SSRG International Journal of Mechanical Engineering
ISSN: 2348 – 8360 / https://doi.org/10.14445/23488360/IJME-V10I4P101

Volume 10 Issue 4, 1-6, April 2023
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Original Article

Effect Valuation of Passive Exoskeleton for Overhead Work

Le Toan Thang

Faculty of Mechanical Engineering, University of Transport and Communications, Hanoi, Vietnam

Received: 11 February 2023 Revised: 19 March 2023 Accepted: 30 March 2023 Published: 10 April 2023

Abstract - *Overhead work is a main risk factor for upper limb work-related musculoskeletal disorders. In this paper, the research team evaluated the effectiveness of a passive exoskeleton(PE) with a mechanical arm linked to the exoskeleton body as an assistive device for overhead work. Ten male volunteers participated in the research by effectuating repetitive overhead lifting tasks using each of three payloads: (1kg, 3kg, and 6kg) and with/without passive exoskeleton (PE). The performance evaluation was then conducted by analyzing the electromyography (EMG) and ratings of perceived discomfort(RPD) of the shoulders and back muscles obtained from experiments.*

Keywords - *Overhead work, Passive exoskeleton, Payloads, Electromyography.*

1. Introduction

Work-related musculoskeletal disorders (WMSD) in the upper limb are frequent in industrial work, mechanics, agriculture, and construction. WMDS is often caused by repetitive tasks such as overhead lifting work. In the United States, the reported number of 2011 musculoskeletal diseases incidence: in the shoulder is 13%, and lumbar is 42% [1]. Shoulders injuries are serious problems, with the average number of days off for shoulder ailments being reported as 23 days (compared with 11 days for other injuries) [1, 11]. Musculoskeletal disorders often have repetitiveness and prolonged elements. Research has shown that overhead lifting tasks have been suggested to be one of the major causes of these diseases in musculoskeletal [2-7],[18]. Those jobs that need to lift heavy objects overhead are very common in the mechanical manufacturing and construction industries as drilling, bolting, and cutting materials.

In recent years, there have been many scientific types of research to resolve upper limb WMSD, including both theoretical and experimental [9]-[17]. Although extensive studies have been conducted over a long period and guidelines for such efforts are available, there is not enough information to judge the effectiveness of such tasks. Laboratory simulations have been performed for overhead lifting work and varied the duty cycle (work/rest ratio), arms reach, and hand orientation of a tapping task. The study results also show that the duration of endurance and the time of onset of fatigue are indicated by feelings of discomfort and a reduction in muscle strength. Significant effects of the cyclical activities were found on fatigue times; prolonged and repetitive overhead lifting objects also increase muscle fatigue. The dismemberment of muscle endurance and fatigue time are presented as standards for evaluating overhead work.

This paper deals with presents experimental research evaluating the effectiveness of a passive exoskeleton for tasks requiring overhead lifting works. The purpose of the research is to reduce the force exerted by heavy objects on the shoulders and back muscles. The passive exoskeleton system (Fig1) supports heavy objects such as machine tools and transmits force to the ground, reducing the force exerted on the shoulder and back muscles. This paper evaluates the effect of using a passive exoskeleton for overhead lifting. It is performed by comparing lifting objects with the support of the passive exoskeleton with the case of lifting objects without the help of the passive exoskeleton through electromyography signals obtained from the shoulder and back muscles. In addition, it is also assessed through the feedback of the experimental participants.

2. Materials and Methods

2.1. Participants

This research considers ten right-handed male participants recruited from the University of Transport and Communication. All participants were of average height 1m70 and average weight 70kg, between ages 18 and 22, and reported moderate levels of physical activity with no recent history of musculoskeletal injuries. Although the study was not limited to male participants, no female participants were included because they could not complete all experimental conditions during an initial practice session.

2.2. Passive Exoskeleton (PE)

The passive exoskeleton system comprises a mechanical arm designed according to the passive gravity compensation mechanisms. The weight of the lifting object will be balanced with the elastic force of the two springs inside the arm. The geometrical dimensions of the arms are calculated to be suitable for an adult. The mechanical arm can move flexibly according to the operator's movement by hinged joints. The mechanical arm is linked to the exoskeleton to form a complete passive exoskeleton system that lifts the weight and transmits the force of the weight to the ground. Thus reducing the force exerted by heavy objects on the operator. (Fig 1)

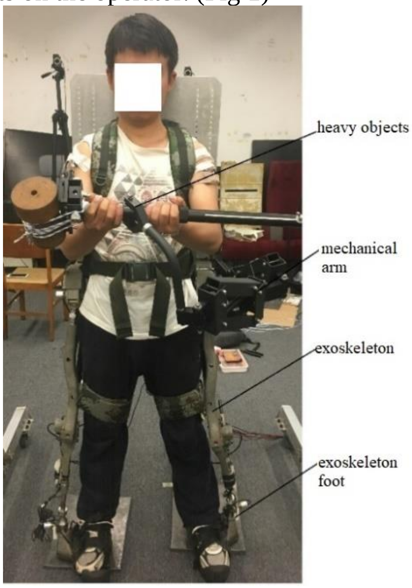

Fig. 1 The passive exoskeleton with a mechanical arm

2.3. Experimental Task

The experimental task simulated occupational overhead work, which is lifting and holding heavy objects overhead. Experimental tasks do not simulate any specific occupational situations but instead were used to capture the need to work overhead lifting and to do so with varied loads, predetermined rest and work cycles, and precision demands.

The task of each of those participants was to perform 6 lifts in 60 s, of which 3 lifted with/without the help of a passive exoskeleton (Figure 2). The lifting load is light load (1kg), medium load (3kg), and heavy load (6kg). During the work period, participants were asked to grasp heavy objects with both hands.

2.4. Experimental Process

The participants completed two experimental parts segregated by at least five days [10]. Before experimenting, the participants were asked to practice overhead lifting at different loads with and without PE, and then formal testing was conducted. In the first experimental session, the participants lifted payloads overhead without the help of PE. In the second part of the test, taken five days later, the participants lifted payloads overhead with the support of PE.

EMG signals were collected from the shoulder and back muscles of the participants in each experiment. EMG signals were monitored bilaterally from the same body and were specifically collected from the anterior deltoid (AD), medial deltoid (MD), and lumbar (LB) muscles on the left and right sides of the body [10]-[12].

During the experiment, participants were also asked to provide ratings of discomfort (RPD) using the Borg CR10 scale [26] to assess the shoulders and back muscles' ratings of perceived discomfort. RPD values of participants were also recorded for shoulders, low back for each experiment, and both the left and right sides of the body.

a **b**

Fig. 2 Experimental working for the overhead task without the PE (a) and with PE (b)

2.5. EMG signal measuring device and processing

In recent years, There have been many scientific studies on recording and processing EMG signals [19]-

[25]. In this research, EMG signal recording equipment and processing devices are produced by Noraxon, USA.

The measuring input device is attached to the electrode sensor's two poles, which are glued to the skin's surface. From these, the EMG signal on the skin's surface can be sent to the computer by the transducer and recorded. The transducer received the electromyography signal data transmitted to the computer by wifi signal.

The specialized software NORAXON MR3.8 installed on the computer measures EMG. Each participant collected the EMG signal on a separate recording. On the record, 6 signal channels can be obtained corresponding to the locations of the measuring input device, which are left anterior deltoid (LAD) muscle, right anterior deltoid (RAD) muscle, left middle deltoid (LMD) muscle, right middle deltoid (RMD) muscle, left lumbar (LLB) muscle and right lumbar (RLB) muscle[11].

The EMG raw signal after receiving has been processed by NORAXON MR3.8 software through steps such as filtering the raw signal, rectifying, and smoothing the signal. Then NORAXON MR3.8 software calculated the EMG root mean square (RMS) values, and the median of the shoulders and lumbar muscle activity was determined (Fig 3). The median EMG values obtained during the experiment were then standardized to the reference values.

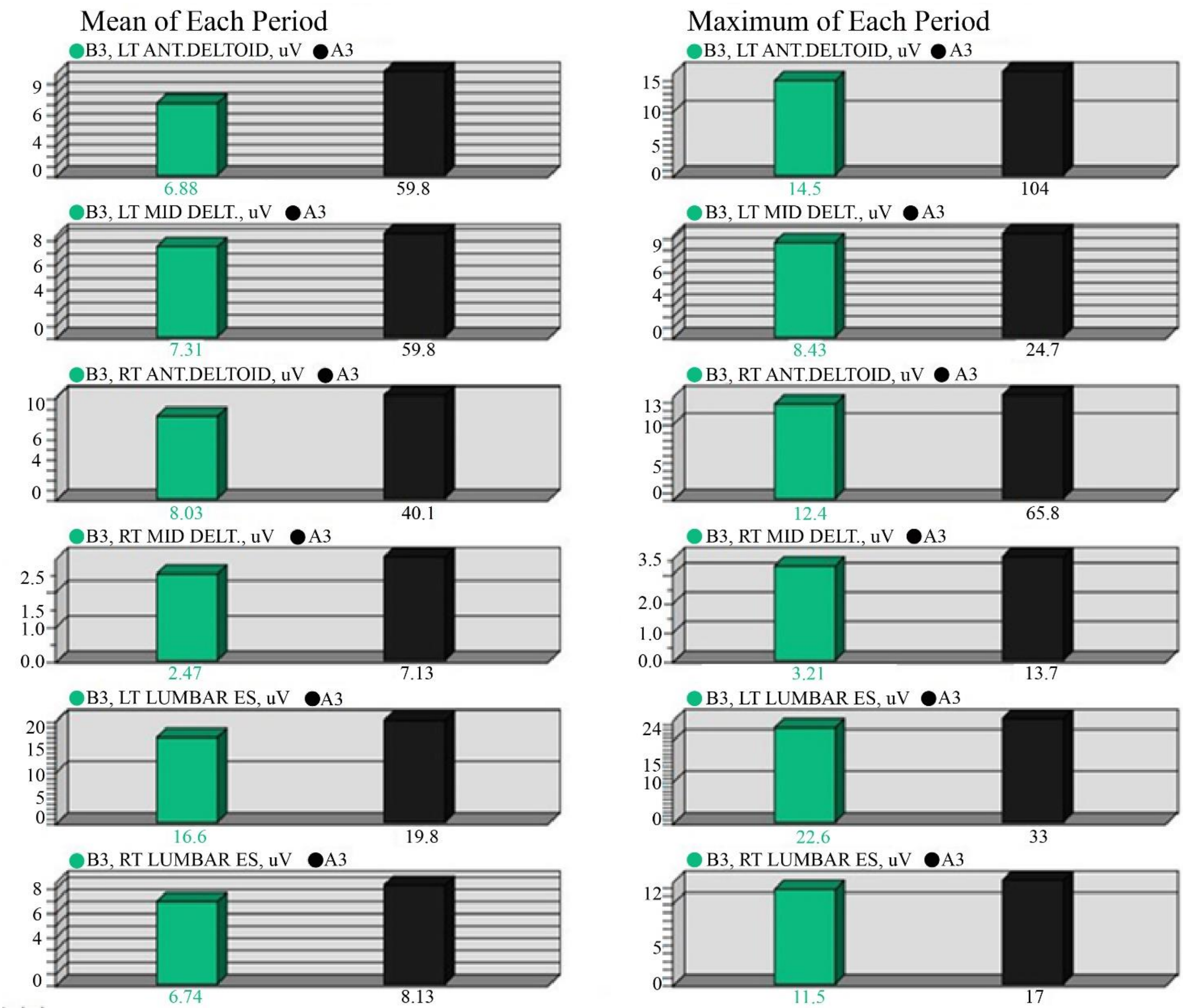

Fig. 3 The EMG root mean square (RMS) values obtained during the experiment

3. Results and Discussions

3.1. Electromyography (EMG)

The EMG root mean square (RMS) values statistical results of the overhead lifting work tasks in this research were presented in Table 1 and exposed in Figs. 4, 5, and 6. The results showed that Intervention of PE with all of the payloads had significant main effects on median nEMG values for most of the shoulder and lumbar muscle groups monitored.

Table 1. Results for median nEMG values

	median nEMG values light payload Q=1kg (μV)		**median nEMG values** medium payload Q=3kg (μV)		**median nEMG values** heavy payload Q=6kg (μV)	
	With PE support	Without PE support	**With PE support**	Without PE support	**With PE support**	Without PE support
LAD	**4.28**	33.2	**4.6**	34.4	**6.88**	59.8
RAD	**7.7**	31.2	**7.92**	33.7	**8.03**	40.1
LMD	**7.1**	12.2	**7.24**	12.7	**7.31**	13.5
RMD	**2.3**	6.7	**2.4**	7.04	**2.47**	7.13
LLB	**10.2**	12.2	**12**	14.4	**16.6**	19.8
RLB	**6.4**	7.68	**6.6**	7.9	**6.74**	8.13

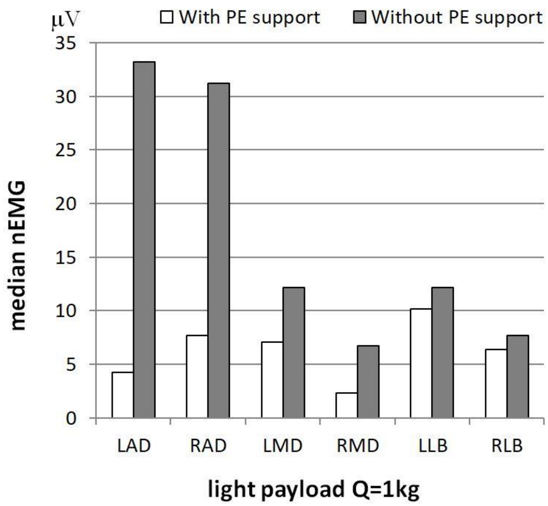

Fig. 4 Intervention of PE with light payload effects on median values of EMG for the right and left anterior deltoid muscle (AD), middle deltoid muscle (MD) and lumbar muscle (LB)

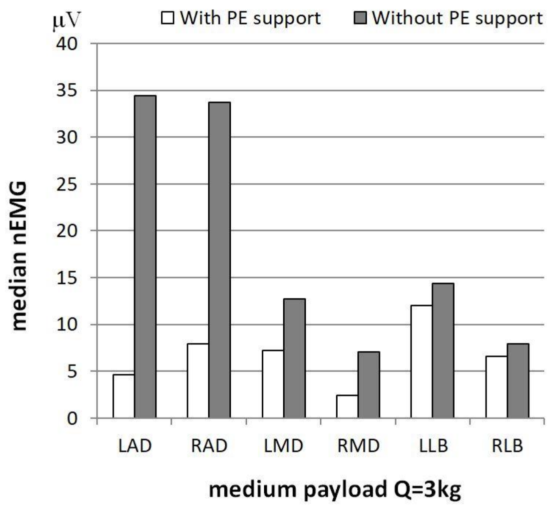

Fig. 5 Intervention of PE with medium payload effects on median values of EMG for the right and left anterior deltoid muscle (AD), middle deltoid muscle (MD) and lumbar muscle (LB)

At all of the payloads, the PE reduced median nEMG values. Mean EMG values had the greatest reduction with anterior deltoid (AD) and medial deltoid (MD) and with minimal decrease in lumbar (LB) muscle for both the left and right sides of the body.

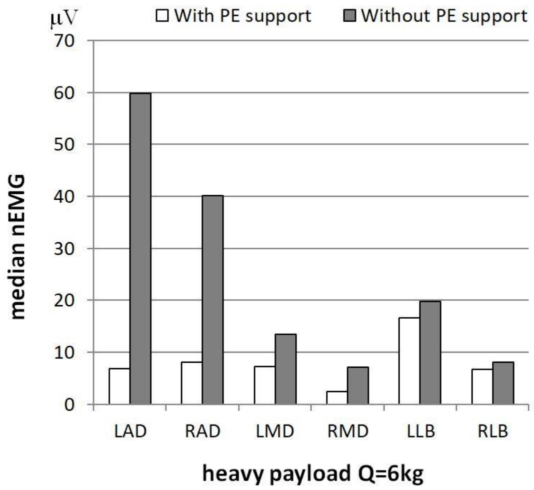

Fig. 6 Intervention of PE with heavy payload effects on median values of EMG for the right and left anterior deltoid (AD), middle deltoid (MD) and lumbar muscle (LB)

Under heavy payload, median nEMG values of LAD were significantly reduced to 85%, RAD reduced by 80%, RMD reduced by 65.3%, LMD reduced by 45.8%, LLB reduced by 16.1%, and RLB reduced by 17%. The reduction of median EMG values in all these muscles was also very significant for light and medium payloads. The use of PE reduced the median nEMG values of all the shoulder and lumbar muscles, especially at the heavy payload. With the support of the PE, when the participants performed the task of lifting objects, median nEMG values for the LAD, RAD, LMD, RMD, RLB, and LLB muscles reduced significantly. That recommended the level of fatigue in these muscles was decreased.

The results have also shown that with overhead lifting work, the anterior deltoid (AD) muscle is mainly active because the median nEMG values of the anterior deltoid (AD) muscle is maximum and because the participants were all right-handed. Hence, the median nEMG values of left muscles were always higher than right muscles in all muscle groups.

3.2. Ratings of Perceived Discomfort (RPD)

The mean values of RPD notified by all participants were below five levels at three loads corresponding to very light, light, average, heavy, and very heavy (Fig 7). The help of the PE normally reduced the total discomfort when participants performed tasks at all payloads. Especially with medium and heavy payloads, all participants reported that the load on their shoulder and back muscles were light. Participants reported that the mean RPD values for their shoulders and back were significantly reduced with the help of PE, which was agreeable with the previous studies. [10-12].

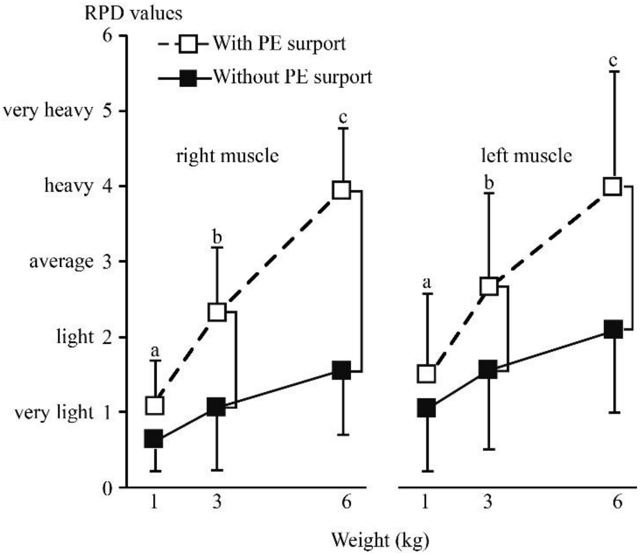

Fig. 7 Intervention of PE with payloads effects on ratings of perceived discomfort (RPD)

It showed that the support of the PE had effects on decreasing the discomfort and muscle fatigue of the shoulders and back in the overhead lifting work. With medium and heavy payloads, all participants only feel the degree of discomfort at very light and light compared to medium and heavy in cases without support of the PE. With the support of the PE, the overall RPD ratings at the medium and heavy payload levels decreased the most, which shows the obvious effect of PE with medium load and heavy load. This shows that the supporting effect of PE in overhead lifting work is very significant.

4. Conclusion

Overhead lifting work has been seen as a main risk factor for upper limb WMSD. The deal of this paper is to valuation the effects of the passive exoskeleton (PE) for overhead lifting work tasks. The EMG signal measures the working state of muscles, and then the mean value of

EMG is evaluated and compared with the case with/without PE support. Muscle fatigue was also assessed through the mean value of RPD using the Borg CR10 scale to rate the shoulders and back muscles of the participants when they performed lifting overhead payloads.

The test results showed that the support of the PE was effective for the participants to perform lifting overhead payloads in the simulation experiment tasks. Participants with support of the PE have decreased median nEMG values for the LAD, RAD, RMD, and LMD muscles reduced by 30% to 80% compared to the case without the help of the PE; this recommends that the fatigue in these muscles was reduced when using the PE. Therefore, it can be seen that the PE's support has likely decreased the risks of upper limb work-related musculoskeletal disorders in repetitive overhead lifting works. The mean of RPD values also showed that the PE had effects on decreasing the discomfort of shoulders and back muscles when the participants performed lifting overhead payloads.

In summary, this research showed that the support of the passive exoskeleton could be effective in supporting workers in performing overhead lifting works; the effects of support were especially significant in the medium and heavy payload. Overhead lifting works cannot be completely replaced in modern work, and it is a main put at-risk factor for upper limb WMSD, according to this research. Therefore, the research and application of supporting devices such as passive exoskeletons in practical work are essential.

References

[1] U. S. Bureau of Labor Statistics, Nonfatal Occupational Injuries and Illnesses Requiring Days Away From Work, 2011. [Online]. Available: https://www.bls.gov/news.release/osh2.toc.htm

[2] Peter Buckle and Dr. Jason Devereux, Work-Related Neck and Upper Limb Musculoskeletal Disorders. [Online]. Available: https://moodle.adaptland.it/pluginfile.php/14054/mod_resource/content/0/P.%20Buckle%2C%20%20J.%20Devereux%2C%20Work-related%20upper%20limb%20musculoskeletal%20disorders.%20European%20Agency%20for%20Safety%20and%20Health%20at%20Work.pdf

[3] Peter Buckle, and Dr. Jason Devereux, "The State of Scientific Knowledge Regarding Work Related Neck and Upper Limb Musculoskeletal Disorders," *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, vol. 44, no. 30, 2000. [CrossRef] [Google Scholar] [Publisher Link]

[4] Grieve, Jason R, and Dickerson, Clark R, "Overhead Work: Identification of Evidence-Based Exposure Guidelines," *Occupational Ergonomics*, vol.8, no. 1, pp. 53-66, 2008. [CrossRef] [Google Scholar] [Publisher Link]

[5] Kai Österberg MS et al., "A Comparison of Approaches to Modeling the Relationship Between Ergonomic Exposures and Upper Extremity Disorders," *American Journal of Industrial* Medicine, vol. 37, no. 6, pp. 645– 655, 2000. [CrossRef] [Google Scholar] [Publisher Link]

[6] William T Stauber, "Factors Involved in Strain-Induced Injury in Skeletal Muscles and Outcomes of Prolonged Exposures," *Journal of Electromyography and Kinesiology*, vol. 14, no. 1, pp. 61 – 70, 2004. [CrossRef] [Google Scholar] [Publisher Link]

[7] Maury A. Nussbaum, "Fatigue and Endurance Limits During Intermittent Overhead Work," *AIHAJ-American Industrial Hygiene Association*, vol. 62, no. 4, pp. 446-456, 200. [CrossRef] [Google Scholar] [Publisher Link]

[8] Huiling Zou, and Qianbing Duan, "Infrared Thermal-Imaging Method Applied to Muscle Behaviour Study of Sport Skill (the Roundhouse Kick of Martial Arts as an Example)," *SSRG International Journal of Humanities and Social Science*, vol. 6, no. 5, pp. 73-79, 2019. [CrossRef] [Publisher Link]

[9] Ruprecht Altenburger, Daniel Scherly, and Konrad S. Stadler, "Design of a Passive, Iso-Elastic Upper Limb Exoskeleton for Gravity Compensation," *Robomech Journal*, vol. 3, 2016. [CrossRef] [Google Scholar] [Publisher Link]

[10] Ehsan Rashedi et al., "Ergonomic Evaluation of a Wearable Assistive Device for Overhead Work," *Ergonomics*, vol. 57, no. 12, pp. 1864-1874, 2014. [CrossRef] [Google Scholar] [Publisher Link]

[11] Le Toan Thang: "Evaluation of a Passive Robot Arm for Overhead Work: Experimental Approach," *SSRG International Journal of Mechanical Engineering*, vol. 9, no. 4, pp. 1-10, 2022. [CrossRef] [Publisher Link]

[12] Peng Yin et al., "Effects of a Passive Upper Extremity Exoskeleton for Overhead Tasks," *Journal of Electromyography and Kinesiology*, vol. 55, p. 102478, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[13] Yasuyuki Yamada et al., "Overhead Work Assist with Passive Gravity Compensation Mechanism and Horizontal Link Mechanism for Agriculture," *29th IEEE International Conference On Robot and Human Interactive Communication (RO-MAN)*, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[14] Yaodong Zhang et al., "Research on New Type of Live Working Robot System for Overhead Transmission Lines," *IOP Conference Series: Journal of Physics*, vol. 1074, p. 012040, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[15] Mitsuhiro Tsuzura, Takashi Nakakuki, and Daigo Misaki: "A Mechanism Design of Waist Power Assist Suit for a Caregiver by Using Torsion Springs," *International Conference On Control, Automation and Systems (ICCAS 2013)*, 2013. [CrossRef] [Google Scholar] [Publisher Link]

[16] Alexander Otten et al., "A Hydraulically Powered Self-Aligning Upper Limb Exoskeleton," *IEEE/ASME Transactions On Mechatronics*, vol. 20, no. 5, pp. 2285-98, 2015. [CrossRef] [Google Scholar] [Publisher Link]

[17] Michiel P. De Looze et al., "Exoskeletons for Industrial Application and Their Potential Effects on Physical Work Load," *Ergonomics*, vol. 59, no. 5, pp. 671-681, 2016. [CrossRef] [Google Scholar] [Publisher Link]

[18] Deepti Sood, Maury A Nussbaum, and Kris Hager, "Fatigue During Prolonged Intermittent Overhead Work: Reliability of Measures and Effects of Working Height," *Ergonomics*, vol. 50, no. 4, pp. 497– 513, 2007. [CrossRef] [Google Scholar] [Publisher Link]

[19] F. S. Ayachi, S. Boudaoud, and C. Marque, "Evaluation of Muscle Force Classification Using Shape Analysis of the sEMG Probability Density Function: aSimulation Study," *Medical & Biological Engineering & Computing*, vol. 52, pp. 673–684, 2014. [CrossRef] [Google Scholar] [Publisher Link]

[20] A. Holtermann et al., "Motor Unit Synchronization During Fatigue: Described with a Novel SEMG Method Based on Large Motor Unit Samples," *Journal of Electromyography and Kinesiology*, vol. 19, no. 2, pp. 232–241, 2009. [CrossRef] [Google Scholar] [Publisher Link]

[21] M.S. Hussain et al., "Electromyography Signal Analysis Using Wavelet Transform and Higher Order Statistics to Determine Muscle Contraction," *Expert Systems*, vol. 26, no. 1, pp. 35–48, 2009. [CrossRef] [Google Scholar] [Publisher Link]

[22] Mario Cifrek et al., "Surface EMG Based Muscle Fatigue Evaluation in Biomechanics," *Clinical Biomechanics*, vol. 24, no. 4, pp. 327–340, 2009. [CrossRef] [Google Scholar] [Publisher Link]

[23] M. Reaz, M. Hussain, and F. Mohd-Yasin: "Techniques of EMG Signal Analysis: Detection, Processing, Classification, and Applications," *Biological Procedures Online*, vol. 8, pp. 11-35, 2006. [CrossRef] [Google Scholar] [Publisher Link]

[24] T. J. Herda et al., "The Influence of Electromyographic Recording Methods and the Innervation Zone on the Mean Power Frequency-Torque Relationships," *Journal of Electromyography and Kinesiology*, vol. 25, no. 3, pp. 423-30, 2015. [CrossRef] [Google Scholar] [Publisher Link]

[25] Sridhar P. Arjunan, Dinesh K. Kumar, and Ganesh Naik, "Computation and Evaluation of Features of Surface Electromyogram to Identify the Force of Muscle Contraction and Muscle Fatigue," *Biomed Research International*, vol. 2014, 2014. [CrossRef] [Google Scholar] [Publisher Link]

[26] Borg, G, The Borg CR10 Scale® Folder, "*A Method for Measuring Intensity of Experience*," Borg Perception, Hasselby, Sweden.