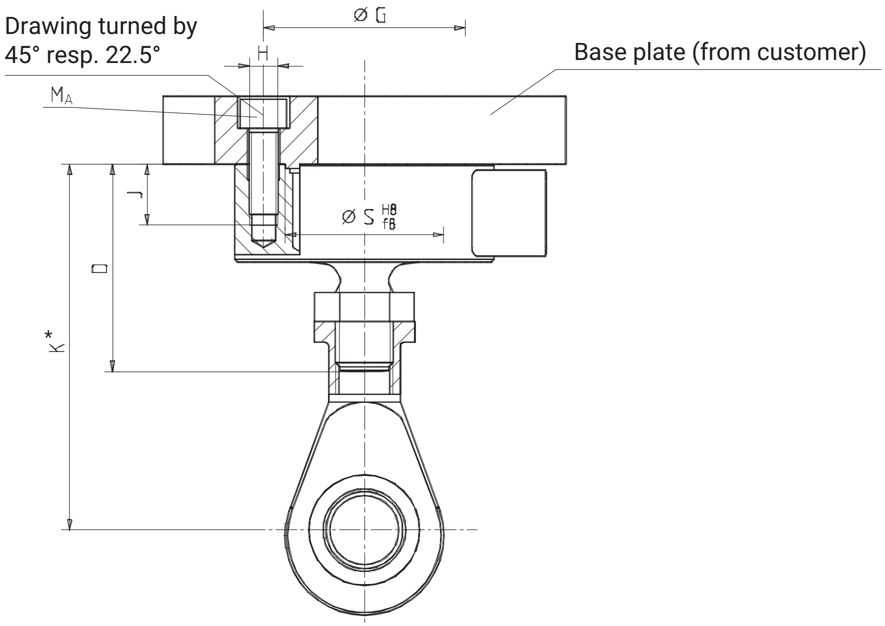
Max. capacity [t]	A_{min}	A_{max}	F_{min}	F_{max}	Min. depth for screwing		Tightening torque M_A [N·m]
					B	C	
0.05 … 0.5	139	156	171	188	9.6	9.6	60 1)
1	141	156	173	188	9.6	9.6	60
2	212	234	262	284	16	16	300
5	260	288	320	348	19.2	19.2	500
10	418	436	541	559	27	31.2	2500
20	466	489	602	625	36.6	38.4	4500

1) Do not exceed this value and handle the load cell with care during fastening to avoid damage to the thin measuring diaphragm. Hold the lock nut in place.



MOUNTING ACCESSORIES, CONTINUED (IN MM; 1 MM = 0.03937 INCHES)

U2A, with ZGOW, without adaptor

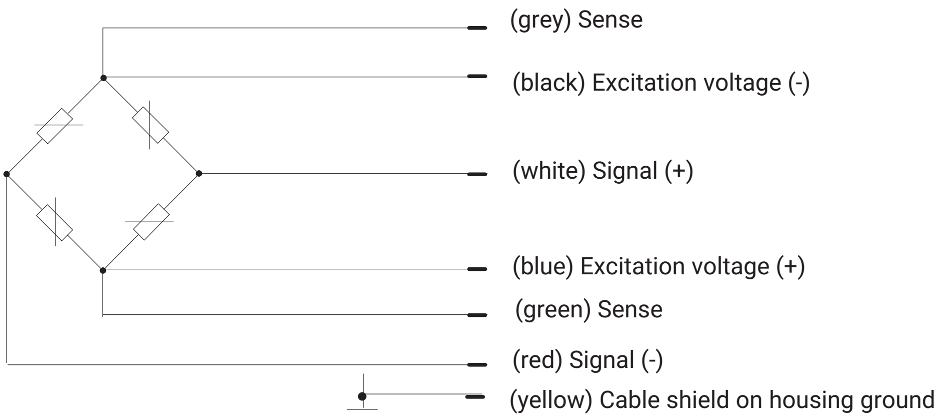


* Dimension, with preferred screwing depth

Max. capacity [t]	D	ØG	H	J	K	ØS	M_A 1) [N·m]
0.05 … 0.5	47	42	4xM5	13	84 … 86.4	34	5
1	47	42	4xM5	13	86.4	34	5
2	72	70	4xM10	20,5	131.6	55	35
5	86	78	4xM12	19	158.2	61	60
10	122	105	8xM12	16	244	79	60
20	142	125	8xM16	26	270.2	97	150

1) Recommended values for a dry thread, using a torque wrench

WIRING CODE



PRODUCT NUMBERS

Type	U2A		
Accuracy class	**0.2**	**0.1**	**D1**
Maximum capacity	**Ordering number**		
50 kg	1-U2A/50KG	-	-
100 kg	-	1-U2A/100KG	-
200 kg	-	1-U2A/200KG	-
500 kg	-	-	1-U2AD1/500KG
1 t	-	-	1-U2AD1/1T
2 t	-	-	1-U2AD1/2T
5 t	-	-	1-U2AD1/5T
10 t	-	1-U2A/10T	-
20 t	-	1-U2A/20T	-

ACCESSORIES

Maximum capacity	Ordering number	
	Upper knuckle eye	**Lower knuckle eye**
50 kg	1-U2A/1T/ZGOW	1-U2A/1T/ZGUW
100 kg		
200 kg		
500 kg		
1 t		
2 t	1-U2A/2T/ZGOW	1-U2A/2T/ZGUW
5 t	1-U2A/5T/ZGOW	1-U2A/5T/ZGUW
10 t	1-U2A/10T/ZGOW	1-U2A/10T/ZGUW
20 t	1-U2A/20T/ZGOW	1-U2A/20T/ZGUW

ORDERING OPTIONS

Ordering number
K-U2A_

1	Code	Option 1: Mechanical design
	S	Standard

2	Code	Option 2: Accuracy class
	S	Standard

3	Code	Option 3: Maximum capacity
	50	50 kg
	100	100 kg
	200	200 kg
	500	500 kg
	1	1 t
	2	2 t
	5	5 t
	10	10 t
	20	20 t

4	Code	Option 4: Explosion protection
	N	No explosion protection
	AI1/21	ATEX+IECEx+FM Zone 1/21, intrinsically safe; ATEX/IECEx: II 2G Ex ia IIC T6/T4 Gb + II 2D Ex ia IIIC T125°C Db; FM(US/CA): Class I Zone 1 AEx/Ex ia IIC T4 Gb + Zone 21 AEx/Ex ia IIIC T125°C Db FM(US): Class I, II, III Division 1, Groups A, B, C, D, E, F, G T4 [only with option 6 =N]
	AI2/21	ATEX+IECEx Zone 2/21, not intrinsically safe; ATEX/IECEx: II 3G Ex ec IIC T6/T4 Gc + II 2D Ex tb IIIC T125°C Db [only with option 6=N]

5	Code	Option 5: Cable length
	S3	3 m (standard) [only with option 3 = 50 / 100 / 200 / 500 / 1]
	S6	6 m (standard) [only with option 3 = 2 / 5]
	S12	12 m (standard) [only with option 3 = 10 / 20]
	6	6 m [only with option 3 = 50 / 100 / 200 / 500 / 1]
	12	12 m [only with option 3 = 50 / 100 / 200 / 500 / 1 / 2 / 5]
	20	20 m

6	Code	Option 6: Operating temperature range
	N	Standard
	120	Operating temperature up to 120 °C [only with option 4 = N]

K-U2A_ - ☐ - ☐ - ☐☐☐ - ☐☐☐☐☐☐ - ☐☐☐ - ☐☐☐
1 2 3 4 5 6

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