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Elastic band resistance for shoulder rehabilitation: Clinical applications and practical exercises

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ABSTRACT

With a paradigm shift towards objectivity, measurements and treatments that prioritize numerical values have become more important to the rehabilitative process for medical practitioners. This objectivity is important for assessing musculoskeletal status as well as informing exercise prescription, the shoulder being the focus of this paper. Previously many physiotherapeutic tests and training interventions have been performed with little thought given to load quantification. For example, elastic band resistance is a commonly employed method of applying load to injured tissue, however, the overload provided by this type of resistance difficult to quantify. The implementation of a novel strain gauge device in-line with elastic-based resistance allows for the ability to measure and determine musculoskeletal loads, enabling better monitoring and measurement of loading parameters for the optimization of treatment and client outcomes. In this Masterclass, we discuss the clinical applications of strain gauge implementation in elastic based resistance training for the physical therapist with a focus on practical exercises for shoulder strengthening.

1. Introduction

The American Physical Therapy Association, published a vision statement, titled: “Vision 2020”, which served as a “call to arms” for the maturation of the physiotherapeutic profession, specifically citing evidence-based medicine as a priority (Sullivan et al., 2011). This was fundamentally centred on reinforcing the objectivity of the examination and intervention processes by implementing modern technologies in the interest of justifying reimbursement in the wake of changing healthcare policies. It has created an initiative to provide physical medicine professionals, such as physiotherapists, with tools that are user-friendly, help synthesize and interpret data, yet are also cost-effective. This “call to arms” and integration of strain gauge technology in everyday practice was the motivation for this article.

This “call to arms” for increased objectivity hinges on the concept of mechanotransduction (Khan and Scott, 2009). Mechanotransduction refers to the process of converting mechanical load to a cellular response and can be accomplished using many different loading methods and parameters, some of which will be addressed in subsequent text (Khan and Scott, 2009). Furthermore, mechanotransduction can be influenced by typical variables associated with resistance training such as load/force, velocity, and tissue length (Khan and Scott, 2009). Resistance training is typically classified into three different resistance categories: 1) constant or free-weight resistance (FWR); 2) accommodating resistance; and, 3) variable resistance (Frost et al., 2010).

Constant resistance refers to dynamic training in which resistive forces are dependent on mass and gravity and is also known as FWR. This type of resistance training is the most common, the use of dumbbell and barbell exercises, exemplars of FWR. The aim of accommodating resistance exercises is to provide maximal tension throughout the entire range of motion of a movement (Frost et al., 2010). Hydraulic and isokinetic dynamometry are examples of technologies that provide accommodating resistance. Variable resistance alters the applied resistance of contracting muscles throughout the range of motion or changes in joint angle (McMaster et al., 2009). Examples of variable resistance are elastic band resistance (EBR), chains, and cam and lever systems.

Of interest to the authors is the application of EBR, particularly in a physiotherapeutic framework. As such the authors will: 1) discuss the benefits of EBR in a generic context; 2) address limitations around the application of EBR in terms of load quantification; 3) explore the use of EBR in a physiotherapeutic context with particular reference to the

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shoulder; 4) provide exercise suggestions how EBR loading could be quantified; and, 5) provide exercise suggestions for rehabilitation of the shoulder. The aim of this masterclass is to provide physiotherapists with an example of a 'rehabilitation by numbers' approach to the shoulder using EBR, which can provide a framework for other injury sites. In adopting such an approach the 'call to arms' and increased objectivity can be addressed.

2. Benefits of EBR

The many benefits of EBR training are articulated below.

- **Accessibility and affordability**: EBR is a cost-effective and accessible type of resistance training, with elastic-based resistance being sold by a multitude of suppliers. EBR is also comparatively inexpensive compared to other resistance types, especially FWR.
- **Utility:** As elastic bands have minimal mass, they are very safe and easily portable. Additionally, they can be affixed to an object/limb, providing a variety of training options.
- **Mechanical advantage:** There are inertial/mechanical disadvantages associated with constant or FWR. For example, there are exercises where the beginning of the movement (long muscle length – LML) is most difficult and end ROM is less challenging (short muscle length - SML) e.g. squat and bench press (McMaster et al., 2009). In these ascending strength curve exercises, more can be lifted in the last quarter of a movement, however, the lifter is limited by muscle force capability in the first quarter of the concentric contraction. EBR overcomes this limitation of FWR by progressively increasing resistance throughout the concentric ROM i.e. EBR is less at LML or where the muscle is weak, and more at SML where the muscle is strong (see Fig. 1). EBR in short allows the force-ROM to be modified for an exercise, and likely explains many of the performance benefits reported in the research.
- **Eccentric:** As the magnitude of EBR is primarily a function of its elastic properties and not the force of gravity, opportunity for much greater eccentric velocities and accelerations exist (McMaster et al., 2009). This is because the band is extended at the end of the concentric and start of the eccentric phases in movements such as the squat and bench press. When the lifter begins their descent, the increased EBR pulls the bar downward with additional force, which may lead to greater velocities in the early parts of the eccentric phase, if not resisted.
- **Multiplanar – Force Vector Diversification:** Typically FWR provides a vertical gravitational overload, which means that other force vectors such as anterior-posterior or medio-lateral can remain unchallenged. Simple 45° turns with an exercise can challenge all those planes of motion as shown in Fig. 2. With EBR you can anchor the band at one or different heights, and simply move a limb or the body in relation to the band, to provide greater force vector diversification to the same movement.
- **Sport Specificity:** EBR provides varying resistance to match the changes in joint leverage (the joint's ability to produce force during a movement) during both concentric and eccentric contractions (Foran, 1985). It also allows for ballistic training and acceleration through greater ranges of movement (Cronin et al., 2003), which in turn enables greater power outputs (Anderson et al., 2008). It is a form of resistance training that is thought more sport specific.

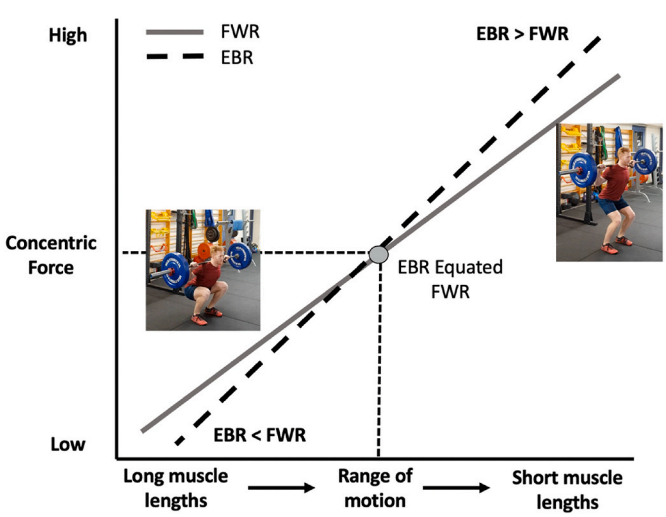


Fig. 1. Ascending strength curve representing changes in force production with muscle length when a percentage of FWR is replaced with EBR.

3. Load quantification

Although EBR has many benefits and is used extensively for rehabilitation purposes, as a form of resistance training, it has a major limitation in that it is difficult to quantify the load associated with each repetition of a movement. Additionally, in certain contexts (e.g., after rotator cuff repair surgery) force applied across the repair needs to be limited for at least 3 months after surgery (Ellenbecker et al., 2020). If the individual cannot quantify how much force they are applying, they may exceed safe limits and compromise the biological healing of the repair site. Firstly, being a form of variable resistance, force output changes as a function of displacement. Secondly, the overload depends on the size and stiffness of the EBR. Triana and Fajardo (2012) described how elastic bands undergo deformations (elongation) when force is exerted yet can recover to their natural state when force is removed. However, when force exceeds the 'elastic limit', elastic bands are unable to recover to their original shape. Subsequently, elastic bands stay somewhat deformed, resulting in changes in the elastic resistance provided. Thus, one of the major limitations to quantifying EBR is that the elastic bands lose elasticity over time and degenerate with use, making quantifying load problematic.

Given these limitations, it is difficult to accurately assign a 'label' that can be used to represent the resistance of an elastic band. A potential solution to this quandary is the integration of strain gauge technology into EBR training. This integration can occur in a number of areas that might add value to physiotherapeutic practice as discussed herewith.

3.1. *Strain gauge*

Strain gauges detect deformation that produces a voltage change within the device, which is converted to a digital reading of load/weight/force. The strain gauge shown in the picture can detect both tensile (pulling) and compressive (pushing) forces depending on the attachments being used as shown in Fig. 3. The strain gauge shown (Hawkin TruStrength, Portland, ME) can measure forces up to 1000 kg or 10,000 N, which is required when measuring movements like isometric mid-thigh pulls and squats; however, smaller strain gauges could be used depending on the needs of the user. This model also collects information (sampling rate) at 1200 Hz, which is thought important for accuracy when measuring time series data such as rate of force development (RFD) or impulse at 200 ms (Dos'Santos et al., 2019). The strain gauge is a highly portable and reliable device, that has high utility as shown in Fig. 4 where it is attached to a rack to measure the EBR during any exercise the practitioner may want to prescribe.

3.2. *Strain gauge integration for quantifying EBR*

In the first instance, it is necessary to understand the magnitude of resistance the EBs provide and considering that elasticity changes over time, frequent calibration of the elastic bands is recommended to ensure that the practitioner understands the workload that the patient is

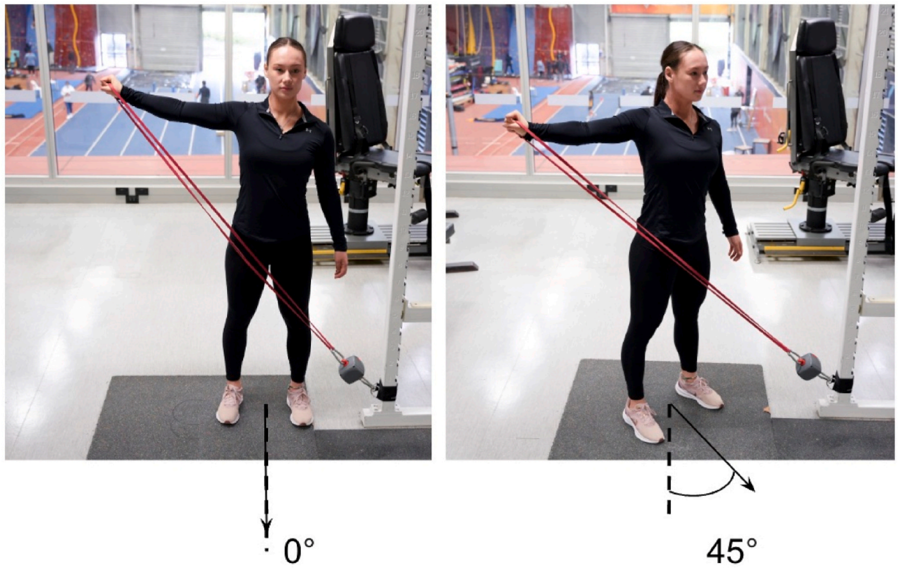


Fig. 2. Changes in angle demonstrate diversification in force vectors of activated muscles.

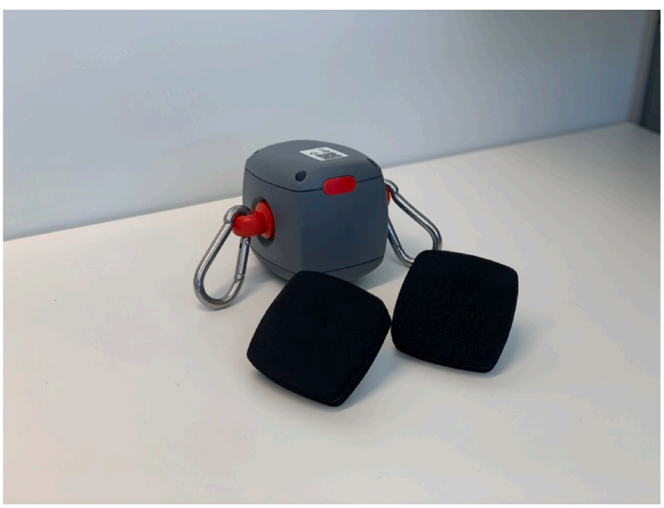


Fig. 3. Strain gauge, including carabiners and push plates.

Fig. 4. Strain gauge affixed to a rack and the EBR affixed to the strain gauge.

experiencing. For this to occur, you need to determine the force-length/deformation/displacement profile for each band you use. This can be performed relatively easily, by attaching the strain gauge to a fixed object and the EBR to the strain gauge as shown in Fig. 5. From resting length extend the EBR in 10 cm increments, stopping at each increment for 5 s and recording the resistance. Thereafter enter the force-length data into a spreadsheet program such as excel (Microsoft, Washington, United States of America) and plot a graph for the data as shown in Fig. 6.

This graph provides baseline data for future comparisons to determine if the extensibility and/or elasticity of the elastic-based resistance has changed. The force for any displacement can be extrapolated from the graph by adding a trendline through the data to produce a regression equation for the EBR. The trendline and equation are shown on the graph. In this case, adding any displacement into the equation enables you to calculate an estimated EBR with 97% confidence i.e. R^2 value (see Fig. 6).

3.3. Strain gauge integration for assessing strength qualities

EBR is used in practice to improve the strength or force capability of muscle. A simple diagram of how to progressively train these strength/force qualities can be observed in Fig. 7. Strength/force endurance can be defined as the ability to produce force without fatiguing. It provides the base of the training pyramid and exercise prescription is typically high-volume and low-intensity muscular contractions. Maximal strength can be defined as the ability to exert peak force/torque throughout a muscle contraction against an external resistance (Thompson et al., 2020). With this type of training, there is an increase in intensity and a decrease in volume. Finally, explosive strength describes one's ability to produce force in very short time periods, otherwise known as the rate of force development (RFD). This strength quality is at the top of the pyramid as the contractions are high-intensity in nature. As shown in Fig. 7, resistance training during rehabilitation should follow this progression from low-intensity higher volume training to high-intensity, lower-volume type training, with greater technical demands. EBR training can be used within such a model to develop these strength qualities, as can other forms of resistance.

Implicit in the systematic progression of these strength qualities is the ability to assess and monitor changes in their status. Strain gauge technology can not only provide a means of quantifying EBR overload, but also provide the practitioner with data about changes in these strength qualities (enhanced diagnostics).

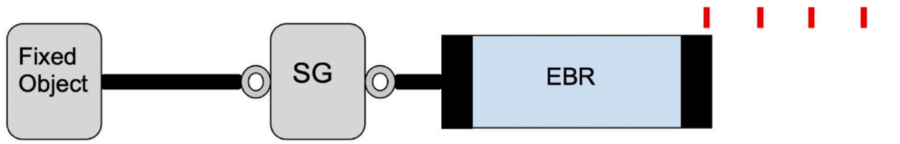


Fig. 5. Strain gauge attached to a fixed object and a rubber plate.

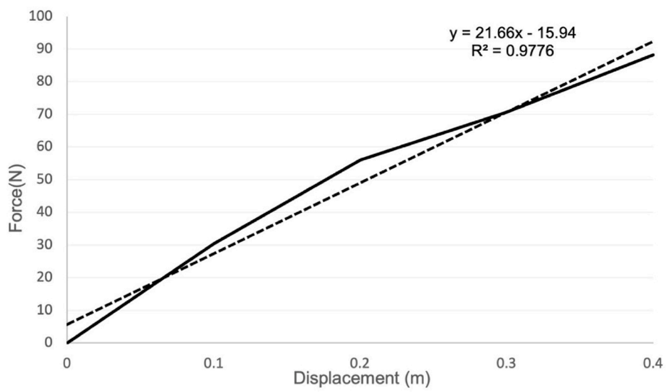


Fig. 6. Force-displacement/length curve for a '20lb' band and associated trendline (dotted line).

3.3.1. *Strain gauge assessment of strength endurance*

The various strength qualities have an equivalent force measure that can be determined from the force-time data provided by the strain gauge software. If working with injured individuals, strength qualities for both the injured and non-injured limbs can be measured to calculate the degree of asymmetry or strength deficits between limbs.

The strain gauge can be used in multiple ways to monitor changes in the strength endurance of your clients. Firstly, the change in initial force production can be measured and compared to final force output via a fatigue index (FI = Final/Initial x 100) for static/isometric and or dynamic contractions (See Fig. 8). It should be considered that strength endurance is measured over multiple repetitions (e.g. > 20) or over longer time periods (e.g. 20–30 s) when applying this method.

A second method to assess and monitor changes in strength endurance is to compare the impulse between limbs and testing occasions. Impulse is a measure of the magnitude of the force applied and the time over which it acts and is calculated as the area under the force-time graph (see Fig. 9). Increases in impulse over the same time period indicate that the client/athlete is applying a greater overall force i.e., force endurance. You need to ensure that your strain gauge device can measure impulse for this option. Another method of assessing changes in strength endurance is to calculate the mean force throughout a bout of exercise. The strain gauge collects data at a sampling rate of 1200 Hz, which means force output is recorded 1200 times per second. If force output is collected for 30 s then there are 36,000 force readings which are averaged to give the mean or average force. An increase in mean force over 30 s would indicate greater strength endurance and is another measure that can be compared recurringly throughout rehabilitation.

The instructions provided to the athlete for assessing strength endurance will be different according to whether the contractions are static or dynamic (i.e., time period vs repetitions) but an example of this would be, "produce as much force as you can for as long as you can or as

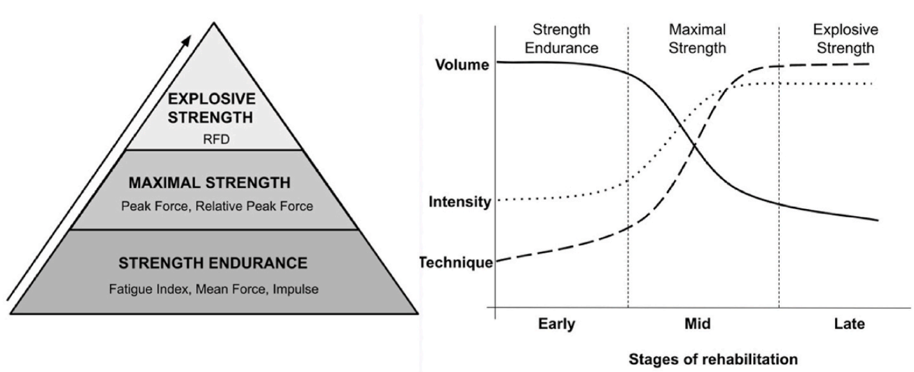


Fig. 7. Model for progressing in endurance strength training qualities during early to late stages of rehabilitation.

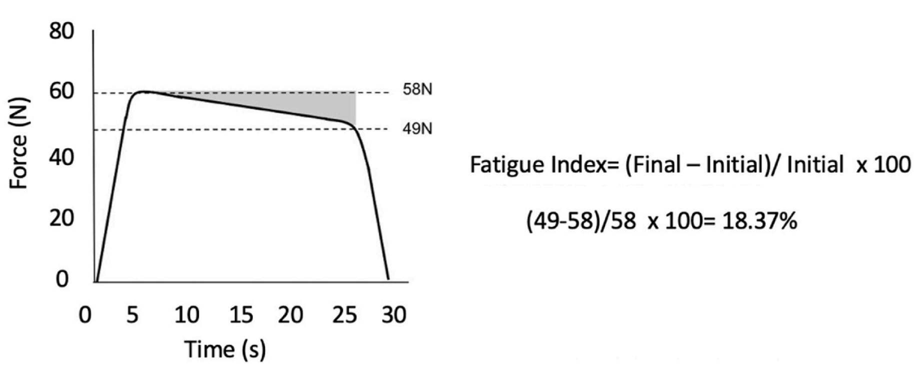


Fig. 8. Assessing strength endurance using the strain gauge during an isometric contraction to calculate the fatigue index.

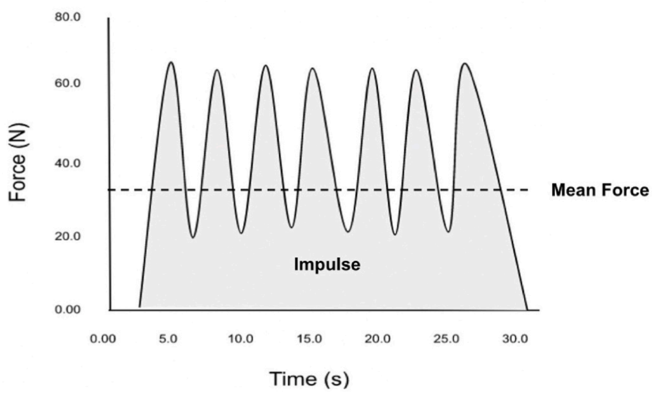


Fig. 9. Assessing strength endurance by using the strain gauge to calculate impulse and mean force.

many reps as you can".

3.3.2. *Strain gauge assessment of maximal strength (peak force)*

The strain gauge can be used to assess and monitor improvements in maximal strength by comparing peak force values between interventions. The peak force can be measured during an isometric or dynamic contraction (Fig. 10). It needs to be ensured that the individual uses a ramped (steadily increasing) contraction over 3–6 s to attain this measurement.

An additional measure to monitor improvements in strength is to compare relative maximal force measures. This can be achieved by dividing peak force values by body mass (N/kg). This allows the comparison of maximal strength between individuals and accounts for any changes in body mass between testing occasions. Instructions for assessing maximum strength could be "produce the greatest amount of force possible" or "push or pull as hard as you can."

3.3.3. *Strain gauge assessment of explosive strength (RFD)*

The strain gauge can be used to assess explosive strength via the calculation of RFD. There are many ways to calculate RFD, from taking the time from the onset of the contraction to the peak force, to finding the peak RFD over the entire force-time signal.

For explosive contractions, the RFD is calculated as RFD = $\Delta F/\Delta t$. It can be observed on Fig. 11 where during dynamic contraction RFD is calculated from the slope of the force-time curve (Drake et al., 2019; Tillin et al., 2013). Contraction onset can be described as "the last instantaneous point where RFD crosses 0", whereas peak force refers to the greatest value on the force-time curve. ΔF can be calculated by subtracting contraction onset force (N) from peak force (N). Similarly, Δt can be calculated by subtracting the time of contraction onset from the time of peak force production. Therefore $\Delta F/\Delta t$ gives us an average RFD between contraction onset and peak force. The less time maximal force can be produced within or the steeper the slope of the curves, indicates a higher RFD, as shown in Fig. 11. The instructions for assessing explosive strength will be to focus on applying force either through "pulling or pushing as fast and as hard as you can" to generate maximum force in the shortest time possible.

3.4. *Strain gauge integration for exercise prescription and recovery*

The general adaptation syndrome (GAS) describes how the body requires stress to allow for adaptive responses (Selye, 1950). As can be seen in Fig. 12, when the muscles are overloaded such as with EBR, they experience fatigue and a loss in force capability. When the exercise stimulus ceases, the muscles begin the recovery process and can recover where they are stronger than the previous baseline status i.e. supercompensation. If another EBR exercise bout is not prescribed in a timely fashion, then strength/force capability will revert to baseline or homeostasis. Alternatively, if EBR is prescribed during the recovery compensation phase when the client/athlete hasn't adequately recovered, then there is a possibility of cumulative fatigue, compromised adaptation and potential overtraining and injury.

The GAS highlights the importance of knowing when and how an applied workload has appreciable effects on adaptation. Integrating strain gauge technology throughout this process can lead to better adaptation. For example, understanding the mechanical stress (the force-length relationship) that is prescribed during EBR training will help understand the magnitude of the overload and fatigue. Also, it provides baseline data to progress on ensuing occasions. During the compensation and supercompensation phases the strain gauge can be used to monitor fatigue and recovery status i.e. optimal time for the next training stimulus and therefore could assist in more effective shoulder rehabilitation.

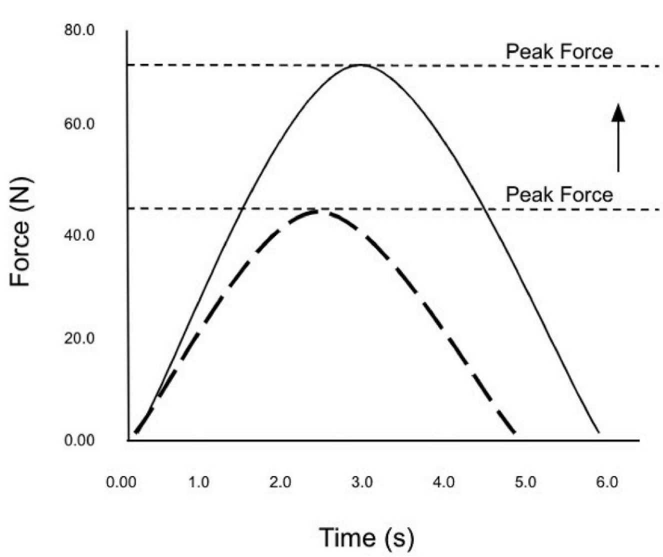


Fig. 10. Assessing maximum strength by using the strain gauge to calculate peak force.

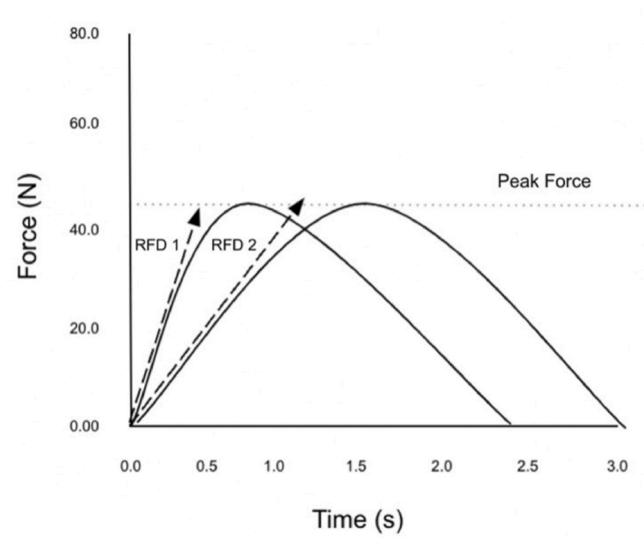


Fig. 11. Assessing explosive strength using the strain gauge to quantify change in RFD.

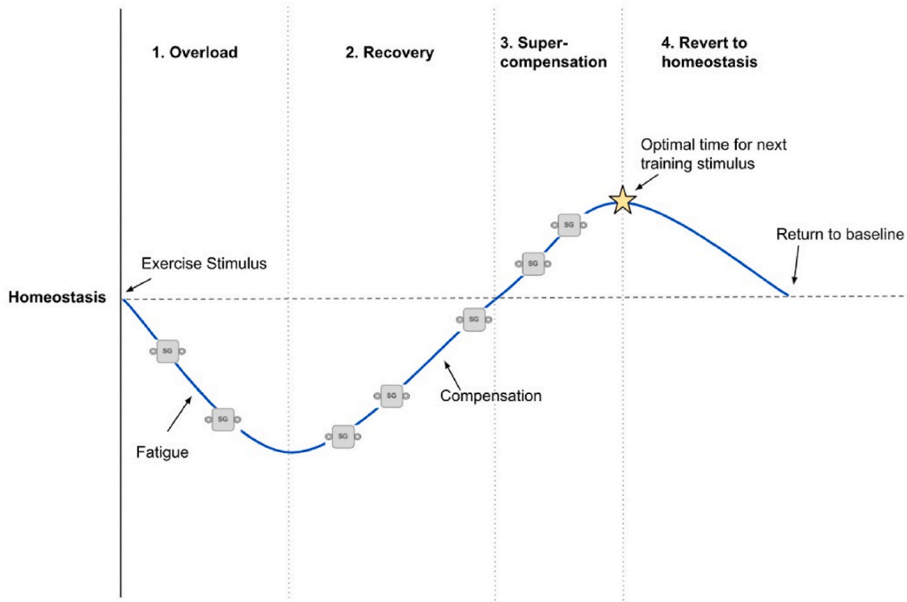


Fig. 12. Diagram of the general adaptation syndrome and where the strain gauge can be integrated.

4. EBR for rehabilitation

EBR is typically combined with FWR in the non-injured, as the elastic resistive force is typically not enough to provide the overload needed for some forms of adaptation. EBR as a sole form of resistance training is used primarily in a physiotherapeutic context, as can be evidenced with the incorporation of EBR in many rehabilitation studies of the upper and lower body. For example, EBR has been used for the treatment of total knee replacement (Liao et al., 2020), total hip replacement (Mikkelsen et al., 2012) and rotator cuff injury (Ellenbecker et al., 2020). Of particular interest to the authors of this paper is the application of EBR in the rehabilitation of shoulder injuries.

Shoulder pathologies including bursitis, rotator cuff tendinopathy and tendon tears are a common cause of shoulder pain and disability especially in older age groups (Van der Windt et al., 1995). Other common shoulder injuries include acromioclavicular joint sprains, glenohumeral joint dislocations, contusions and fractures (Bonza et al., 2009). Rehabilitation of the rotator cuff and shoulder girdle muscle groups are an important component of rehabilitation for both traumatic and non-traumatic shoulder conditions. Substantial muscle deconditioning in both injured and non-injured muscle groups also occurs following shoulder surgery, thus requiring careful attention to exercise prescription to restore muscle strength and function through a wide range of movements. Therefore, exercises in which EBR can be incorporated for the rehabilitation of common shoulder injuries will be summarised in Table 1.

The primary purpose of this review of the literature (Table 1) was to determine the most commonly prescribed EBR exercises and loading parameters for effective shoulder injury rehabilitation. The most commonly prescribed exercise was external rotation of the shoulder, occurring in seven out of ten studies. As reported by Hintermeister et al. (1998) the external rotation exercise was found to have the greatest EMG activity in the infraspinatus muscle; one of four rotator cuff muscles. Similarly, internal shoulder rotation and abduction were commonly prescribed, contributing significantly to strengthening the supraspinatus and subscapularis. Therefore, a combination of these exercises seems common as they are effective in strengthening multiple muscles of the rotator cuff; an important group of muscles required for restoring shoulder function. Other commonly prescribed exercises consisted of; scapula retraction, scapula protraction and shoulder extension. The following exercises and rehabilitation programmes were beneficial in improving strength, relief of pain and function in post-shoulder injury patients.

The loading parameters were unclear in some of the included papers in terms of quantifying EBR training. Many studies included the 'TheraBand' in their intervention, yet some papers failed to state the applied force that the bands provided or the colour (strength of band) that the patients were using. The force provided by different coloured TheraBands can be viewed online (https://www.performancehealth.com/theraband-professional-resistance-band-loops). However, it needs to be noted that these values are for new bands and with use, these bands will lose their resistive capability. Two papers did not state the manufacturer or resistance of the elastic bands that were used. There was a common trend in that many papers prescribed increasing EBR throughout the course of intervention. Progressions in resistance were often up to each individual, e.g. Heron et al. (2017) instructed patients to advance to a stronger band when they were able to complete three sets of ten repetitions. However, no information was provided about how they standardised resistance for each exercise session during the study.

The reviewed intervention programmes consisted of four to twelve weeks and involved around 2–3 sets of 10–20 repetitions of each exercise, especially within the early stages of rehabilitation. However, Gaballah et al. (2017) and Sugimoto and Blanpied (2006) undertook progressive designs in prescribing the number of repetitions. For example, the programme used by Gaballah et al. (2017) consisted of three stages. Over time the patients increased the EBR whilst decreasing the total number of repetitions per exercise. Three studies did not state the number of sets and repetitions involved for each exercise. Rather, Senbursa et al. (2007) only stated the duration of which patients were exercising per session (10–15 min). This provided an insight into the nature of these protocols, yet provides uncertainty of other factors involved such as applied load, intensity, etc. In general, these papers have provided very limited information on the nature of rest periods between sets. Only two papers (Lee and Yoo, 2013; Sugimoto and Blanpied, 2006) specified the duration of rest in their programmes, consisting of 30–60 s periods.

There was great variability in the frequency of training sessions, ranging from three times per week to every day. As stated by Mulligan and colleagues (2016) and Sharma et al. (2021), the time of intervention is seen to have a significant effect on the percentage of improvement scores, including relative increases in strength. Therefore, associated

Table 1
Literature review of EBR for shoulder injury rehabilitation.

Author Date	Purpose Outcome	Groups Subjects Gender Age Training status	Design Duration Sessions Intensity Quantified?	EBR Equipment Exercises
Ellenbecker et al. (2020)	Understanding perception of effort during rotator cuff and scapula rehabilitation exercises in patients with shoulder injury. Commonly prescribed elastic resistance exercises for rehabilitation show light-moderate ratings of perceived exertion; which is ideal for post-shoulder surgery	Single group study n = 66 Age = 53.3 ± 12.8 Gender not specified All participants had rotator cuff repairs, shoulder arthroplasty or labral repair Novice	Descriptive Cross-sectional Cohort 6 weeks *Limited information on programme design Elastic resistance is quantified in kg	Theraband 1. Side-lying external rotation w/cuff weight 2. External rotation oscillation w/band 3. External rotation and retraction w/band 4. Prone extension w/cuff weight 5. Prone horizontal abduction w/cuff weight 6. External rotation w/band 7. Extension w/band
Gaballah et al. (2017)	Design a physical rehabilitation program using the elastic band and resistive exercise to improve joint strength and range of motion in individuals diagnosed with a first-time shoulder dislocation. The physical rehabilitation program proposed in this study was effective at improving strength and range of motion in the injured shoulder	Single group study n = 12 Age: 18.6 ± 1.32 All Male Physically active, competitive athletes, first-time acute shoulder dislocation	Controlled Trial (injured and uninjured shoulder) 6 weeks 5 sessions per week 12-15 reps (stage 1) 8-10 reps (stage 2) 3-6 reps (stage 3) Red, blue, black, silver, and gold bands	Theraband 1. Flexion 2. Abduction 3. Adduction 4. Hyperextension
Ginn and Cohen (2005)	To compare the effectiveness of exercise therapy aimed at restoring neuromuscular control mechanisms at the shoulder with other conservative interventions for the treatment of chronic shoulder pain Exercise therapy aimed at restoring neuromuscular control, corticosteroid injection and multiple physical modalities (MPM) and range of motion exercises are equally effective in the short-term treatment of shoulder pain	Injection group n = 48 Age: 55.4 M: 29 F: 19 Exercise Group (range of movement exercise) n = 48 Age: 52.6 M:27 F: 21 MPM Group n = 42 Age: 57.4 M: 26 F:16	Randomized control trial 5 weeks Daily exercise Resistance was not quantified	Elastic resistance- not specified 1. Abduction 2. Flexion 3. Extension 4. Horizontal flexion 5. Horizontal extension
Heron et al. (2017)	To assess the efficacy of three different exercise programmes in treating rotator cuff tendinopathy/shoulder impingement syndrome. Open chain, closed chain and range of movement exercises all seem to be effective in bringing about short term changes in pain and disability in patients with rotator cuff tendinopathy	ROM (Range of movement exercises) group n = 40 Age:49.5 M:25 F:15 OC (Open chain exercises) group n = 40 Age:50.4 M:24 F:16 CC (Closed Chain exercises) group n = 40 Age:49.8 M:22 F:18 All participants had chronic shoulder pain	Parallel group randomised clinical trial Three sets of 10 repetitions, twice per day. Most participants initially started using a red band and progressed to green or black as soon as they were able to complete three sets of 10 with this band.	Theraband Using elastic resistance bands; 1. Lateral rotation 2. Medial rotation 3. Abduction to approximately 30°-increased to 90°
Lee and Yoo (2013)	Evaluate the effectiveness of rehabilitation training, using elastic bands and a body blade, for ice hockey players with confirmed diagnosis of shoulder joint instability The rehabilitation program given in this study had a positive effect on stabilization of the shoulder joint	Control group n = 9 Age: 25.56 ± 1.33 Training group n = 9 Age:26.56 ± 2.83 Players without shoulder instability (control group)and adult ice hockey players with shoulder instability (training group)	Controlled Trial 8 weeks 4 days per week 40–50 min 3 sets of 10–20 reps (70% of 12RM) 1 min rest between exercise modes Yellow = 1#(2 kg), Red = 3#(6.5 kg), Green = 5#(11 kg), Blue = 7#(15.5 kg).	Elastic band 1. Horizontal abduction 2. Horizontal adduction 3. Internal rotation 4. External rotation 5. Protraction 6. Scapular retraction.

(*continued on next page*)

Table 1 (*continued*)

Author Date	Purpose Outcome	Groups Subjects Gender Age Training status	Design Duration Sessions Intensity Quantified?	EBR Equipment Exercises
Mulligan et al. (2016)	To determine if there is a difference in pain or function in patients who are given rotator cuff strengthening prior to or after initiating scapular stabilization exercises. Patients with SAIS demonstrate improvement in pain and function with a standardized program of physical therapy regardless of group exercise sequencing.	SS (Scapula stabilization) Group n = 20 Age: 50.8 ± 11.1 M:5 F:15 RC (Rotator cuff) Group n = 20 Age: 49.4 ± 10.6 M:9 F:11 All participants had subacromial impingement with a primary pain complaint in the shoulder and/or upper arm	Randomized crossover trial 16 weeks Two to three sets of 20 repetitions daily Resistance is not quantified	Theraband 1) External rotation with the arm in a resting position supported by a towel roll 2) 0–30° short arc military press 3) Internal rotation isolation with the forearm adjacent to the trunk 4) Horizontal abduction at shoulder level 1) Supine shoulder protraction punch 2) Wide-grip rows at shoulder level in standing 3) Shoulder extension/scapular depression and retraction from an overhead position in standing 4) Shoulder retraction with both shoulders in external rotation with the elbows at the side
Senbursa et al. (2007)	To compare the effectiveness of two physical therapy treatment approaches for impingement syndrome The patients treated with manual physical therapy applied by experienced physical therapists combined with supervised exercise in a brief clinical trial showed improvement of symptoms	Group 1 (self guided training programme (EBR)) n = 15 age: 49.5 ± 7.9 years Group 2 (joint and soft tissue mobilization techniques) n = 15 age: 48.1 ± 7.5 years All were diagnosed with outlet impingement syndrome	Randomized clinical study 4 weeks 7 times per week 10–15 min Band resistance is not specified	Theraband 1. Shoulder flexion 2. Shoulder extension 3. Shoulder internal rotation 4. Shoulder external rotation 5. Shoulder elevation 6. Shoulder abduction 7. Scapula external rotation 8. Scapula internal rotation
Sharma et al. (2021)	To compare the effects of two different treatment programs on isometric strength The study concluded that compared to motor control exercises, progressive resistance exercises plus manual therapy provides greater improvement in the isometric strength of scapulohumeral muscles.	PRE + MT (progressive resistance exercises plus manual therapy) group n = 40 Age: 21:30 ± 2:10 MCE(motor control exercises) group n = 40 Age: 21:80 ± 2:80 All male overhead athletes diagnosed with SIS (Shoulder impingement syndrome)	Randomized controlled trial 8 weeks 3 times a week 10 reps x 2–3 sets Red to green to blue bands	Elastic resistance band 1. Shoulder internal rotation 2. Shoulder external rotation 3. Shoulder extension 4. Scapula retraction 5. Scapula protraction
Walther et al. (2004)	To compare the results of treating subacromial impingement syndrome of the shoulder by a guided self-training program. Guided self-training can lead to results similar to those of conventional physiotherapy.	Group 1: Standardized self-training n = 20 Age: 52.1 M:9 F:11 Group 2: Conventional physiotherapy n = 20 Age: 51.5 M:11 F:9 Group 3: Functional brace n = 20 Age: 48.6 M:14 F:6 All patients had painful disabling impingement syndrome of the shoulder.	Prospective, randomized study 12 weeks 5 times a week 10–15 min Thera-Band was chosen according to the results of the initial force measurements- has not stated what band correlates with what force.	Theraband 1. Shoulder external rotation 2. Shoulder abduction 3. Shoulder external rotation whilst in elbow flexion 4. Scapula retraction (row) 5. Shoulder extension

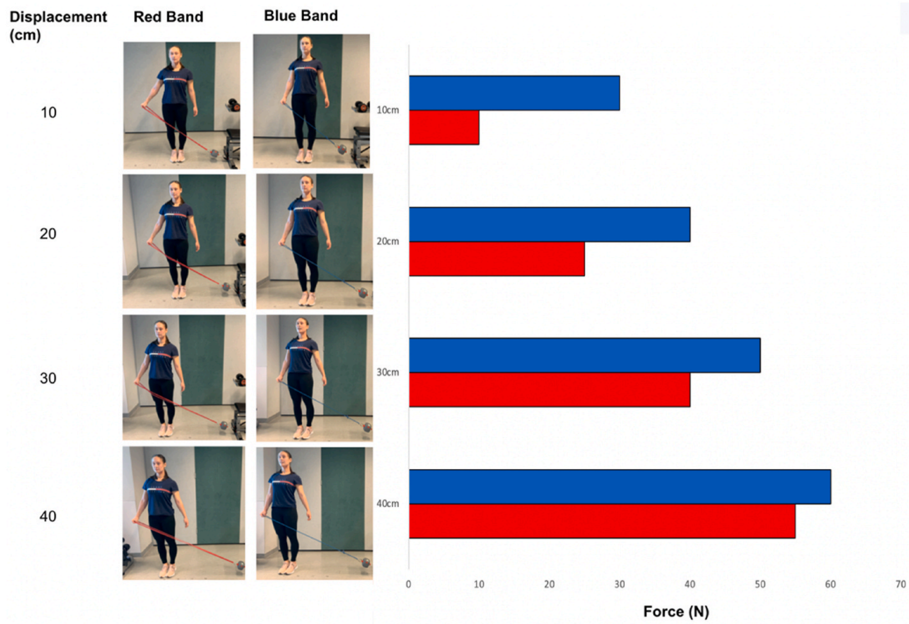


Fig. 13. Force (N) production with different EBR (red and blue) for shoulder abduction at different starting displacements. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Fig. 14. Long, medium and short muscle lengths during shoulder abduction.

gains are likely relative to sufficient durations and frequencies of training; however, there were difficulties in comparing the efficacy of interventions due to researchers measuring many different variables, including subjective outcomes such as perceived pain. The intervention included in Ginn and Cohen's (2005) study was seen to be particularly effective in terms of reducing pain intensity by 62%, whilst exercising daily for five weeks. Alternatively, Gaballah et al., (2017) also saw significant improvements in terms of strength and ROM by over 90% after the course of six weeks of exercising five times a week. The overall consensus of the studies reviewed was that EBR exercises were effective in a physiotherapeutic setting and had similar benefits to other commonly prescribed resistance types (FWR).

5. Strain gauge based exercise prescription

To implement a number and data-driven EBR rehabilitation approach to practice, the strain gauge needs to be attached to an object and the EBR to the strain gauge. From there progressively control loading of any exercise is ensured by noting the change in force output, which can be achieved by using different colour bands (Seal Fitness, Tauranga, New Zealand) or adjusting the starting length of each contraction. The effects of which can be quantified as shown in Fig. 13. In essence, there is no need for a whole lot of plates or dumbbells but rather starting a contraction with greater elastic resistive force by moving further from the anchor point.

Also when prescribing exercise, the ROM you want the resistive force to be applied needs to be considered as well. For example, the forces associated with short to long muscle lengths are shown in Fig. 14. In this example, the greatest forces can be seen at the inner range, short muscle lengths. By simply moving away from the anchor point, you can overload the outer range - long muscle length with ease, and all quantifiable with the strain gauge.

It also needs to be noted when using the strain gauge with EBR, exercises that are isometric or dynamic in nature can also be prescribed. For example, asking the client/athlete to hold 30 N of force at inner range short muscle lengths for 30 s, or conversely prescribing 10 repetitions of slow concentric and eccentric contractions with 30 N of EBR force at end range.

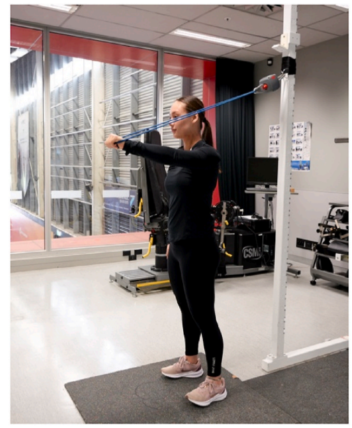
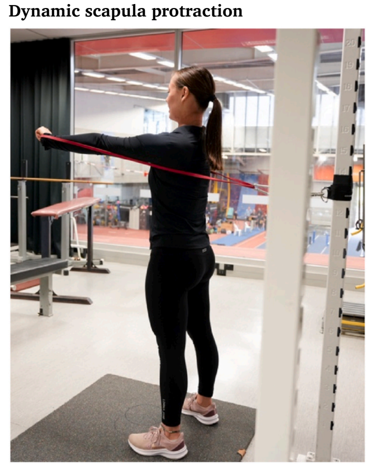
6. Exercise suggestions

As mentioned previously, a key limitation with EBR is the inability to

Table 2
Suggested exercises for rehabilitation of the shoulder using EBR.

Dynamic shoulder abduction	Standardisation
	The individual should stand with their body and feet facing perpendicular to the band. Commence movement at 0° of shoulder abduction i.e. arm lies parallel to body. The elbow and wrist should remain fully extended throughout the duration of the movement whilst the spine remains neutral. The patient should conduct movement within the frontal plane only and up to 90°.
Dynamic shoulder external rotation	**Standardisation**
	The individual should stand with their body and feet facing perpendicular to the band. The elbow remains flexed at 90° throughout the entire movement whilst being positioned at ~ 10° from the body*. Movement commences at 0° of shoulder rotation i.e. the forearm is facing anteriorly to the body. Rotation occurs away from the body within the transverse plane only whilst ensuring wrists stay fully extended. *A rolled towel can be placed between the side of the body and elbow to ensure an appropriate angle.
Dynamic shoulder internal rotation	**Standardisation**
	The individual should stand with their body and feet facing perpendicular to the band. The elbow remains flexed at 90° throughout the entire movement whilst being positioned at ~ 10° from the body*. Movement commences at a comfortable angle of shoulder rotation (approximately 45°). Rotation occurs towards the body within the transverse plane only whilst ensuring wrists stay fully extended. *A rolled towel can be placed between the side of the body and elbow to ensure an appropriate angle.
Dynamic shoulder extension	**Standardisation**

Table 2 (*continued*)

Dynamic shoulder abduction	Standardisation
	The individual should stand with their body and feet facing parallel to the band, facing away from the attachment point. Commence movement at 180° of shoulder flexion (or at an angle that is comfortable). The forearm should remain in pronation whilst the elbow and wrist remain extended. Movement occurs within the sagittal plane only and up to 0° (arm lies parallel to body).
Dyanmic scapula retraction (banded row)	**Standardisation**
	The individual should stand with their body and feet facing parallel to the band, facing towards the attachment point. The band should be held in each hand at an equal distance from the point of attachment. Movement commences with full extension of the elbows with the scapula fully protracted (shoulder blades spread apart). Movement occurs across the transverse plane, as elbows flex up to 90° and the scapula retracts (shoulder blades squeeze together). Depression of the scapula remains throughout the movement.
Dynamic scapula protraction	**Standardisation**
	The individual should stand with their body and feet facing parallel to the band, facing away from the attachment point. The band should be held in each hand at an equal distance from the point of attachment. Movement commences with 90° flexion of the elbows with the scapula fully retracted (shoulder blades squeeze together). Movement occurs across the transverse plane, as elbows fully extend and the scapula protracts (shoulder blades spread apart). Depression of the scapula remains throughout the movement.

quantify the magnitude of the prescribed resistance with precision, and thereafter progressively overload the musculotendinous system in a safe and effective manner. A potential solution to this dilemma is to attach a strain gauge in line with the EBR and quantify the resistive load with this technology. Using the information from Table 1, examples of strain gauge integration are given for; shoulder abduction, internal rotation, external rotation and extension, and scapula retraction and protraction (Table 2).

7. Conclusion

The integration of strain gauge technology should allow the practitioner a better understanding of mechanotransduction, a process that is important in understanding the effects that certain mechanical variables have on cellular signalling and tissue remodelling. Ultimately it is mechanical variables like force, length and velocity, that drive adaptation and optimises the repair and remodelling of injured tissue (Khan and Scott, 2009). Khan and Scott (2009) reported that mechanotransduction was not being taught as an important biological principle in physical therapy and medical programmes, which they thought was a major failing of medical education. With the integration of strain gauge in practice, and consequently constant mapping of loading and monitoring of tissue and movement recovery, the fundamentals of mechanotransduction are being implemented and with it a mechanotherapy approach to the healing of tendon, muscle, cartilage, and bone. The implementation of a strain gauge device allows for the quantification of the load applied to the repaired system, which is a tremendous value add for the practitioner and allows for the rehabilitation process to be more individually focused. It needs to be noted that the rehabilitation process is a very non-linear process, and regular monitoring is recommended to ensure the tissue healing process is progressed safely.

Finally, the strain gauge is a portable, affordable and flexible device that can be used for assessment, monitoring and exercise prescription across a multitude of pathologies. Shoulder rehabilitation was used as an example in this article, however, the device and the many attachments allows the user to quantify the force output of many different movements and resistance types. With continued use by the practitioner from objective examination to a rehab by numbers approach to patient care, it is envisaged that the rehabilitation and return to activity pathway of the client will be better optimised.

CRediT authorship contribution statement

Bailey Green: Writing – review & editing, Writing – original draft, Methodology, Investigation, Conceptualization. **John Cronin:** Writing – review & editing, Writing – original draft, Supervision, Project administration, Investigation, Conceptualization. **Angela Cadogan:** Writing – review & editing, Writing – original draft. **Chloe Ryan:** Writing – review & editing, Writing – original draft. **Michael Rumpf:** Writing – original draft.

Declaration of competing interest

John Cronin is employed by Hawkin TruStrength.

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