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ORIGINAL ARTICLE

Muscle Activation Levels During Upper Limb Exercise Performed Using Dumbbells and A Spring-Loaded Exoskeleton

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Abstract A spring-loaded exoskeleton design was recently developed for the upper limbs of physically challenged and healthy people, enabling them to move multiple joints of the upper limbs on different motion planes. A four-degree-of-freedom design allows the exoskeleton arms to perform shoulder abduction–adduction, flexion–extension, internal–external rotation, and elbow flexion–extension motions. The purpose of this study was to compare the muscle activation levels during upper limb resistance exercises that were performed using dumbbells and a spring-loaded exoskeleton. The upper limb resistance exercises were conducted under varying conditions, using 1- and 3-kg applied loads, and with 1- and 2-s motion speeds. Six healthy participants performed three movements: shoulder abduction–adduction, shoulder flexion–extension, and elbow flexion–extension. Dumbbells and a spring-loaded upper limb exoskeleton were used as resistance sources. Surface electromyography was applied to analyze participant muscle functions; surface electrodes were placed over the anterior deltoid, middle deltoid, posterior deltoid, pectoralis major, biceps brachii, triceps brachii, upper trapezius, and supraspinatus. All results were presented as normalized surface electromyography amplitudes. Our study findings suggest that muscle activation levels during the three designated upper limb resistance exercises have consistent patterns, and that the difference between using dumbbells and the spring-loaded exoskeleton was mostly nonsignificant; therefore, the spring-loaded exoskeleton is able to provide similar training effects to that of dumbbells.

Keywords Electromyography · Exoskeleton · Free weight exercise · Muscle activation · Upper limb

1 Introduction

A sedentary lifestyle can lead to increased health risks such as decreased physical function from disease. Decreased labor forces caused by aging populations have led to a shortage of nurses and therapists in Taiwan as well as other developed countries, resulting in an increased burden on health care services. In particular, demand has risen for exercise training devices and medical care devices for home use to facilitate functional recovery following rehabilitation. Resistance training based on scientific methods has been endorsed by major national health organizations because of its potential value in improving functional capacity and other health-related factors [1–6]. However, most exercise machines and devices have been designed for healthy young people and athletes to improve their general fitness in gyms or exercise studios. Few upper limb training devices have been developed for home-based health care and rehabilitation.

A spring-loaded upper limb exoskeleton for resistance training (SLERT) was proposed and developed by Wu et al. [7, 8]. The SLERT was designed for physically challenged and healthy people, allowing upper limb movement at multiple joints on different motion planes. The mechanical structure of the SLERT comprises four

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links and four revolute joints, which cover the fundamental degrees of freedom (DOF) of the arms for achieving shoulder abduction–adduction (abd–add), flexion–extension (flx–ext), internal–external rotation (int–ext), and elbow flx–ext motions. Most devices for upper limb muscle training permit movement only on a single plane to isolate specific muscle groups. Compared with those devices, the SLERT allows physically challenged or a healthy people to move their limbs on different planes to train more muscle groups. Movement is also enabled on different planes during free weight exercises. However, additional weights are applied as the resistance increases during free weight exercises; therefore, the muscles have to produce more force to overcome the inertial force of the heavier weights. Higher inertial force implies a higher chance of injury if the training devices are not operated properly. Free weight exercises are therefore more suitable for athletes and healthy people than people with muscle degeneration. Compared with that of free weight exercises, the resistance of the SLERT is provided using three sets of zero-free length springs rather than additional weights. Hence, the resistant force can be gradually adjusted, allowing for progressive training and reducing the potential risk caused by large moments of inertia. This device has been proven to diminish the unfavorable lengthening of muscles and to reduce joint overload, which are often associated with large moments of inertia during high-intensity free weight exercises, rendering the SLERT a safer device for upper limb muscle training [8]. The SLERT can be applied to various types of strength training including home-based health care and exercise training in the rehabilitation of elderly or physically challenged patients. However, muscle activity during SLERT exercises has not yet been investigated. We sought to determine whether the SLERT exerts similar training effects on muscles compared with those of free weight exercises by comparing the differences between their muscle activation levels.

Electromyography (EMG) is a method for analyzing muscle function that has been used to assess muscle activity for function, control, and learning [9]. Caution must be exercised to prevent errors in the selection of the recording electrodes, recording sites, and signal acquisition specifications when using EMG for studying human movements. A comprehensive understanding of EMG signals is also essential to interpret them properly [10]. Surface electromyography (sEMG) is a frequently employed electrophysiology technique for recording the physiological characteristics of muscle activity, offering a simple tool for online assessment of the activation of muscles, tendons, and other tissues. sEMG is a safe, easy, noninvasive, and painless method for objectively quantifying muscle excitation levels and has been used under numerous experimental conditions including rehabilitation, neurology, neurology, neurophysiology, sports science, and ergonomics [11–13]. A variety of uses for sEMG has been proposed including the estimation of individual rehabilitation protocols [14, 15], effectiveness of warm-up exercises [16], evaluation of neural signal changes [17, 18], and therapeutic efficacy of robot-assisted exercise [19–21].

The primary purpose of this study was to evaluate muscle activation levels when two different loading types (i.e., dumbbells or a spring-loaded upper limb exoskeleton) are applied to the palm of the users' hands during upper limb resistance exercises. We hypothesized that muscle activation levels are markedly similar when the same exercises with equivalent applied resistance are performed using dumbbells or a spring-loaded upper limb exoskeleton. Statistically nonsignificant findings from the Wilcoxon signed-rank test indicate that the muscle training effects exerted by the two types of equipment have no significant difference. An experimental study that used sEMG as a measurement tool was conducted to gain a comprehensive understanding of the muscle activation levels during upper limb resistance exercises that involve using dumbbells or a spring-loaded exoskeleton.

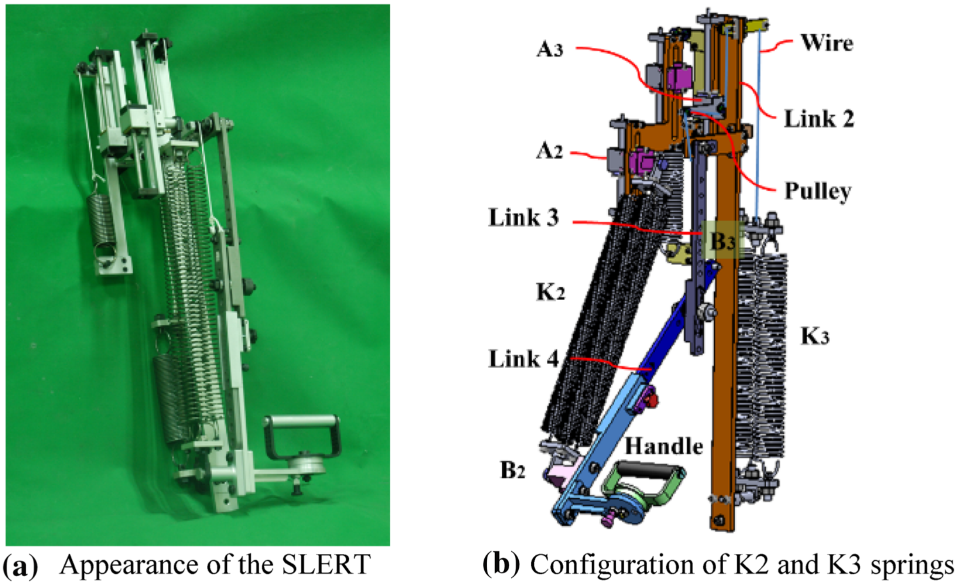
2 Methods

2.1 Spring-Loaded Exoskeleton

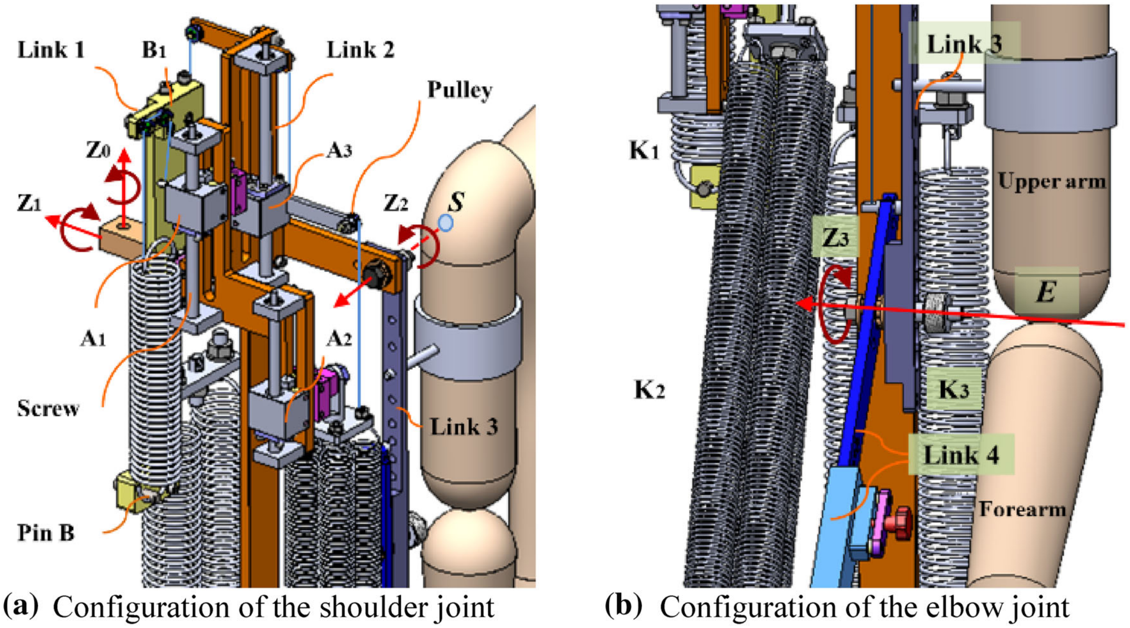
The SLERT is a passive, four-DOF body-powered design that allows physically challenged or healthy people to move their limbs at multiple joints on different planes. It can generate resistance to enhance the strength, power, and endurance of either chronic-stage patients or healthy people, providing intensive, repetitive, and long conditioning training. The length of the upper arm and forearm can be adjusted to fit different users. The SLERT applied in this study was a modified version of the one proposed by Wu et al. [7], which was not available on the market and was designed for functional and performance-based resistance training. Figure 1a shows the new mechanical structure comprising four links and four revolute joints, which cover the fundamental DOF of the arms for performing shoulder abd–add, flx–ext, int–ext, and elbow flx–ext motions. The required loadings are accompanied by three sets of zero-free length springs for upper limb resistance training during movement.

Figure 2a illustrates the configuration of the three revolute joints for the shoulder joint with three DOFs (axes z_0, z_1, and z_2). The ball bearings or thrust bearings are implemented in revolute joints to handle friction and reduce drawbacks of clearance. An adjustable revolute joint for various arm lengths is implemented to accommodate the one-DOF elbow joint (axis z_3). Elbow flx–ext

Fig. 1 Appearance and configuration of the SLERT



(a) Appearance of the SLERT **(b)** Configuration of K2 and K3 springs



(a) Configuration of the shoulder joint **(b)** Configuration of the elbow joint

Fig. 2 CAD drawings of the configuration of the shoulder and elbow joints of the upper limb exoskeleton

motion is achieved using the thrust bearings. The length of the forearm link is also adjustable (Fig. 2b). Both the shoulder and elbow joints can be independently locked to achieve specified movements. The structure of the SLERT mostly consists of aluminum alloy materials, whereas links 3 and 4 (the high-stress joint sections) are composed of steel.

A zero-free length spring is emulated by a conventional spring with a pulley and wire structure, where the force is proportional to the spring length, rather than spring elongation, thereby allowing the resistance of the SLERT to be modified by changing the spring length. The bearings are attached to the pulleys to smooth the motion of the springs and to reduce their friction. Figures 2a and b illustrates how pin B is employed to fix the standard spring K_1 that is connected with wires and pulleys to points B_1 (on link 1) and A_1 (on link 2). Springs K_2 and K_3 are arranged identically to spring K_1 (Fig. 1b). The spring attachment locations, A_1, A_2, and A_3, are combined with nuts on slide screws separately on link 2; therefore, resistance during exercises can be easily adjusted using the three slides. To generate the required resistance, users need only vary the attachment locations (A_1, A_2, and A_3) of the springs, rather than having to change the spring stiffness. Thus, convenience and flexibility are ensured for users during resistance exercise.

Considering the intended users of the SLERT, the current prototype was designed with a maximum resistant force of 49 N (corresponding to a 5-kg dumbbell). The resistant force generated by the SLERT is changeable by adjusting the spring attachment locations (A_1, A_2, and A_3). The relationship between the selection of these locations and the resistance generated has been modeled and well assessed in previous studies [7, 8]. The spring stiffness was selected according to the spring design constraints, practical implementation practices, anthropometric parameters, and limitations and mass properties of the linkages [7]. The springs were chosen from a catalog of standard springs and the design specifications were the same as those listed by Wu et al. [22].

2.2 Study Participants and Preliminary Sessions

Six healthy participants (three males and three females) volunteered to participate in this study (age: 22.5 ± 0.5 years; height: 164.8 ± 6.0 cm; body weight: 57.6 ± 9.2 kg). The inclusion criteria required that the participants had no previous injury to the shoulders or elbows, or any history of musculoskeletal or neural impairments. In addition, professional athletes and people engaging in regular athletic training were excluded from this study. We explained the study process to each participant, and an informed consent document approved by the Industrial Technology Research Institute ethics committee was signed by each participant before instrumentation and data collection.

2.3 Instrumentation

EMG data of the muscle groups of interest (right shoulder and right elbow) were obtained using sEMG. sEMG signals were recorded using a 16-channel wireless Zero Wire EMG system (ZW180/R WiFi; Aurion, Milan, Italy) to monitor participant muscle electrical activity. The system comprised two parts: a main unit (receiver) and wearable EMG probes (34 × 26 × 19 mm, 0.01 kg each). Each probe could collect and amplify the EMG signals and transmit the EMG data.

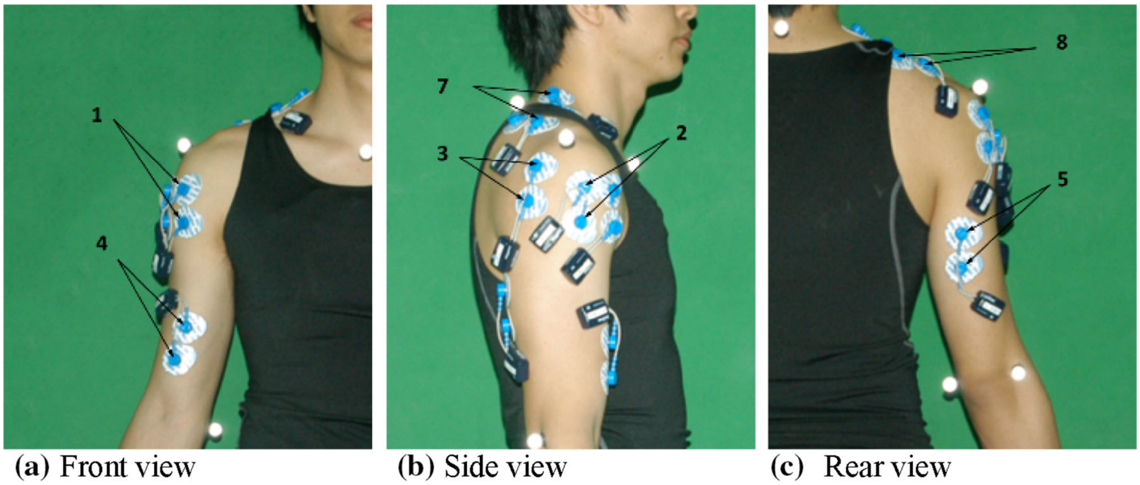
The relevant skin areas of each participant were scrubbed with an isopropyl alcohol swab to minimize contact impedance. sEMG conductive adhesive electrodes (Ag–AgCl, 22-mm potential sensitive area, 36-mm diameter; Kendall Medi-Trace 200; Chicopee, MA, USA) were attached to the skin surface over eight upper limb muscles: the anterior deltoid (AD), middle deltoid (MD), posterior deltoid (PD), pectoralis major (PM), long heads of biceps brachii (BB), long heads of triceps brachii (TB), upper trapezius (UT), and supraspinatus (SS), as shown in Fig. 3. These muscles were selected for their involvement in shoulder abd–add, shoulder flx–ext, and elbow flx–ext movements [23, 24]. The electrodes were placed precisely on the midline of the muscle belly between the tendon and the most distal motor point, and oriented along the line parallel to the direction of the underlying muscle fibers [9, 25] (Fig. 3). Ground reference electrodes were unnecessary and not employed, which significantly reduced artifacts from the wire movements; in addition, the absence of cables surrounding the participants increased their comfort and freedom of movement. Each electrode was attached to the skin by using double-sided tape and linked to a wearable probe that processed and transmitted the signals.

2.4 Experimental Protocol

To ensure that clear signals could be detected with negligible noise, all of the EMG channels were carefully inspected before the start of each EMG recording session. The electrodes were removed and reattached if the signals were considered unsatisfactory. The EMG data and applied weight and resistance were obtained from the eight muscles of the right shoulder for each participant. The participants performed one elbow and two shoulder movements by using both dumbbells and a resistance training exoskeleton.

Even though the preparation and processing protocols may be strictly followed, inherent EMG signal variability is attributable to numerous factors; clinical interpretation of sEMG requires normalization to control the variability for accurate physiological interpretation and for comparisons among muscles, among subjects, and among signals obtained on different days [26]. Exercises with dumbbells and with those the spring-loaded exoskeleton were performed on two separate days in this study; therefore, the standardized method for maximum voluntary isometric contraction (MVIC) was applied for the data normalization.

To produce the MVIC of the eight muscles of interest during the EMG tests, each participant was guided through a series of isometric resistance contractions. The MVIC values were collected for each muscle individually; the participants performed each exercise while a qualified person held their shoulders, upper arms, or forearms (see Table 1 for the MVIC actions for each muscle) [24]. Verbal encouragement was provided during all of the trials [27, 28]. The MVICs were performed according to standard muscle strength testing positions that optimally isolate each muscle. Three MVICs were presented for each muscle by using standard limb positions [24]. The participants were instructed to gradually increase their muscle contraction force toward the maximum over a period of 2 s and then sustain the MVIC for approximately 3 s before slowly



(a) Front view (b) Side view (c) Rear view

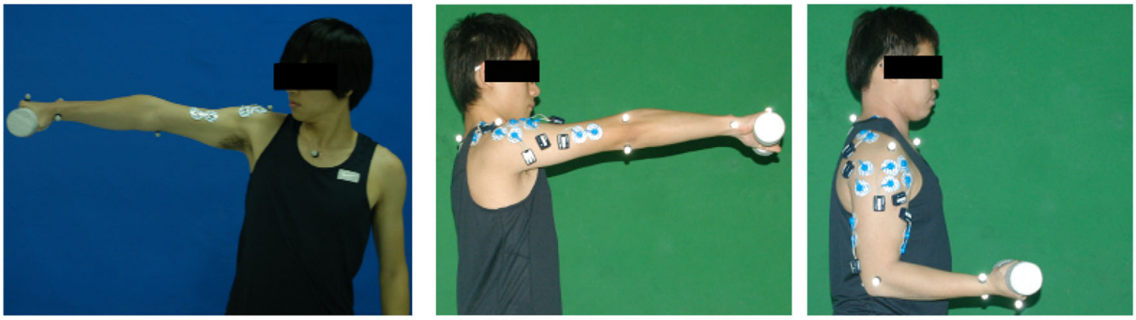
Fig. 3 Locations of the surface EMG (channel 6 for the pectoralis major was under the participant's shirt)

Table 1 Muscles tested and corresponding MVIC actions

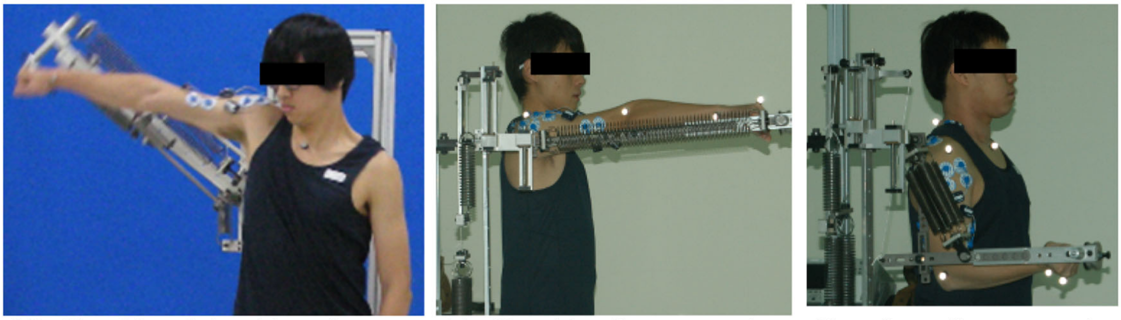
Channel	Muscle	MVIC action
1	Anterior deltoid	Shoulder abduction in slight flexion with the humerus in slight lateral rotation against the anteromedial surface of the arm in the direction of abduction and slight extension.
2	Middle deltoid	The arm was abducted to 90° in neutral rotation (palm down) with resistance applied just proximal to the elbow in an inferior direction.
3	Posterior deltoid	Shoulder abduction in slight flexion with the humerus in slight medial rotation against the posterolateral surface of the arm above elbow in the direction of abduction and slight flexion.
4	Biceps brachii	Forearm flexion at a right angle and the forearm in supination with resistance applied against the lower forearm in the direction of extension.
5	Tricep brachii	Extension of the elbow to slightly less than full extension against the forearm in the direction of flexion.
6	Pectoralis major	Horizontal adduction of the arm with the elbow extended against the forearm in the direction of horizontal abduction
7	Upper Trapezius	Elevation the acromial end of the clavicle and scapula against the shoulder in the digression of depression.
8	Supraspinatus	The shoulder was elevated to 90° in the scapular plane, the elbow was extended, and the shoulder was in neutral rotation.

reducing the force, with 1 to 3 min of rest between each contraction [27, 28]. For each muscle, the MVIC values were applied to normalize the EMG signals on a scale of 0–100% of each cycle. The EMG recordings and all EMG data were sampled at 2000 Hz and stored for offline analysis.

Each participant performed the exercises both with dumbbells and the upper limb exoskeleton. Three resistance training exercises (i.e., shoulder abd–add, shoulder flx–ext, and elbow flx–ext) were conducted during each session. Four sets of each 1- or 3-kg resistance and 1- or 2-s motion speeds were required from all the participants. In each resistance training exercise, the muscle activation levels under different training intensities were evaluated to investigate whether the results would differ between the use of different loadings and movement speeds. Each movement comprised six consecutive repetitions in a slow, controlled manner without any sudden jerks or acceleration, as well as lifting and lowering at 1- or 2-s motion speeds. A metronome was employed to guide the participants in maintaining the tempo of their movements. A maximum 5-min rest was provided between each set of exercise. Detailed procedures for performing the movements were explained and demonstrated to each participant prior to each test. To ensure that the participants' left arm did not affect the movement of their right arm, the participants were instructed to hold their left arm relaxed at their side. Figures 4a–f illustrate the evaluated movements and grip patterns. The experimental protocol for the designated arm movements was adopted from Wu et al. [22].



(a) Dumbbell lateral raise **(b)** Dumbbell frontal raise **(c)** Dumbbell curl



(d) Shoulder abd–add motion **(e)** Shoulder flx–ext motion **(f)** Elbow flx–ext motion

Fig. 4 Movement and grip patterns of the free weight and exoskeleton exercises

For both free weight and upper limb exoskeleton exercises, the resistance was set at the same level, as with a 1- or 3-kg dumbbell. The recordings were discarded and redone if mistakes were made or if the participants were notably off pace (e.g., moving too fast or too slow). The participants were allowed to engage in warm-up practice prior to the tests to reduce time lost to inaccurate pacing or movement during the tests.

The initial position entailed standing comfortably with the arms naturally hanging and relaxed at the participants' sides. For every general movement and action, the involved arm was fully extended from the initial position.

2.5 EMG Analysis

All raw EMG signals, including those of the MVIC trials, were digitally filtered through a band-pass filter (10–200 Hz) [29] and processed by applying a root mean square (RMS) algorithm with time window of 10-ms [30–32].

$$RMS = \sqrt{\frac{1}{N}\sum_{i=1}^{N} v_i^2} \tag{1}$$

where v_i is the voltage value at the ith sampling and N is the sample number in a segment. N was set at 20. The RMS was used to rectify the raw signals and convert them into an amplitude envelope for easier viewing.

The collected data from the three MVICs for each muscle group were processed by applying the RMS. The mean EMG value of the three trials was adopted as the peak MVIC. For each exercise, the mean muscle activation level was calculated from the first three repetitions for each muscle with 1- and 3-kg loadings at two motion speeds; if the data from any of the three trials were considered unreliable, then those of the fourth, fifth, or sixth trials were used as substitutes. The strongest effort observed was determined from the subsequent recordings and the recordings were expressed as a percentage of the MVIC (%MVIC):

$$\begin{aligned}\%\text{MVIC} &= 100\% \times (\text{EMG value of movement} \\ &\quad / \text{ average EMG value of the three} - \text{peak MVIC})\end{aligned} \tag{2}$$

There were no absolute microvolt values, but only a relative comparison to a maximal effort. Therefore, all muscle function could be reduced to the common feature of % MVIC by normalizing the EMGs and the EMG amplitudes recorded from the same muscle on separate occasions (the sEMG electrodes were removed between testing with the dumbbells and testing with the SLERT) and from different muscles; thus, data for each participant could be compared directly. The data were processed using Matlab (MathWorks Inc., Natick, MA).

2.6 Statistical Analysis

The Wilcoxon signed-rank test was used to ascertain the association of muscle activation levels between the use of dumbbells and the spring-loaded exoskeleton. A significant value implied that the muscle activation levels had some statistically significant differences between the two types of loads, whereas a nonsignificant value implied that the muscle activation levels were not significantly different between the two types of loads. We hypothesized that all muscle activation levels would show nonsignificant values in the Wilcoxon signed-rank test during pairwise movements. Nonsignificant results would suggest that the muscle activation levels from the two types of loads were associated or similar.

3 Results and Discussion

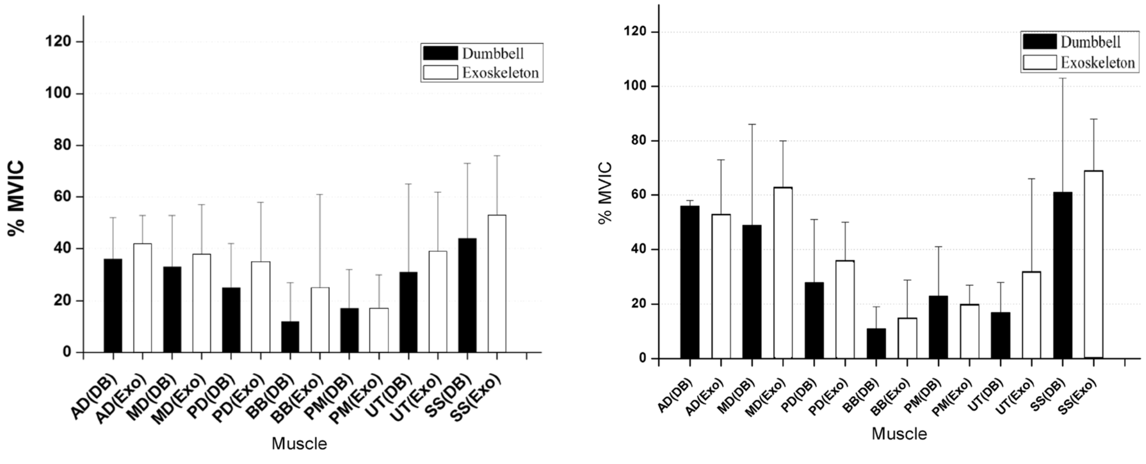
Figures 5, 6, 7, 8, 9, 10 indicate the mean peak EMG activity and muscle activation for shoulder abd–add, shoulder flx–ext, and elbow flx–ext movements performed using 1- and 3-kg loadings for both dumbbells and the spring-loaded exoskeleton at two motion speeds (1-s lifting, 1-s lowering; 2-s lifting, 2-s lowering). If the data acquired from a selected muscle during the dumbbell exercise were invalid, the counterpart data from the same muscle for the spring-loaded exercises were discarded; likewise, if the data acquired from a selected muscle during the spring-loaded exercise were unqualified, the counterpart data from the same muscle for the dumbbell exercises were discarded.

Because of system technical problems and operational errors, the EMG data collected from participants S1, S4, and S6 during the shoulder abd–add exercise with the spring-loaded exoskeleton (3-kg resistance) at 1-s lifting and 1-s lowering motion speeds, as well as at 2-s lifting and 2-s lowering motion speeds, failed to be processed. The same problems were encountered for participant S6 (1-kg resistance at 1-s lifting, 1-s lowering motion speeds; 1-kg at 2-s lifting, 2-s lowering motion speeds) as well as participants S2 and S6 (3-kg resistance at 1-s lifting, 1-s lowering motion speeds; 3-kg at 2-s lifting, 2-s lowering motion speeds) during the elbow flx–ext exercise.

The AD, MD, PD, BB, PM, SS, and UT muscles were primarily responsible for shoulder abd–add movement; the AD, PD, BB, TB, and PM were the greatest contributors to shoulder flx–ext movement; and the BB and TB were the most prominently involved muscles in elbow flx–ext movement [23, 24]. We focused on these primary contributing muscles during each set of exercises throughout the analysis.

The muscle activation levels of primarily involved muscles during exercises performed using dumbbells and the spring-loaded exoskeleton are shown in Figs. 5, 6, 7, 8, 9, 10. The conditions of movement types (shoulder abd–add, shoulder flx–ext, and elbow flx–ext), loadings (1- and 3-kg resistance), and motion speeds (1- and 2-s) are specifically described in the head of each fig. Figures 5, 6, 7, 8, 9, 10 provide an overview showing that the muscle activation levels are similar between corresponding muscles.

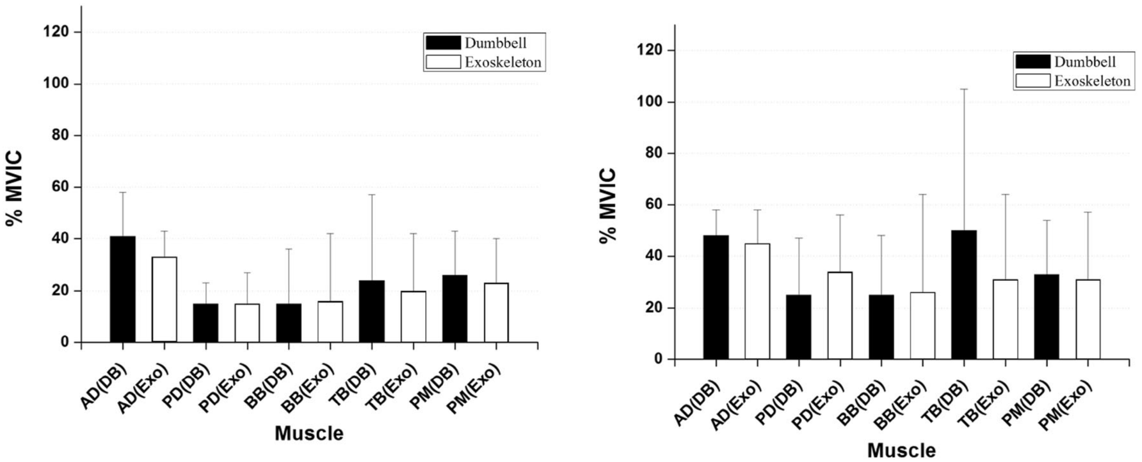
The normalized sEMG amplitudes of some muscles are counterintuitively lower under the 3-kg condition compared with the 1-kg condition; for example, the values (Fig. 5a, b) for the BB and UT in the shoulder abd–add exercise using 1- and 3-kg loadings at 1-s lifting and 1-s lowering motion speeds, the values (Fig. 7a, b) for the TB



(a) Loading at 1-kg

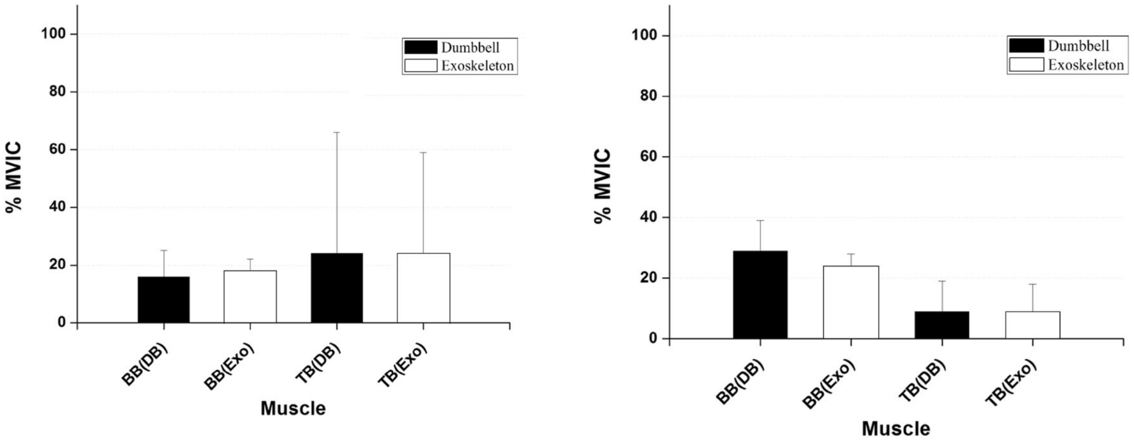
(b) Loading at 3-kg

Fig. 5 Muscle activation levels during the shoulder abd–add exercise at 1-s lifting and 1-s lowering motion speeds



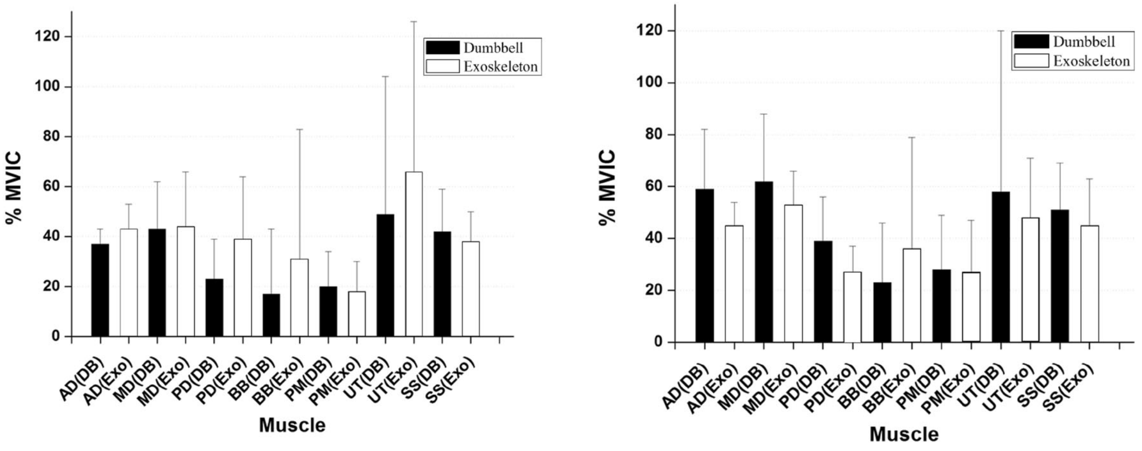
(a) Loading at 1-kg **(b)** Loading at 3-kg

Fig. 6 Muscle activation levels during the shoulder flx–ext exercise at 1-s lifting and 1-s lowering motion speeds



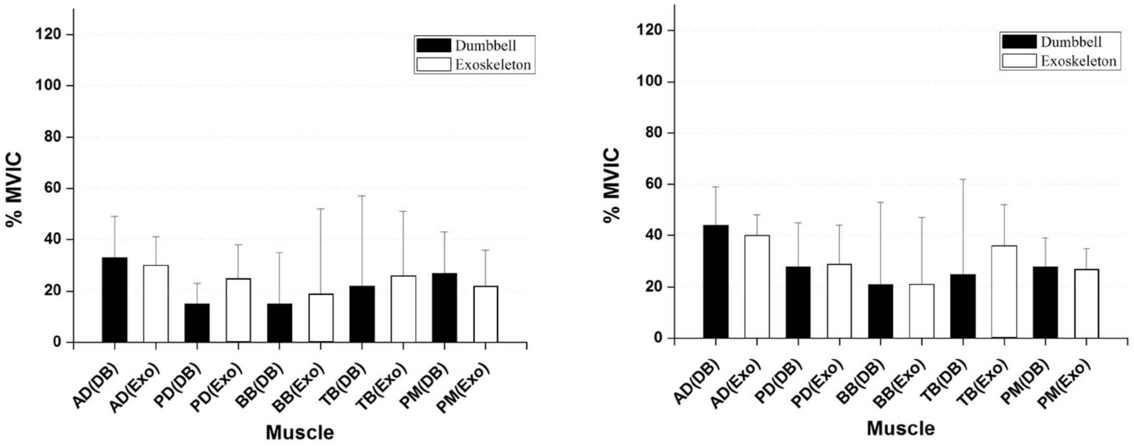
(a) Loading at 1-kg **(b)** Loading at 3-kg

Fig. 7 Muscle activation levels during the elbow flx–ext exercise at 1-s lifting and 1-s lowering motion speeds



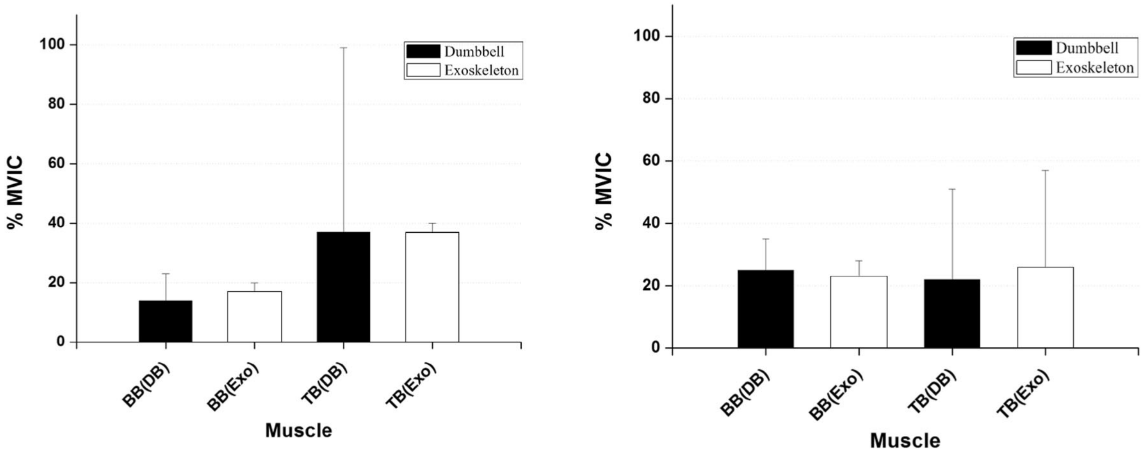
(a) Loading at 1-kg **(b)** Loading at 3-kg

Fig. 8 Muscle activation levels during the shoulder abd–add exercise at 2-s lifting and 2-s lowering motion speeds



(a) Loading at 1-kg **(b)** Loading at 3-kg

Fig. 9 Muscle activation levels during the shoulder flx–ext exercise at 2-s lifting and 2-s lowering motion speeds



(a) Loading at 1-kg **(b)** Loading at 3-kg

Fig. 10 Muscle activation levels during the elbow flexion–extension exercise at 2-s lifting and 2-s lowering motion speeds

in the elbow flx–ext exercise performed using 1- and 3-kg loadings at 1-s lifting and 1-s lowering motion speeds, and the values (Fig. 10a, b) for the TB in the elbow flx–ext exercise performed using 1- and 3-kg loadings at 2-s lifting and 2-s lowering motion speeds. The aforementioned results found for the dumbbell exercises can also be found for SLERT. The reason could be that the body uses compensation patterns to perform motions when strength and mobility are insufficient.

The P values of the Wilcoxon signed-rank test of the muscle activation levels of dumbbells and the spring-loaded exoskeleton for shoulder abd–add, shoulder flx–ext, and elbow flx–ext movements using 1-kg or 3-kg loadings at two motion speeds (1-s lifting, 1-s lowering; 2-s lifting, 2-s lowering) are listed in Table 2. All reported P values were two-tailed and were considered significant if less than 0.05. As illustrated in Table 2, most results were nonsignificant, which confirmed our hypothesis that muscle activation levels while using dumbbells and the spring-loaded exoskeleton during pairwise movements would be notably similar.

Some of the significant values were found and listed as follows: values for the BB and SS in the shoulder abd–add exercise performed using 1-kg loadings at 2-s lifting and 2-s lowering motion speeds; values for the PD in the shoulder flx–ext exercise performed using 1-kg loadings at 2-s lifting and 2-s lowering motion speeds; and values for the SS in elbow flx–ext exercise performed using 1-kg loadings at 1-s lifting and 1-s lowing motion speeds. As shown in Table 2, most of the Wilcoxon signed-rank test results were found to be nonsignificant. Within these tests, only 4 of 56 P values were significant. In other words, exercises with the spring-loaded exoskeleton and those with dumbbells are similar in muscle activation levels. The four significant results were observed in the comparisons by using 1-kg loading. A possible reason might be that the

Table 2 Analysis of the Wilcoxon signed-rank test results for dumbbell and exoskeleton exercises

	AD	MD	PD	BB	TB	PM	UT	SS	N
Shoulder abd–add									
1 kg_1 s	0.144	0.144	0.144	0.068		1.000	0.068	0.068	4
1 kg_2 s	0.080	0.138	0.138	0.043*		0.686	0.138	0.043*	5
3 kg_1 s	0.180	0.180	0.180	0.180		0.180	0.655	0.655	2
3 kg_2 s	0.715	0.273	0.144	0.715		1.000	0.273	0.068	4
Shoulder flx–ext									
1 kg_1 s	0.500		0.893	0.138	0.500	0.500			5
1 kg_2 s	0.173		0.046*	0.116	0.600	0.173			6
3 kg_1 s	0.686		0.345	0.345	0.080	0.686			5
3 kg_2 s	0.600		0.753	0.463	0.917	0.600			6
Elbow flx–ext									
1 kg_1 s				0.028*	0.345				6
1 kg_2 s				0.068	0.715				4
3 kg_1 s				0.463	0.173				6
3kg_2 s				0.500	0.893				5

* $P < 0.05$; two-tailed Wilcoxon signed-rank test. The sample number (N) for each test is listed on the right side of the table

movement was more likely to be disturbed with lighter loadings, and the outcome of the hypothesis test with the small sample size could have varied markedly when the disturbance occurred. Further research is necessary to understand the specific reasons for the few inconsistencies of the results.

The results of the Wilcoxon signed-rank test indicated that most of the corresponding muscle activation levels during pairwise motions were not significantly different; in other words, significant differences were not observed in the muscle activation levels of most exercises under different training intensities using dumbbells or a spring-loaded upper limb exoskeleton as loads, indicating that the muscle activation levels were similar between using the two types of applied loads. These findings confirm that a spring-loaded exoskeleton can exert similar training effects to those of dumbbells.

Overall, the spring-loaded exoskeleton produced similar results to those of dumbbells in the performance of the designated movements in this study; however, inconsistencies remained in the test results, possibly caused by errors in the experimental procedure, data processing, or precision of the spring-loaded exoskeleton. To prevent inaccuracies in future testing, the standardized procedure described in the aforementioned experimental should be further improved, and the same study examiner should be used for each collection assessment. According to our research, no study has recommended such a method for providing results that are more reliable. The proper location for electrode placements is also a critical topic that has been debated within the last two decades [33]. Despite strict adherence to methods and protocols, the production of MVIC still depends on participant exertion of maximum effort, which differs greatly by personal ability; therefore, we cannot guarantee that MVIC can always be achieved. The same concerns apply to the variation of the applied resistance. Therefore, it is suggested that to maintain consistency, the positioning and resistance applied should be conducted by the same person. In our study, the low number of participants affected the confidence of our statistical findings. However, this study provides evidence regarding the use of two types of exercise equipment to further support the feasibility of the SLERT, comparing the muscle activation levels for designated exercises performed using dumbbells with those performed using the spring-loaded upper limb exoskeleton.

4 Conclusions

In this experimental study, EMG data were obtained from six healthy participants, comprising three males and three females. The muscle activation levels and applied loads were quantified in this study for three exercises: shoulder abd–add, shoulder flx–ext, and elbow flx–ext exercises. The loads were applied using dumbbells or a spring-loaded exoskeleton at two motion speeds. In general, the muscle activation levels of the exercises performed using dumbbells and the spring-loaded upper limb exoskeleton exhibited high similarity, although some muscle activation levels did not match expectations. The Wilcoxon signed-rank test revealed that most muscle activation levels for the pairwise motions were nonsignificant, suggesting that the muscle activation levels were similar even if the loads were induced by different sources. This confirms that a spring-loaded exoskeleton can exert training effects similar to those of dumbbells. This study provides further evidence to support the feasibility of the SLERT. To assist patients suffering from muscle degeneration in improving their dynamic stability or recovering physiological functions, resistance exercise has been widely adopted. The upper limb spring-loaded exoskeleton could be used for muscle strength recovery, especially for physically challenged or elderly people because it has the advantages of injury prevention and high DOFs in exercises. This device may also be used for home-based rehabilitation in the absence of a professional instructor or therapist. However, the glenohumeral joint is complicated, with numerous muscles involved in a simple movement, and only eight muscles were assessed. Additionally, the small sample size limited the significance of our findings. Nevertheless, this study described a practical method and collected valuable data for the improvement of future study designs and the development of SLERTs.

Compliance with Ethical Standards

Conflict of interest Tzong-Ming Wu, Chih-Han Yang, and Dar-Zen Chen declare that they have no conflict of interest.

Ethical approval The judgement reference number is 9703007.

Informed consent Informed consent was obtained from all individual participants included in this study.

Statement of human rights All procedures performed in this study involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Statement on the welfare of animals This study did not contain any procedures involving animals.

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