SEZNZ
SPORT & EXERCISE SCIENCE
NEW ZEALAND

The Journal of Sport and Exercise Science, Vol. 8, Issue 2, 26-36 (2024)

www.jses.net

JSES
ISSN: 2703-240X

Electromyographic signals during pullover exercise variants, and relationships between strength and throwing performance

Jad Adrian Washif[1*], Christopher Martyn Beaven[1,2], Kim Hebert-Losier[1,2]

[1]*Sports Performance Division, National Sports Institute of Malaysia (Institut Sukan Negara Malaysia), Malaysia*
[2]*Te Huataki Waiora School of Health, Division of Health, Engineering, Computing and Science, University of Waikato, New Zealand*

ARTICLE INFO

Received: 13.02.2024
Accepted: 13.09.2024
Online: 30.12.2024

Keywords:
Athletics
EMG
Javelin throw
Long muscle length
Overhand throw
Specific strength

ABSTRACT

Developing event-specific strength is necessary for optimising throwing performance. Currently, the movement patterns and transferability of pullover exercise to javelin throw performance are unknown. This study assessed the electromyography (EMG) signals during pullover exercise variants, and examined whether maximum strength related to release velocity and throwing performance. Seven national-level javelin throwers performed four barbell pullover variants (conventional [CONV], straight-arm [STR], bent-arm [BENT], and conventional on an exercise ball [BALL]) at approximately 85% of one-repetition maximum (1-RM) and three repetitions of javelin throw (JAV) while EMG activity was recorded from nine muscles: upper-trapezius; anterior, middle, and posterior-deltoid; triceps brachii; clavicular and sternal portions of pectoralis major; latissimus dorsi; and rectus abdominus. Bench press and back squat 1-RM were also determined. BENT variant peak muscle activation most closely approximated JAV peak muscle activation, especially for posterior deltoid, clavicular, and latissimus dorsi ($p > 0.05$, < 10% vs JAV). Significant correlations were found for CONV, STR, BENT, and half-squat absolute strength with release velocity ($r = 0.77$ to 0.80), and for BENT relative strength with throwing performance ($r = 0.85$). Training to improve overhand throwing may consider exercises that specifically target the muscles activated during throwing to maximise training transference. Herein, muscle activation during the BENT pullover variant was most similar to JAV, and elicited the greatest muscle activation for most muscles examined. Furthermore, developing maximal strength, particularly by engaging in exercises such as BENT, seems to be crucial for optimising release velocity and throwing performance, potentially leading to a more effective training program.

1. Introduction

The pullover exercise is an integral part of strength and conditioning routines of athletes to develop upper body athleticism. It typically involves lying on a bench or stability ball while holding a weight (external load) with both hands above the chest. From this position, the weight is then lowered in a controlled manner behind the head until the arms are parallel to the ground or slightly below, and then lifted back to the starting position. As this exercise involves a succession of eccentric-concentric muscle actions (Marchetti et al., 2011), it “mimics” upper-body actions seen in several throwing sports. The exercise engages muscles in the chest, back, and arms, and is often used to improve performance in sports involving overhead throwing motions. Apart from the muscle actions, the movement pattern and range of motion involved in this exercise appear relevant for various throwing movement sports, such as the javelin throw. Hence, these particular characteristics of the pullover exercise are

---

[*]Corresponding Author: Jad Adrian Washif, National Sports Institute of Malaysia, Malaysia, jad@isn.gov.my

thought to be useful to improve throwing performance and are commonly integrated into resistance training programs of javelin throwers (Chelly et al., 2010; Young, 2001).

Electromyography (EMG) has been used as a method to examine the level of muscle activation during the pullover exercise, with higher activity reported in the pectoralis major compared to the latissimus dorsi muscles (Marchetti et al., 2011). Assessment in this aforementioned study, however, was limited to these two muscle groups. The pullover exercise may also be used to develop various other upper body muscles, including the teres major, pectoralis minor, serratus anterior, triceps brachii, and posterior deltoid (Leavy, 2004). Further, the level of activation of these muscles likely depends on individual technique as well as variants of the pullover exercise.

Specialised training needs to provide stimuli that reflects those of the actual sporting movement and that recruits higher threshold motor units, which is crucial for developing the requisite skills and strength required for an event (Zaras et al., 2013). The pullover exercise may be performed in different techniques (variants) and in both stable and unstable conditions to elicit preferential training effects. Examining pullover variants may therefore provide additional information relating to muscle activation patterns helpful for training prescription and transference to overhand throwing capability. Indeed, implementing appropriate and targeted strength and conditioning exercises (i.e., pullover variants) that mimic activation patterns during the javelin throw may help optimise performance gains in athletes. Furthermore, it is well accepted that even among experienced athletes, technical skills can be improved when implementing specialised strength-training development programs (Bartonietz, 2000). For the pullover exercise, there are a limited number of studies examining EMG activity, which have only addressed certain techniques and variants of the pullover exercise (Borges et al., 2018; Marchetti et al., 2011). Indeed, previous studies focused solely on the "conventional" pullover exercises (Borges et al., 2018; Marchetti et al., 2011), despite variants to this exercise commonly used. This limited focus constrains our understanding and evidence-based implementation of pullover exercise variants, thereby hindering the effective application of the pullover variants for, among others, progressive overload, balanced muscle development, and optimal transference benefits. The most common pullover variants involve slight modifications to the technical execution, such as positioning the elbows straight or bent, as well as incorporating an unstable surface during the pullover exercise.

Likewise, the relationship between pullover performance, release velocity, and throwing ability has not been thoroughly examined. Muscle strength is a component that can affect throwing performance (Zaras et al., 2013) and increasing strength and power of the upper body may improve success in throwing-related sports (Hermassi et al., 2015). Specifically, strength and power, as well as technique and temporal coordination of body segments, are key determinants of throwing release velocity, which is an essential component of performance (Lehmann et al., 2010; Murakami et al., 2006; Ogiolda, 1993; van Muijen et al., 1991). Indeed, 'strength' refers to the capacity of an athlete to handle an external load, usually quantified by the maximum load that can be lifted once (Haff & Triplett, 2015). Understanding the maximum load capabilities in various pullover variants helps in tailoring strength and conditioning programs that meet the specific demands of throwing sports. Previous research suggests that the maximum strength achieved in specific exercise variants can directly influence the power and efficiency of performance movements (Young, 2001). However, there are limited data on the relationship between maximum strength and release velocity in throwing events – including javelin throw – or on the relationship between ability to perform pullover exercise and throwing performance.

Therefore, the purpose of this study was three-fold: (i) to quantify and compare muscle activation of nine upper-body muscles during four variants of pullover exercise and maximum javelin throwing attempts; (ii) to examine the relationship between maximum strength and release velocity; and (iii) to investigate the relationship between maximum external load (strength) lifted and javelin throw performance. Due to kinematic dissimilarities, we hypothesised that each type of pullover exercise would produce different muscle activation levels. We also hypothesised that maximum strength in the BENT pullover variant would correlate to javelin throw performance and release velocity more strongly, due to an arm-straightening motion that mimics throwing action.

2. Methods

This cross-sectional study required all participants to perform four pullover exercise variants in a random order: conventional (CONV), straight-arm (STR), bent-arm (BENT), and CONV on an unstable Swiss-ball surface (BALL). Following pullover exercise variants, all participants completed a series of three maximum javelin throws (JAV) using standard equipment for men (800 g) and women (600 g). Surface EMG signals were recorded throughout the movements from the following nine muscles on the throwing-arm side: upper trapezius; anterior, middle, and posterior deltoid; triceps brachii; clavicular (upper) and sternal (middle) portions of pectoralis major; latissimus dorsi; and rectus abdominus. Maximum strength in CONV, STR, BENT, half-squat, and bench press exercises were also established in a separate session to investigate the relationship between maximum strength, release velocity, and javelin throw performance.

2.1. Participants

The entire population of athletes meeting inclusion (at the national training centre) participated in this study. Seven javelin throwers, 5 men (*M* age = 20.2 ± 0.4 years; *M* body mass = 77.6 ± 7.5 kg; *M* stature = 1.77 ± 0.05 m) and 2 women (*M* age = 21.5 ± 3.5 years; *M* body mass = 59.5 ± 7.8 kg; *M* stature = 1.60 ± 0.01 m) (combined *M* age = 20.6 ± 1.6 years; *M* body mass = 72.4 ± 11.2 kg; *M* stature = 1.72 ± 0.09 m), gave their written informed consent to participate in the study after being thoroughly informed regarding the objectives, benefits, and risks of the study. The participants were considered to be moderately trained in regard to throwing performance (World Athletics score = 724 ± 71 points). The throwers reported no history of musculoskeletal injury in the last 3 months. All athletes competed in national-level competitions and had been engaged in resistance training for at least 2 years that incorporated the pullover exercise and all variants under examination. All participants completed a medical history and physical activity questionnaire before participation and were instructed to refrain from any strenuous activities involving the upper body in the 48 hours before data collection. This study adhered to the ethical principles of the World Medical Association (Declaration of Helsinki) and was approved by a Research Ethics Committee.

2.2. Procedures

All throwers attended four sessions within a 10-day period. The first session involved obtaining informed consent signatures, familiarisation to the testing protocol, and collection of baseline anthropometric characteristics. The second session involved incremental loading tests to obtain maximum strength values for CONV, STR, and BENT. The following day, maximum strength for half-squat and bench press were assessed in the third session. A week later, the fourth session was conducted that involved EMG assessment of all pullover variants and the javelin throws. The order of pullover exercises was randomised to balance any effect of fatigue across exercises.

All data were collected within one testing session to avoid repositioning of electrodes between sessions. However, only the second to fifth repetitions (4 repetitions; 1 set) of pullover variants were used (averaged) and analysed to minimise the chances of end-point errors resulting from the improper execution of the initial and final exercise sets.

2.2.1. Maximum external load assessment

The warm-up protocol involved approximately 10-min general dynamic movements, followed by a warm-up specific to the exercise tested using an unloaded pullover bar (i.e., E-Z curl barbell [Figure 1] or Olympic bar for bench press and back squat) for 10 repetitions. The warm-up set for each exercise was done using the same exercise at approximately 50% of the estimated 1 repetition-maximum (1-RM) for approximately 8 repetitions, and at approximately 70% of 1-RM (5 repetitions).

Figure 1: An E-Z curl barbell used for the current study

Next, participants followed a modified National Strength and Conditioning Association testing protocol, performing 3 to 5 sets with progressively increased loads to reach their 1-RM. The testing sequence involved 2 to 3 repetitions at approximately 85% of expected 1-RM, 1 to 2 repetitions at approximately 95% of 1-RM, and then 1 repetition, of which the load was added or reduced by 2.2 to 4.4 kg (for pullover exercises), 4.4 to 9 kg (for bench press), or 9 to 20 kg (for half-squat) to reach 1-RM exactly. The inter-set rest was set to 2 to 4 min, and rest between exercises was approximately 10 min (Haff & Triplett, 2015; Washif & Kok, 2022; Washif et al., 2024). A trained investigator oversaw participants during all performances to ensure safety and correct technique. Both absolute (kg) and relative strength (kg per kg of body mass) were analysed.

2.2.2. MVICs and pullover procedures

Participants performed three maximum voluntary isometric contractions (MVICs) of approximately 7 s (2 s ramped effort, 3 s of max hold, 2 s decrease effort) with 2 min rest interval between contractions prior to pullover variants and javelin throws. An MVIC task was done for each one of the muscles. Three researchers provided manual resistance, adequate stabilisation, and strong verbal encouragement during efforts. The maximum efforts were followed by a 10-min recovery period.

Subsequently, all throwers performed 6 repetitions of each pullover variant (CONV, STR, BENT, and BALL, in random order) using a free-weight curled barbell (named E-Z) against an external load equivalent to 85% of 1-RM (Figure 2).

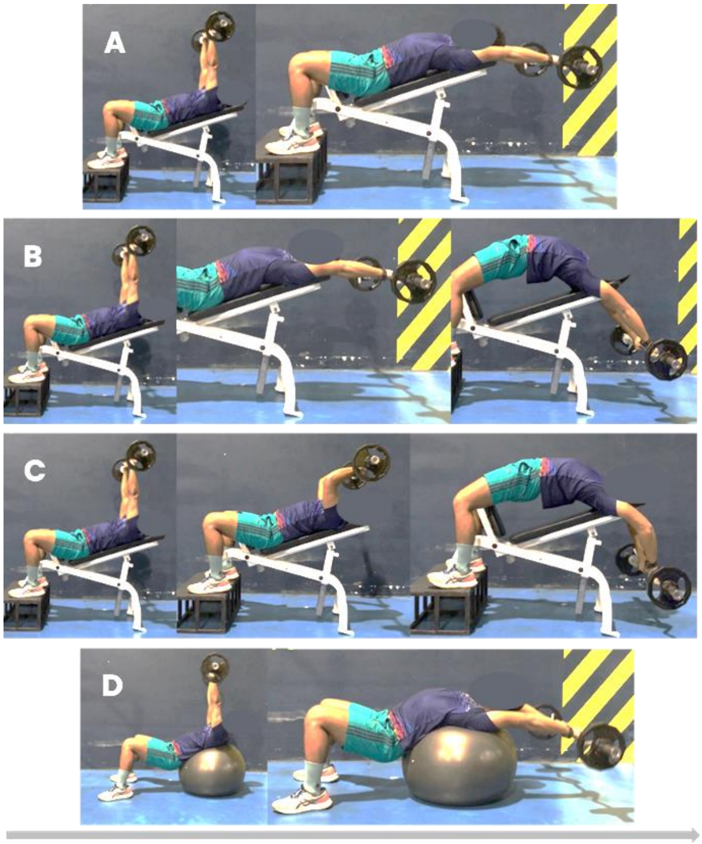

Figure 2: The specific movement pattern of each pullover variant (A = conventional [CONV], B = straight-arm [STR], C = bent-arm [BENT], D = conventional on an exercise ball [BALL]). The standard five-point body contact position technique (head, upper back, and buttocks firmly on the bench with both feet flat on the floor or box) was implemented at the start of each pullover exercise (except for D). However, dependent on exercise, the five-point contact was not always maintained throughout the exercise (e.g., buttocks raised in STR and BENT – third image of B and C). At start of each exercise, the shoulder was in a flexed position so that the arms were perpendicular above the chest. The exercise was initiated through flexion of the shoulders until the forearms were about parallel to the floor or trunk (or optimal elbow-flexion during C). To complete one repetition, the arms needed to return to the initial position through shoulder extension.

A rest of at least 5 min and up to 15 min between each exercise was permitted to allow participants to feel recovered between trials. As we used a sample of national-level javelin throwers, 85% of their 1-RM represents a common training load. Prior to beginning each exercise variant, participants performed a warm-up set of 6 repetitions at 50% of 1-RM to ensure proper execution and re-familiarisation. A detailed description of each variant is provided as supplementary material.

2.2.3. Javelin throw

Participants performed three maximal-effort javelin throws using a standard javelin implement with a 5 min rest interval between throws.

Release velocity and throwing performance. Release velocity was recorded during the EMG recording session (javelin throw) with the synchronised infrared camera system. The throw in which the highest velocity was attained was maintained for further analysis. This kinematic parameter was taken from a selected time-instant of the delivery phase, called javelin release. The linear velocity was calculated as resultant velocity of the grip of the javelin at the instant of release (i.e., the first frame the implement and hand lost contact). Throwing performance was derived from the most recent competitive event for each athlete that was classified based on the World Athletics scoring table.

2.2.4. Electromyography assessment

Electrodes placement. Similar to the maximum strength assessment, participants performed a standardised 5-min dynamic warm-up followed by a warm-up specific to the exercises tested using the unloaded pullover bar, allowing re-familiarisation. A 10-min recovery period was given during which time the electrodes were applied to the nine selected muscles on the throwing-arm side. Before electrode placement, the area of the skin where electrodes were to be positioned were shaved, gently abraded with fine sandpaper, and wiped with isopropyl alcohol. The position of electrodes was determined by palpating the pre-selected muscle bellies, while under contraction. A pair of Ag-AgCl pre-gelled electrodes (Noraxon USA Inc., Scottsdale, AZ) of 10 mm in diameter were subsequently placed in parallel on the non-contracted muscle bellies, with an interelectrode distance of 20 mm on each of the specified locations: (a) upper trapezius; (b) anterior deltoid; (c) middle deltoid; (d) posterior deltoid; (e) triceps brachii; (f) pectoralis clavicular portion; (g) pectoralis sternal portion; (h) latissimus dorsi; and (i) rectus abdominus. Double-sided tape and Hypafix® medical tape were used to affix each sensor to the skin and allow freedom of movement during actions. After positioning the electrodes, a quality check was performed to ensure EMG signal validity by requesting individuals to actively contract the muscles under investigation. Skin preparation and electrode positioning followed the recommendations of SENIAM organisation (Hermens et al., 2000) and other scientific sources (see Supplementary Table 2).

EMG recording procedures. EMG signals were collected during pullover variants and javelin throws using wireless Noraxon system, MyoMuscle v3.6 (Noraxon USA Inc., Scottsdale, AZ) at a sampling rate of 1500 Hz, which was synchronised with an infrared camera system (100 Hz) that recorded the exercise motion concurrently. EMG signals were recorded during both the concentric (shoulder extension) and eccentric (shoulder flexion) phases of the movement. Signals collected were filtered through a 4th order Butterworth band-pass filter with a pass band of 10 to 500 Hz. EMG data were rectified and smoothed by calculating the root mean square (RMS, µV) using a moving window with a window size of 250 ms, which resulted in smoothing of the data. EMG signals were then normalised to their peak amplitudes collected during a maximum voluntary isometric contraction (see Section 2.2.2.) and expressed a percent of MVIC. All data were stored within the Noraxon software and exported to Excel for further processing.

2.3. Data analysis

All data are presented as means and standard deviations. Friedman test was employed to assess the normalised (% MVIC) EMG amplitude data for the nine muscle groups during each exercise: CONV, STR, BENT, BALL, and JAV. Next, Wilcoxon signed-rank post hoc test was implemented where statistically significant differences were detected. The same analyses were conducted for the comparison of maximal loads in strength exercises. The Spearman's rank correlation coefficient was used to determine relationships between maximum strength with release velocity and throwing performance. The magnitudes of correlation coefficients were interpreted as: trivial, $r < 0.10$; small, $r = 0.10$ to 0.29; moderate, $r = 0.30$ to 0.49; large, $r \geq 0.50$ (Cohen, 1988). Furthermore, we computed percentage differences to evaluate relative difference between exercises (pullover vs javelin throw). We also calculated the sum of squared differences to quantify overall variability (difference) in muscle activity between pullover variations and javelin throw, summing the square of the difference in EMG activity between a given pullover variant and javelin throw of each muscle. Analyses were performed in Microsoft Excel 2010 (Microsoft Corp., Redmond, WA, USA) and SPSS Statistics 26 for Windows (SPSS Science, Chicago, IL, USA). Alpha was set at $p \leq 0.05$ for all analyses.

3. Results

3.1. Muscular strength

The mean absolute and relative 1-RM loads are presented in Table 1. Absolute BENT strength was significantly greater than both absolute CONV ($z = -2.37$, $p = 0.018$; +46% difference) and STR ($z = -2.21$, $p = 0.027$; +18% difference). Similarly, relative BENT strength was significantly greater than both relative CONV ($z = -2.37$, $p = 0.018$; +49% difference) and STR ($z = -2.21$, $p = 0.027$; +19% difference). Additionally, STR strength was significantly greater than CONV for both absolute ($z = -2.37$, $p = 0.018$; +25% difference) and relative ($z = -2.37$, $p = 0.018$; +25% difference) values.

Table 1: Mean ± SD of peak EMG amplitudes (% MVIC) of nine upper body muscles during the conventional (CONV), straight-arm (STR), bent-arm (BENT), unstable (BALL) pullover variants, and javelin throw (JAV).

		CONV	STR	BENT	BALL	JAV	χ2(5)	*p*
Upper trapezius	% MVIC ± SD	23 ± 4*†	39 ± 11*†	***59 ± 6***†	40 ± 17*†	64 ± 4*	19.385	0.001
	% to JAV	-41	-25	***-5***	-24			
Anterior deltoid	% MVIC ± SD	24 ± 3†	27 ± 20	**34 ± 13**	28 ± 12	47 ± 15	10.382	0.034
	% to JAV	-23	-20	**-13**	-19			
Middle deltoid	% MVIC ± SD	16 ± 1†	15 ± 1*†	**23 ± 7**†	17 ± 5*†	44 ± 8*	19.238	0.001
	% to JAV	-28	-29	**-21**	-27			
Posterior deltoid	% MVIC ± SD	14 ± 4	17 ± 8	**28 ± 16**	23 ± 10	27 ± 21	4.311	0.366
	% to JAV	-13	*-10*	***1***	*-4*			
Clavicular	% MVIC ± SD	76 ± 24	72 ± 27	**84 ± 26**	54 ± 32	91 ± 51	4.427	0.351
	% to JAV	-15	-19	***-7***	-37			
Sternal	% MVIC ± SD	76 ± 12	74 ± 29	77 ± 25	**65 ± 37**	63 ± 34	2.212	0.697
	% to JAV	13	11	14	***2***			
Tricep bracii	% MVIC ± SD	73 ± 20	**58 ± 21**	75 ± 25	65 ± 23	43 ± 25	6.254	0.181
	% to JAV	30	**15**	32	22			
Rectus abdominal	% MVIC ± SD	**71 ± 35**	107 ± 36	84 ± 32	99 ± 45	46 ± 37	8.366	0.079
	% to JAV	**25**	61	38	53			
Latissimus dorsi	% MVIC ± SD	29 ± 11	*52 ± 33*	**46 ± 26**	40 ± 15	47 ± 31	2.617	0.624
	% to JAV	-18	*5*	***-1***	*-7*			

Notes: EMG = electromyography; MVIC = maximum voluntary isometric contraction; BALL = CONV on an exercise ball. *Statistically significant difference from the BENT. †Statistically significant difference from the JAV. Muscle activations among pullover variants most closely to JAV are in bold. Muscle activations within 10% of JAV (absolute difference) are in italic.

3.2. EMG analysis

The comparisons of root mean square (RMS) amplitudes (% MVIC) elicited from each muscle examined are summarised in Table 2. Among pullover variants and JAV, no significant differences (*p's* > 0.07) were observed for posterior deltoid, clavicular or sternal portions of pectoralis major, lateral triceps, rectus abdominal, and latissimus dorsi muscles in terms of muscle activation levels.

Table 2: Descriptive values of maximum absolute and relative strength (± SD).

	CONV	STR	BENT	HS	BP
Absolute 1-RM (kg)	30 ±11	37 ±13	44 ±10	129 ±26	72 ±18
Relative 1-RM (kg·kg^{-1})	0.40 ±0.09	0.50 ±0.10	0.60 ±0.05	1.77 ±0.16	0.98 ±0.13

Notes: CONV = conventional pullover, STR = straight-arm pullover, BENT = bent-arm pullover, HS = half-squat, BP = bench press.

Percent difference between pullover variants and javelin throw. Furthermore, percent differences indicated that BENT exercise variant most closely approximated the peak muscle activation during JAV in six of the nine muscle groups (67%). Similarly, when the sum of squared differences from the JAV was calculated for the four exercise variants, the BENT variant was the most similar to the javelin throw peak activation pattern, with muscle activations of four muscle groups (upper trapezius, posterior deltoid, clavicular and latissimus dorsi) within 10% of JAV (Table 1). Figure 3 shows the normalised percentage of muscle activations relative to JAV (100% baseline).

Difference among pullover variants. Significant differences were found between exercise variants in the muscle activation levels for the upper trapezius ($\chi2(5) = 19.385$; $p = 0.001$), anterior deltoid ($\chi2(5) = 10.382$; $p = 0.034$), and middle deltoid ($\chi2(5) = 19.238$; $p = 0.001$). Post hoc analysis for the upper trapezius revealed that BENT elicited a significantly greater peak muscle activity than CONV ($z = -2.23$, $p = 0.026$), STR ($z = -2.01$, $p = 0.044$), and BALL ($z = -2.01$, $p = 0.044$), that was closer but significantly less than JAV ($z = -2.05$, $p = 0.040$). Furthermore, JAV was significantly higher than CONV for anterior deltoid activation ($z = -2.20$, $p = 0.028$). For the middle deltoid, BENT induced a relatively higher muscle activity than other pullover variants, and significantly higher against STR ($z = -2.20$, $p = 0.028$).

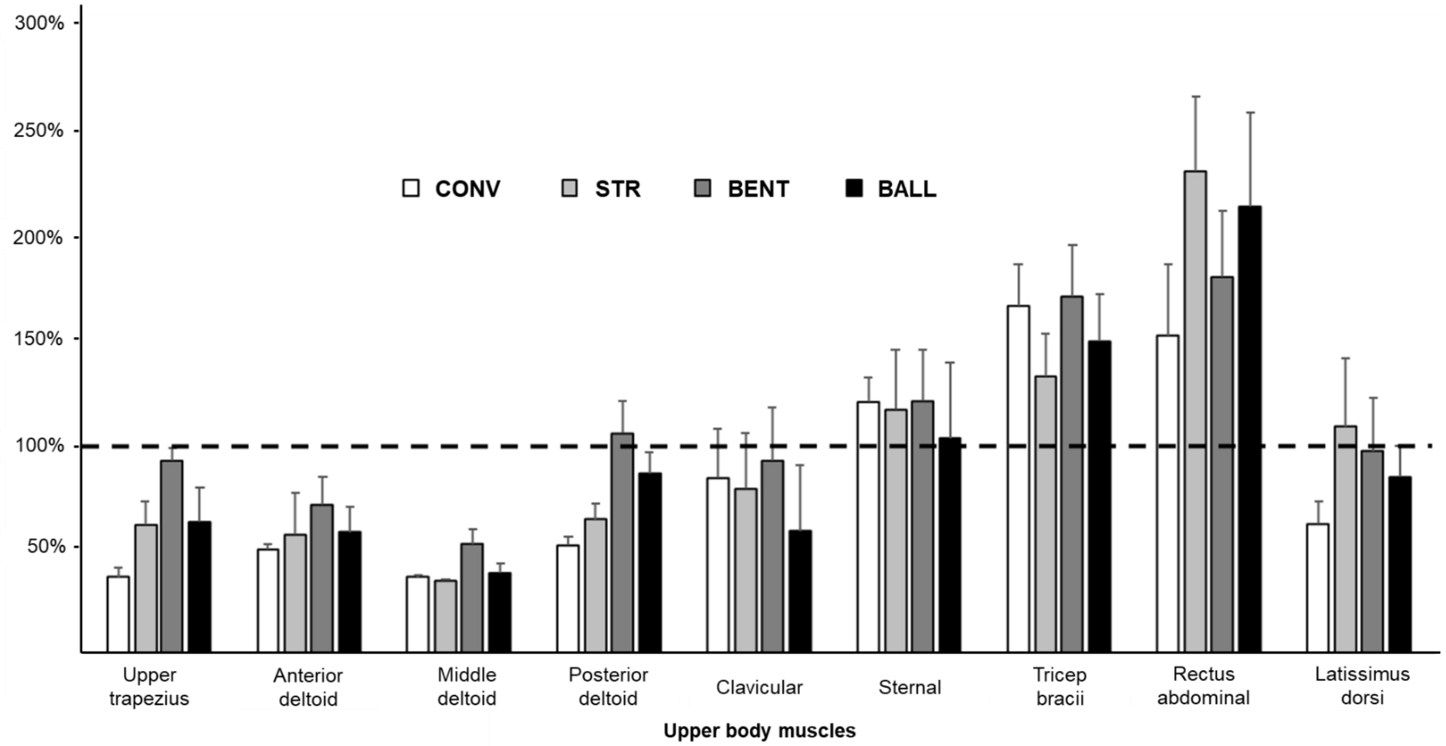

Figure 3: Differences (normalised %) from the javelin throw (100% line) for the four exercises variants. *Notes:* CONV = conventional pullover, STR = straight-arm pullover, BENT = bent-arm pullover, BALL = CONV on an exercise ball.

Moreover, for this muscle, JAV produced a significantly higher muscle activity than the four pullover variants (*p's* < 0.03). Additionally, lower peak activity levels were observed for upper trapezius, anterior deltoid, and middle deltoid relative to JAV (-5 to -21%). Activation of the triceps brachii and rectus abdominus exceeded peak levels observed during JAV (Table 1).

3.3. Relationship between maximum strength and javelin throw

The throwing performance, recorded within official competition was equivalent to 50.40 ± 6.00 m across participants. Table 3 shows the relationship between maximum strength values and release velocity and performance. The absolute CONV, STR, BENT, and half-squat showed significant and very large relationships with release velocity (r = 0.77 to 0.80), with the largest relationship seen for absolute BENT. In contrast, only one large significant relationship was found between relative strength in the BENT variant and throwing performance (r = 0.85).

4. Discussion

In our study, muscle activity levels during four variants of pullover exercise as well as maximal-effort javelin throw were examined. Overall, these five exercises yielded no statistically significant difference for posterior deltoid, clavicular or sternal, pectoralis major, lateral triceps, rectus abdominal, and latissimus dorsi muscle activity levels. Further, among exercise variants, the BENT condition most closely mimicked the muscle activity levels observed when performing a javelin throw (6 of 9 muscles), confirming the hypothesis of the current study. Furthermore, muscle activation levels were within 10% of JAV for upper trapezius, posterior deltoid, clavicular, and latissimus dorsi during BENT. Additionally, relative strength during BENT was significantly and largely related to throwing performance; as were absolute strength during CONV, STR, BENT, and half-squat to release velocity. Taken together, muscle activations depended on pullover variants, with BENT producing the greatest muscle activation levels and strongest correlations with throwing performance.

The level of muscle activity profile was dependent on the exercise variants, even though a similar load intensity was used for each pullover variant (i.e., 6 repetitions at 85% 1-RM) during the EMG recording sessions. The variation in execution altered the moment arm and muscle leverage (Hébert-Losier et al., 2012), and according to the concept of mechanical advantage, the BENT technique resulted in a greater amount of lifted load by the throwers. Specifically, during BENT, the load resistance was brought closer to the pivot point or 'fulcrum' via flexions of the elbows and shoulders, providing a shorter lever arm of the external load (Figure 2C). As a result, the absolute lifted load value for BENT in the present study was, on average, 18% and 46% greater than STR and CONV, respectively (see Results). Given that load increases have been shown to increase muscle activation (Pinto et al., 2013), this observation might reflect the load experienced by muscles and not merely the external load being lifted. Importantly, favourable changes in moment arm can lead to reduced muscle loading, allowing more external load to be lifted. Consequently, BENT resulted in a greater muscle activation than other pullover variants.

Table 3: Relationship (*r*) between maximum strength with release velocity and javelin throw performance, *p*-value, and descriptor.

	CONV	STR	BENT	HS	BP
Absolute strength					
Release velocity	0.78	0.79	0.80	0.77	0.68
p-value	0.040*	0.036*	0.032*	0.045*	0.093
Descriptor	Very large	Very large	Very large	Very large	Large
Javelin throw performance	0.59	0.63	0.66	0.45	0.21
p-value	0.164	0.126	0.104	0.308	0.669
Descriptor	Large	Large	Large	Medium	Small
Relative strength					
Release velocity	0.67	0.68	0.51	0.23	0.30
p-value	0.099	0.091	0.240	0.623	0.515
Descriptor	Large	Large	Large	Small	Medium
Javelin throw performance	0.55	0.65	0.85	0.18	-0.17
p-value	0.204	0.112	0.016*	0.696	0.722
Descriptor	Large	Large	Very Large	Small	Trivial

Notes: CONV = conventional pullover, STR = straight-arm pullover, BENT = bent-arm pullover, HS = half-squat, BP = bench press. *$p < 0.05$.

Regardless of the above, the individual ratio of pullover variants indicate BENT exercise was the closest to JAV, which implies "specificity" in muscle activation among the muscles involved during BENT and JAV actions. Upon close examination, pullovers and javelin throws may exhibit inconsistencies in terms of muscular engagement and techniques. Pullovers involve a bilateral exercise, and a relatively "slow pace" motion of the arms (adducted) towards the midline (Marchetti et al., 2011), whereas JAV is unilateral and involves a forceful movement of the arm away from the midline together with considerable body torsion or rotational movement (Murakami et al., 2006).

To our knowledge, no study has examined the relationships between pullover variants and throwing performance to understand their importance for training and sports performance, which limits comparisons to existing literature. However, both Marchetti and Uchida (2011) and Borges et al. (2018) have reported a higher activation of the pectoralis major when compared to the latissimus dorsi when performing the pullover exercise using lighter loads than those used in the current study. It was noted though that the bench press (68% MVIC) and lateral pulldown (60% MVIC) exercises enabled greater activation of the pectoralis major and latissimus dorsi, respectively, than the pullover (Borges et al., 2018). The present study extends these previous research findings by demonstrating similar results (i.e., greater activations of pectoralis major than latissimus dorsi) across the range of pullover variants examined. Interestingly, the activation levels of the latissimus dorsi in the STR condition (52% MVIC) approached those reported for the lateral pulldown by Borges et al. (2018). It is noteworthy that despite being the same exercise, performance on the unstable surface displayed a relatively greater peak muscle activity than CONV, except for the pectoralis muscles and triceps brachii. This observation agrees with findings that exercises on an unstable surface (e.g., using Swiss ball) either decreases, increases, or does not affect muscle activation levels when performed with some ground contact (de Mey et al., 2014), such as placing both legs on the floor, as done in the present study.

The relatively high activation levels of the pectoralis major (63% and 91% MVIC for sternal and clavicular, respectively) and upper trapezius (64% MVIC) found during JAV demonstrates the importance of these specific muscles during JAV. For each of these muscles, the BENT condition elicited the greatest activations, with 93 to 122% of the peak activity observed during the javelin throw (Figure 3). While we did not examine muscle activity during the bench press, the activation of the pectoralis major during the BENT condition was on average 84% MVIC compared to the 68% reported by Borges et al. (2018). Importantly, our study subsequently performed correlational analyses to examine the relationship between the strength during pullover variants – as a proxy for upper body strength – on release velocity and throwing performance.

We found some strong relationships between absolute and relative strength values with release velocity and throwing performance as shown in Table 3. An overhand exercise like javelin throwing is a complex action involving the whole body that is performed in a synchronised manner to generate a high release velocity and attain a greater throwing distance (van Muijen et al., 1991). Release velocity depends on four fundamental factors: technique, temporal coordination of actions of different body segments, muscular strength, and power of the upper- and lower-body (van Muijen et al., 1991). The best thrower in the current study produced the highest release velocity (23.9 m/s). For perspective during the 2009 World Championships, the average release velocity in men's javelin throw was 28.5 m/s, with the best performers (80+ m) reaching 29.4 m/s (Lehmann, 2010). Previous studies have highlighted the contributions of strength and power for enhanced throwing velocity and performance (e.g., Chelly et al., 201; Granados et al., 2007; Terzis et al., 2003; Terzis et al., 2007; Young, 2006). Our findings in javelin throwers align with an earlier study among professional handball players that reported a relationship between throwing velocity and maximal dynamic strength, peak power, and peak bar velocity during the bench press (Marques et al., 2007).

The present study found a stronger relationship between absolute strength with the release velocity and throwing performance versus relative strength (except BENT, Table 3). These findings suggest that increasing absolute strength levels can be considered as a precursor for the other strength qualities necessary to improve throwing performance (i.e., release velocity). Overall, the clear outcome of the present study is that the correlations between both absolute and relative strength with release velocity and throwing performance are large to very large (Table 3), which implies high levels of strength in the lower-body limbs and in the musculature involved in the pullover variants are important for javelin throwers.

The magnitude of the correlations between the strength exercises with release velocity and throwing performance in the present study suggests a potential dependency on "exercise specificity," which could contribute to better transference to performance (Washif & Kok, 2020). Despite bench press being traditionally considered an important upper-body exercise for throwing performance, our results indicate weaker relationships to throwing metrics compared to pullover variants and the half squat (Table 3). Thus, the outcomes of the present study suggest that pullover variants may be more relevant and similar to throwing performances involving shoulder extension, which contrasts with handball studies that reported the bench press exercise (elbow extension) as most relevant to the overhand throwing (Fleck et al., 1992; Granados et al., 2013). Specifically, the barbell pullover requires flexion (descending) and extension (ascending) of the shoulder, almost imitating an overhand throw movement such as the javelin throw; whereas the bench press exercise requires elbow flexion and shoulder horizontal adduction during the descending phase, and elbow extension and shoulder abduction during the ascending phase. Importantly, the relative strength in the BENT exercise variant was the only variable examined that significantly correlated with actual throwing performance. Overall, while our results suggest exercise specificity may play a role in throwing performance, further research with more targeted interventions is needed to confirm these findings and better understand the nuances of exercise selection and their impact on athletic performance.

Finally, our study presents limitations that should be considered when interpreting the findings. Due to the calibre and requirement of familiarity with the exercise variants, the sample size is relatively small. While this adds to the ecological validity, it does limit the ability to generalise to a larger population. We also acknowledge that collecting EMG data during the javelin throw, although wireless, may have influenced the skill execution. Throwing distance was taken from recent competitions that were competed in a different environment to allow for use of actual competitive throwing performance in the analysis. Even though we conducted separate MVICs for each of the nine muscles, it is also possible that a muscle may not reach maximal contraction during this task, which potentially affects the inter-muscular comparisons. Finally, while relative differences between muscles within the same individual were considered, caution should still be exercised in interpreting absolute EMG values. Furthermore, EMG is unable to directly measure force production, but instead provides insight into muscle activity patterns (Dick et al., 2024). Notably, EMG alone offers limited insight into muscle force or force-sharing strategies during dynamic contractions, as force also depends on biomechanical (e.g., specific tension, force-length, force-velocity) and physiological (e.g., cross-sectional area, fiber length, pennation angle) factors (Dick et al., 2024). The variability of EMG readings can be influenced by factors such as the precise placement of electrodes, skin impedance, and the potential for signal contamination from neighbouring muscles. It is important to note that electrode placement (or relocation) was not an issue in our study because we did not replace electrodes (see 'electrodes placement' section in the Methods). Furthermore, factors like variations in muscle lengths (e.g., exercise techniques), and movement velocity can also influence EMG data. EMG recordings are typically higher in dynamic contractions due to changes in muscle fiber length, differing neural control strategies, and lower recruitment thresholds (Tsai et al., 2014). Dynamic tasks, requiring more complex motor control and coordination, suggest that strong isometric performance may not translate to dynamic tasks if inter-muscular coordination is poor, and vice versa (Van Hooren et al., 2022). Therefore, EMG patterns can vary with muscle contraction types (concentric, eccentric, and isometric) and should be interpreted carefully (Tsai et al., 2014). These considerations are critical for interpreting EMG data accurately and understanding its implications for our findings.

In conclusion, exercise selection is one important variable for attaining athletic training aims and transference to performance. Our results suggest that for enhancing overhand throwing performance like the javelin throw, exercise selection such as the BENT condition is vital due to its similarity in muscle activation levels to actual throwing (JAV). We recommend including additional exercises targeting the upper trapezius and middle deltoid, and emphasising maximum strength development using pullover variants (especially BENT) and half squats. These recommendations are also due to their observed relationships with release velocity and throwing performance. Being bilateral and non-torsional (i.e., without body rotation), application of the pullover variants can form a fundamental basis, complementing other (unilateral and specific) exercises for a more effective training program.

Conflict of Interest

The authors declare no conflict of interests.

Acknowledgment

The authors sincerely thank the athletes, coaches (especially coach Mohamad Ali Hamid), and those who helped in the study (including Ms Ngieng Siew Yin), for their participation and contributions.

References

Bartonietz, K. (2000). Javelin throwing: An approach to performance development. In: V. M. Zatsiorsky (Eds.). *Biomechanics in Sports: Performance enhancement and injury prevention.* Blackwell Science.

Borges, E., Mezencio, B., Pinho, J., Soncin, R., Barbosa, J., Araujo, F., Gianolla, F., Amadio, C., & Serrao, J. (2018). Resistance training acute session: pectoralis major, latissimus dorsi and triceps brachii electromyographic activity. *Journal of Physical Education and Sport, 18*(2), 648–653.

Chelly, M. S., Hermassi, S., & Shephard, R. J. (2010). Relationships between power and strength of the upper and lower limb muscles and throwing velocity in male handball players. *Journal of Strength and Conditioning Research, 24*(6), 1480–1487.

Cohen, J. (1988). *Statistical Power Analysis for the Behavioral Sciences* (2nd Ed.). Lawrence Erlbaum.

de Mey, K., Danneels, L., Cagnie, B., Borms, D., T'Jonck, Z., Van Damme, E., & Cools, A. M. (2014). Shoulder muscle activation levels during four closed kinetic chain exercises with and without Redcord slings. *Journal of Strength and Conditioning Research, 28*(6), 1626–1635.

Dick T. J. M., Tucker, K., Hug, F., Besomi, M., van Dieën, J. H., Enoka, R. M., Besier, T., Carson, R. G., Clancy, E. A., Disselhorst-Klug, C., Falla, D., Farina, D., Gandevia, S., Holobar, A., Kiernan, M. C., Lowery, M., McGill, K., Merletti, R., Perreault, E., Rothwell, J. C., Søgaard, K., Wrigley, T., & Hodges, P. W. Consensus for experimental design in electromyography (CEDE) project: Application of EMG to estimate muscle force. *Journal of Electromyography and Kinesiology*, 79, 1–12.

Fleck, S. J., Smith, S. L., Craib, M. W., Denahan, T., Snow, R. E., & Mitchell, M. R. (1992). Upper extremity isokinetic torque and throwing velocity in team handball. *Journal of Applied and Sports Science Research, 6*, 120–124.

Granados, C., Izquierdo, M., Ibañez, J., Bonnabau, H., & Gorostiaga, E. M. (2007). Differences in physical fitness and throwing velocity among elite and amateur female handball players. *International Journal of Sports Medicine, 28*(10), 860–867.

Granados, C., Izquierdo, M., Ibanez, J., Ruesta, M., & Gorostiaga, E. M. (2013). Are there any differences in physical fitness and throwing velocity between national and international elite female handball players? *Journal of Strength and Conditioning Research, 27*, 723–732.

Hébert-Losier, K., Schneiders, A. G., Garcı´a, J. A., Sullivan, S. J., & Simoneau, G. G. (2012). Influence of knee flexion angle and age on triceps surae muscle activity during heel raises. *Journal of Strength and Conditioning Research, 26*(11), 3124–3133.

Hermens, H. J., Freriks, B., Disselhorst-Klug, C., & Rau, G. (2000). Development of recommendations for SEMG sensors and sensor placement procedures. *Journal of Electromyography and Kinesiology, 10*(5), 361–334.

Hermassi, S., van den Tillaar, R., Khlifa, R., Chelly, M. S., & Chamari, K. (2015). Comparison of in-season-specific resistance vs. a regular throwing training program on throwing velocity, anthropometry, and power performance in elite handball players. *Journal of Strength and Conditioning Research, 29*(8), 2105–2114.

Leavy, C. M. (2004). Dumbbell pullover. *Strength and Conditioning Journal, 26*(2), 48–49.

Lehmann, F. (2010). Biomechanical analysis of the javelin throw at the 2009 IAAF World Championships in athletics. *New Studies in Athletics, 25*(3/4),61–77.

Marchetti, P. G., & Uchida, M. C. (2011). Effects of the pullover exercise on the pectoralis major and latissimus dorsi muscles as evaluated by EMG. *Journal of Applied Biomechanics, 27*, 380–384.

Marques, M. C., van den Tilaar, R., Vescovi, J. D., & Gonzalez-Badillo, J. J. (2007). Relationship between throwing velocity, muscle power, and bar velocity during bench press in elite handball players. *International Journal of Sports Physiology and Performance, 2*(4), 414–422.

Murakami, M., Tanabe, S., Ishikawa, M., Isolehto, J., Komi, P. V., & Ito, A. (2006). Biomechanical analysis of the Javelin at the 2005 IAAF World Championships in athletics. *New Studies in Athletics, 21*, 67–80.

Haff, G. G., & Triplett, N. T. (Eds.) (2015). *Essentials of strength training and conditioning* (4th ed.). Human Kinetics.

Ogiolda, P. (1993). The javelin throw and the role of speed in throwing events. *New Studies in Athletics, 8*(3), 7–13.

Pinto, R., Cadore, E., Correa, C., da Silva, B. G. C., Alberton, C. L., Lima, C. S., & de Moraes, A. C. (2013). Relationship between workload and neuromuscular activity in the bench press exercise. *Medicina Sportiva, 17*, 1–6.

Terzis, G., Georgiadis, G., Vassiliadou, E., & Manta, P. (2003). Relationship between shot put performance and triceps brachii fiber type composition and power production. *European Journal of Applied Physiology, 90*(1–2), 10–15.

Terzis, G., Karampatsos, G., & Georgiadis, G. (2007). Neuromuscular control and performance in shot-put athletes. *Journal of Sports Medicine and Physical Fitness 47*(3), 284–290.

Tsai, A. C., Hsieh, T. H., Luh, J. J., Lin, T. T. (2014). A comparison of upper-limb motion pattern recognition using EMG signals during dynamic and isometric muscle contractions. *Biomedical Signal Processing and Control, 11*, 17–26.

van Hooren. B., Kozinc, Ž., Smajla, D., & Šarabon, N. (2022). Isometric single-joint rate of force development shows trivial to small associations with jumping rate of force development, jump height, and propulsive duration. *JSAMS Plus, 1*, 1 – 8.

van Muijen, A. E., Jorisa, H., Kemperb, H. C. G., & van Ingen Schenau, G. J. (1991). Throwing practice with different ball weights: effects on throwing velocity and muscle strength in female handball players. *Sports Medicine, Training and Rehabilitation, 2*(2), 103–113.

Washif, J. A., & Kok, L. Y. (2020). The reactive bounding coefficient as a measure of horizontal reactive strength to evaluate stretch-shortening cycle performance in sprinters. *Journal of Human Kinetics, 21*(73), 45–55.

Washif, J. A., & Kok, L. Y. (2022). Relationships between vertical jump metrics and sprint performance, and qualities that distinguish between faster and slower sprinters. *Journal of Science in Sports and Exercise, 4*, 135–144.

Washif, J. A., Hébert-Losier, K., Gill, N., Zainuddin, M., Nasruddin, S., Zakaria, A. Z., & Beaven, C. M. (2024). Reliability, interrelationships, and minimal detectable changes of strength and power metrics among well-trained Rugby Sevens players. *Biology of Sport 41*(3), 231–241.

Young, M. (2001). Developing event-specific strength for the javelin throw. *Track Coach 13*, 4921–4931.

Young, W. B. (2006). Transfer of strength and power training to sports performance. *International Journal of Sports Physiology and Performance, 1*(2), 74–83.

Zaras, N., Spengos, Z., Methenitis, S., Papadopoulos, C., Karampatsos, G., Georgiadis, G., Stasinaki, A., Manta, P., & Terzis, G. (2013). Effects of strength vs. ballistic-power training on throwing performance. *Journal of Sports Science and Medicine, 12*, 130–137.

Supplemental material

Supplementary Table 1: Step by step protocols of pullover exercise variants.

Pullover exercise variant	Step by step protocol
Conventional Pullover	*Starting Position* 1. Lie down on a (flat or incline) bench ensuring five point contact with the bench or floor.* 2. Grasp a barbell (e.g., E-Z curl barbell) with both hands, using pronated grips, with both arms fully extended above your chest. Your grips/palms face internally (~45 degrees) when using E-Z curl barbell. *Descent Phase* 1. Inhale as you gradually lower the barbell behind your head, maintaining an unlocked elbows (slightly bend). 2. Continue to lower the barbell until you feel a stretch in your chest and shoulders. 3. Align your arms so that they are parallel to or slightly below your torso. *Ascent Phase* 1. Gradually lift the weight back to the initial position, following the same trajectory during the lowering phase. Exhale at the ‘sticking point’ (the heaviest part). 2. Keep your elbows unlocked throughout the movement. *5-point contacts: (1) back of head, (2) shoulder blades/upper back region, (3) gluteal, (4) right foot, and (5) left foot.
Straight-Arm Pullover	*Starting Position* 1. Lie down on a (flat or incline) bench ensuring five point contact with the bench or floor. 2. Grasp a barbell (e.g., E-Z curl barbell) with both hands, using pronated grips, with both arms fully extended above your chest. Your grips/palms face internally (~45 degrees) when using E-Z curl barbell. *Descent Phase* 1. Inhale as you gradually lower the barbell behind your head, maintaining an unlocked elbows (slightly bend). 2. Continue to lower the barbell. 3. As the barbell reaches a position almost parallel to the torso, raise your glutes and simultaneously lower the barbell further in a controlled manner to maximise the stretch. *Ascent Phase* 1. Gradually lift the barbell back to the initial position, simultaneously lowering the gluteus, following the same trajectory during the lowering phase. Exhale at the ‘sticking point’ (the heaviest part). 2. Keep your elbows unlocked throughout the movement.
Bent-Arm Pullover	*Starting Position* 1. Lie down on a (flat or incline) bench ensuring five point contact with the bench or floor. 2. Grasp a barbell (e.g., E-Z curl barbell) with both hands, using pronated grips, with both arms fully extended above your chest. Your grips/palms face internally (~45 degrees) when using E-Z curl barbell. *Descent Phase* 1. Inhale as you gradually bend and lower the barbell behind your head. 2. As the barbell reaches a position almost parallel to the torso, with elbows bent at approximately 45 degrees, raise your glutes and simultaneously lower the barbell further in a controlled manner to maximize the stretch. 3. Keep the elbows bent or extend them slightly to reach further down and further maximise the stretch. *Ascent Phase* 1. Gradually lift the barbell back to the initial position, simultaneously lowering the gluteus, following the same trajectory during the lowering phase. Exhale at the ‘sticking point’ (the heaviest part).
Conventional Pullover on an Exercise Ball	Similar to conventional pullover with 3-point contacts (upper back, right foot, and left foot) performed on an exercise ball (or unstable surface)

Supplementary Table 2: Electrode positions based on SENIAM recommendations (Hermens et al., 2000) available at www.seniam.org, and other sources.

Electrode positions	Recommendations
Upper trapezius	50% on the line from the acromion to the spine on vertebra C7.[1]
Anterior deltoid	One finger width distal and anterior to the acromion.[1]
Middle deltoid	The greatest bulge of the muscle (from the acromion to the lateral epicondyle of the elbow).[1]
Posterior deltoid	About two finger breaths behind the angle of the acromion.[1]
Triceps brachii	50 % on the line between the posterior crista of the acromion and the olecranon at 2 finger widths medial to the line.[1]
Pectoralis clavicular portion	Placed medially along the belly of the clavicular part.[2,3]
Pectoralis sternal portion	Placed medially along the imaginary angle bisector (that forms a boundary) of the sternal part.[2,3]
Latissimus dorsi	4 cm below the inferior tip of the scapula, and midway between the spine and lateral edge of the torso; oblique angle (throwing side).[4]
Rectus abdominus	3 cm from the sagittal plane and 5 cm above the umbilicus.[5]

---

[1] Hermens, H. J., Freriks, B., Disselhorst-Klug, C., & Rau, G. (2000). Development of recommendations for SEMG sensors and sensor placement procedures. *Journal of Electromyography and Kinesiology, 10*(5), 361–334.

[2] Król, H., Sobota, G., & Nawrat, A. (2007). Effect of electrode position on EMG recording in pectoralis major. *Journal of Human Kinetics, 17*, 105–111.

[3] Lee, H. M. (2019). Force direction and arm position affect contribution of clavicular and sternal parts of pectoralis major muscle during muscle strength testing. *Journal of Hand Therapy*, *32*(1), 71–79.

[4] Park, S. Y., & Yoo, W. G. (2013). Comparison of exercises inducing maximum voluntary isometric contraction for the latissimus dorsi using surface electromyography. *Journal of Electromyography and Kinesiology*, *23*(5), 1106–1110.

[5] Moraes, A. C., Pinto, R. S., Valamatos, M. J., Valamatos, M. J., Pezarat-Correia, P. L., Okano, A. H., Santos, P. M., & Cabri, J. M. (2009). EMG activation of abdominal muscles in the crunch exercise performed with different external loads. *Physical Therapy in Sport, 10*(2), 57–62.