World Academy of Science, Engineering and Technology
International Journal of Mechanical and Mechatronics Engineering
Vol:15, No:3, 2021

An Ergonomic Evaluation of Three Load Carriage Systems for Reducing Muscle Activity of Trunk and Lower Extremities during Giant Puppet Performing Tasks

Cathy SW. Chow, Kristina Shin, Faming Wang, B. C. L. So

***Abstract*—**During some dynamic giant puppet performances, an ergonomically designed load carrier system is necessary for the puppeteers to carry a giant puppet body's heavy load with minimum muscle stress. A load carrier (i.e. prototype) was designed with two small wheels on the foot; and a hybrid spring device on the knee in order to assist the sliding and knee bending movements respectively. Thus, the purpose of this study was to evaluate the effect of three load carriers including two other commercially available load mounting systems, Tepex and SuitX, and the prototype. Ten male participants were recruited for the experiment. Surface electromyography (sEMG) was used to collect the participants' muscle activities during forward moving and bouncing and with and without load of 11.1 kg that was 60 cm above the shoulder. Five bilateral muscles including the lumbar erector spinae (LES), rectus femoris (RF), bicep femoris (BF), tibialis anterior (TA), and gastrocnemius (GM) were selected for data collection. During forward moving task, the sEMG data showed smallest muscle activities by Tepex harness which exhibited consistently the lowest, compared with the prototype and SuitX which were significantly higher on left LES 68.99% and 64.99%, right LES 26.57% and 82.45%; left RF 87.71% and 47.61%, right RF 143.57% and 24.28%; left BF 80.21% and 22.23%, right BF 96.02% and 21.83%; right TA 6.32% and 4.47%; left GM 5.89% and 12.35% respectively. The result above reflected mobility was highly restricted by tested exoskeleton devices. On the other hand, the sEMG data from bouncing task showed the smallest muscle activities by prototype which exhibited consistently the lowest, compared with the Tepex harness and SuitX which were significantly lower on lLES 6.65% and 104.93, rLES 23.56% and 92.19%; lBF 33.21% and 93.26% and rBF 24.70% and 81.16%; lTA 46.51% and 191.02%; rTA 12.75% and 125.76%; IGM 31.54% and 68.36%; rGM 95.95% and 96.43% respectively.

***Keywords*—**Exoskeleton, load carriage aid, giant puppet performers, electromyography.

Cathy SW. Chow is with the Institute of Textiles & Clothing, The Hong Kong Polytechnic University, HK (phone: 852-9650-4596; e-mail: cathychow76@gmail.com).
Kristina Shin is with the Institute of Textiles & Clothing, The Hong Kong Polytechnic University, HK (phone: 852-2766-6295; e-mail: kristina.shin@polyu.edu.hk).
Faming Wang is with Department of Architecture at Central South University, China (phone: 86-137-9446-9070; e-mail: dr.famingwang@gmail.com).
B.C.L.So is with the Department of Rehabilitation Sciences, The Hong Kong Polytechnic University, HK (phone: 852-2766-4377; e-mail: billy.so@polyu.edu.hk).

I. Introduction

EXTREME load carrier systems commonly used in the industry challenge the puppet operators with not only the accumulation of muscle stress and strain but also the risk of permanent musculoskeletal impairment from the complex tasks including bouncing, forward leg shifting and moving. The traditional harness systems currently used in the industry, such as the Tepex harness device, are found to be inefficient in alleviating the muscle output in most performing situations.

There has been a numerous effort to find an effective load carrying solution. NASA Task Load Index (NASA-TLX) that defines the subjective experience of total workload with weighted variables including mental, physical, temporal demands, frustration, effort for performing a variety of activities [1] demonstrates the effort. However, Centers for Disease Control and Prevention (CDC) and National Institute for Occupational Safety and Health (NIOSH) have not reviewed the evidence proving the wearable exoskeletons as a prevention measure for workplace musculoskeletal injuries and illnesses.

According to a systematic review of [2], most of 40 scientific studies are done over 20 years (1995-2014) on the exoskeleton's effect on reducing musculoskeletal loading. It was discovered that most of studies were conducted in the laboratory environment settings without further information on workers' acceptance and adoption of the devices and long-term use in real work situations.

The recent studies found that the exoskeleton systems were effective for heavy lifting tasks [3], [4]; ES muscle activity reduction during repetitive lifting tasks in the industry setting [5], [6]; walking tasks with heavy load in logistic fields [7].

Although these various research studies emphasize the needs for the assistive wearable exoskeleton device design and development to reduce the muscle strain and risk of injury, there has been few research studies [8] done in this area. In addition, the effect of exoskeleton application on ES muscle activity in particular lower extremities, during the rigorous puppet performance, is unknown. The exoskeleton technologies could augment physical capabilities and mitigate injury not only in giant puppet operating applications but also to heavy duty industrial workers and military soldiers. Therefore, the objective of this study is to investigate the effects of different exoskeleton structures (load carrier systems) by analyzing the sEMG of the related muscles. The results would contribute to the industry in a wider scope from the performance enhancement to the injury prevention.

II. Methodology

A. Design and Participants

This was a cross-sectional study. Ten healthy male participants (mean age: 35 ± 5.48, height: 178 ± 2 cm, weight: 74.5 ±10.05 kg and the body mass index (BMI): 23.41 ± 2.63 kg/m) who are working as a professional performer were recruited. The experienced performers were mainly recruited from local performing organizations, theme parks or theatres, including Ocean Park HK, HK Disneyland and Hong Kong Youth Arts Foundation (HKYAF). To ensure sufficient competence in giant puppet performing skills across participants, only those with at least two year of related experience were recruited. Participants were screened by an experienced puppet operating trainer for inclusion and exclusion criteria and suitable participants were recruited for the study. They were excluded if they had declared experienced any pain on the lower back or lower extremities area in the previous 6 months during the recruitment process. To avoid inducing any adverse events, only participants without any musculoskeletal symptoms were recruited for this study, as limited prior published studies [1] had evaluated the effects of exoskeleton application among lower back or lower extremities pain patients in performing with giant puppet

An information sheet was provided to and a signed informed consent was collected from recruited subjects prior to the starting of the trials. The protocol for this study was approved by Ethical Committee of The Hong Kong Polytechnic University Human Subjects Ethics Committee (Reference Number: HSEARS20191126003).

B. Apparatus

1. sEMG

A wireless sEMG device (aktos, myon A, Schwarzenburg, Switzerland) was used to measure muscle activity and local muscle activation over the LES RF, BF, TA and GM. Raw sEMG data were recorded from the wireless sEMG sensor at a sample rate of 2000 Hz using a 30-200 Hz band-pass filter. The average muscle activity of each muscle was normalized using its peak 1-s root mean square (RMS) value so the average was expressed as a percentage of the MVC (%MVC). Average RMS values for each muscle were obtained during 2 tasks of forward moving and bouncing. The power spectral density was computed from raw data by using a Fast Fourier Transform algorithm to transform the data.

Data processing was completed using MATLAB software (MathWorks Inc., Natrick, MA, USA).

2. Harness and Exoskeleton

The devices tested in the trial consisted of 3 mountings, the Tepex harness system, prototype and SuitX. Tepex is a supportive structure adapted from a recreational hiking backpack. SuitX includes BackX and LegX, a combined set of passive industrial exoskeleton (model AC, US Bionics Inc., California, USA), which is now available in the market and has been adopted for industrial usage. BackX was designed to support the thoracic and lumbar spine during forward bending and lifting tasks [8] (Fig. 2.) The LegX is a passive hip exoskeleton developed for work and industry. This passive exoskeleton is designed to remove some of the loads from the knees while crouching, squatting or standing for prolonged periods of time. It also reduces the stress on the knees and thereby reduces muscle fatigue and increases safety for workers using the exoskeleton. Prototype was built by the research team and it was obligated to cater load carriage and body bending specifically of puppet operators. All 3 mountings were extended with a frame and load (total 11.1 kg) and 0.6 m away from the highest point of the wearer's shoulders.

Baseline information, including demographic data, years of performing experience, and the injury history of lower back and lower extremities (if any) from the participants was collected. The study was conducted in a laboratory setting. Prior to donning the exoskeleton that was being tested, participants were taught by the trainer for the proper procedures to don, doff and practice the device (30 min) in the familiarization session. The sequence day of the test lasted 3 days, Tepex - prototype - SuitX; each test was separated at least 2 days.

Before the electrodes were attached, the skin was cleaned with alcohol pads. For detecting the related muscles, five pairs of sEMG electrodes were attached bilaterally over the muscle belly in the direction parallel to previous study [9] and were adhered at instructed locations. sEMG amplitude was normalized for the test muscles using 10-s maximum voluntary isometric contractions (MVC) performed against a manual resistance prior to the start of the trial. In performing MVC of LES, the subject lay facing down a flat plane and was asked to lift the trunk while resisting an external load applied by examiner near scapular region (Fig. 3) [10].

3. NASA-TLX

The scale of NASA-TLX was used to measure subjective and objective workload of each subject. In this experiment, NASA-TLX was adopted to evaluate correlations between the sub-scores weighted exoskeletal tasks of different mountings and the subjectively voted affordable performing time. Subjects rated the NASA-TLX six measures including mental requirements, physical requirements, temporal demand, work performance, effort and frustrations. The score was analyzed within each individual. Before workload evaluation, the subjects performed pairwise comparisons of the importance of elements of the workload involved in tasks [1]. The weighted workload (WWL) score was obtained by reading the position of each evaluation mark on a scale of 0 to 20 and multiplying by the weight for each measure determined by pairwise comparison, then averaging all the mountings.

World Academy of Science, Engineering and Technology
International Journal of Mechanical and Mechatronics Engineering
Vol:15, No:3, 2021

(a) (b)

Fig. 1 (a) Tepex system, total handling weight is 16.62 kg (structural flamed harness system, weighted 4.64 kg + external weighs 11.98 kg). (b) Prototype, total handling weight is 21.18 kg (structural Tepex frame for torso area 4.64 kg and exoskeleton for lower extremities 4.56 kg; system weighted total 9.24 kg + an Exoskeleton Harness & external weighs 11.98 kg)

Fig. 2 SuitX system, total handling weight is 22.68 kg. (BackX - Model AC hardware weighs 3.4 kg and LegX weight 6.2 kg, Exoskeleton Harness that weighs 1.1 kg + an external weight 11.98 kg)

Fig. 3 MVC (maximum voluntary isometric contractions) 1 - Lumbar by lifting the trunk from a prone position

Fig. 4 MVC 2 - BF by pressing against the leg proximal to the ankle in the direction of knee extension

Fig. 5 MVC 3 – RF: Subject extends the knee without rotating the thigh while experimenter applies pressure against the leg above the ankle in the direction of flexion

Fig. 6 MVC 4 & 5- TA and GM, Medialis Plantar flexion of the foot with emphasis on pulling the heel upward more than pushing the forefoot downward. For maximum pressure in this position it is necessary to apply pressure against the forefoot as well as against the calcaneus

Task 1: Forward moving

Fig. 7 Participants are required to walk/slide 6 left + 6 right steps alternately forth and back, totally 4 cycles, 48 gaits, total 4 x (20 +/- 4 sec.)

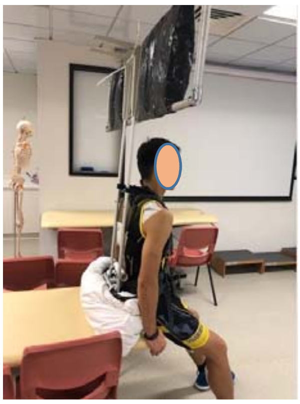

Fig. 8 A 2-min rest provided between each recording to avoid muscle fatigue from heavy exertion

Fig. 9 Task 2: Bouncing. Participants are required to bounce up-and-downs continuously for 20 sec for 1 recording

4. Questionnaire

After participants completed weighted and rated the TASA-TLX, they were interviewed with a set of questions which were organized to form the demographic information chart. Details included puppet performing experience duration, 2 sport specialty (if any), affordable exoskeletal (Tepex/ Prototype/SuitX) performing time and feeling after experienced using the mounting.

5. Data Analysis

Statistical analyses were performed using SPSS Statistics Software Version 21 (SPSS Inc., Chicago, IL, USA). Differences in the mean sEMG data and NASA-TLX were analyzed to assess the difference between groups without the violation of the parametric test assumption. Other potential confounding variables such as personal factors (work experience, age and sport specialty) were evaluated for the effects on the dependent variables using the Pearson's correlation coefficient. P value < 0.05 was considered to indicate statistical significance with balance between type 1 & II errors.

III. Results

A. Participants' Demographic Information

Table I showed the demographic characteristics of the ten experienced performers. The mean body height and weight are 1.78 ± 0.02 m and 74.5 ± 10.05 kg respectively.

B. Muscle Activity during 2 Tasks

As a result of observation from forward moving task in this study, the sEMG data (Fig. 11) showed that smallest muscle activities by Tepex harness which exhibited consistently lowest, compared with prototype and SuitX significantly higher on lLES 68.99% and 64.99%, rLES 26.57% and 82.45%; lRF 87.71% and 47.61%, rRF 143.57% and 24.28%; lBF 80.21% and 22.23%, rBF 96.02% and 21.83%; rTA 16.32% and 4.47%; lGM 5.89% and 12.35% respectively. The result above reflected mobility was highly restricted by tested exoskeleton devices.

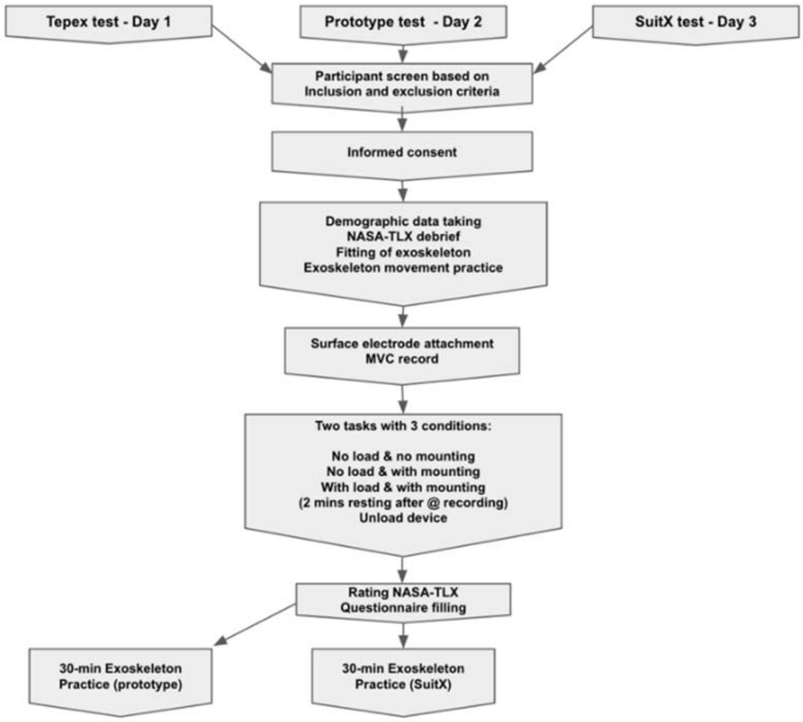

Fig. 10 Procedure flow chart

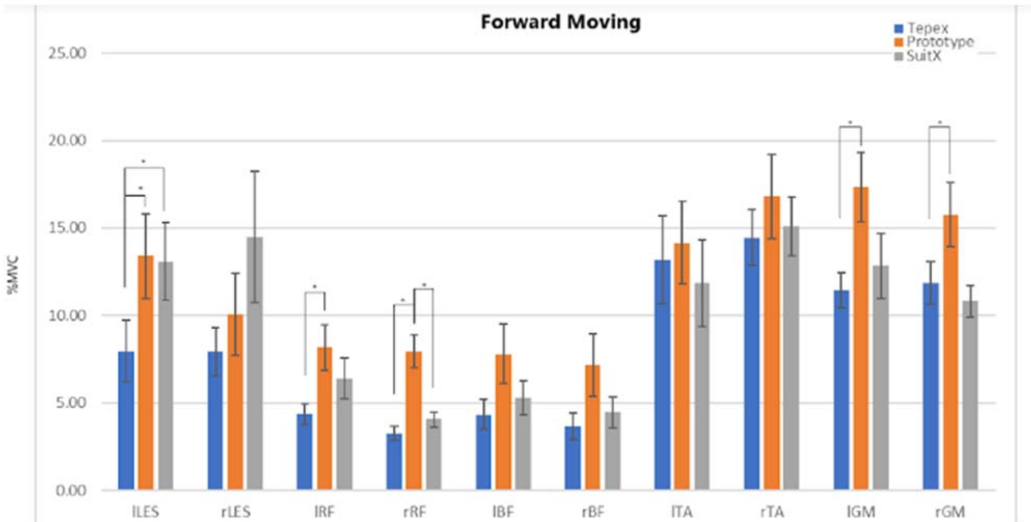

Fig. 11 Muscle activity of 2 erector spinae and 8 lower extremities muscles during forward moving task. *significant at $p < 0.05$

The sEMG data obtained in the bouncing task (Fig. 12) showed that smallest muscle activities by prototype which exhibited consistently lowest, compared with Tepex harness and SuitX significantly lower on lLES 6.65% and 104.93, rLES 23.56% and 92.19%; lBF 33.21% and 93.26% and rBF 24.70% and 81.16%; lTA 46.51% and 191.02%; rTA 12.75% and 125.76%; lGM 31.54% and 68.36%; rGM 95.95% and 96.43% respectively.

C. NASA_TLX Mountings

The six task-related measures reflected significantly high in mental demand and physical demand, while apparently lowest in temporal demand. This reflected physical output is the most concerned by the participants on using both exoskeletal models.

IV. Discussion

A. Difference in Muscle Activity between Three Different Mountings during Forwarding Moving Task

There has been limited documentation of trunk and lower extremities' muscle activation levels and patterns during the performance of puppet operation. Park et al. [11] observed in walking task that carriage of higher system weighted beyond 9 kg significantly affected on body balance and elevated peak EMG amplitude in the RF to maintain body balance and in the medial GM to increase propulsive force. In this study, greater handling loads of prototype and SuitX are 27.4% and 36.5% compared to Tepex system that also reflected significance higher EMG activation (Fig. 11). The result was consistent with the study of the prolonged load carriage, in which heavy exertion on muscle activity of lower limb including VL and GM increased significantly from the ranges of load carriage [12], [13]. The exoskeletons used in this study were found forward moving with difficulties and resistance on body balance. Hip abduction/adduction joint were adopted as passive elements for expanding the mobility and improving with greater lateral balancing was necessary [14].

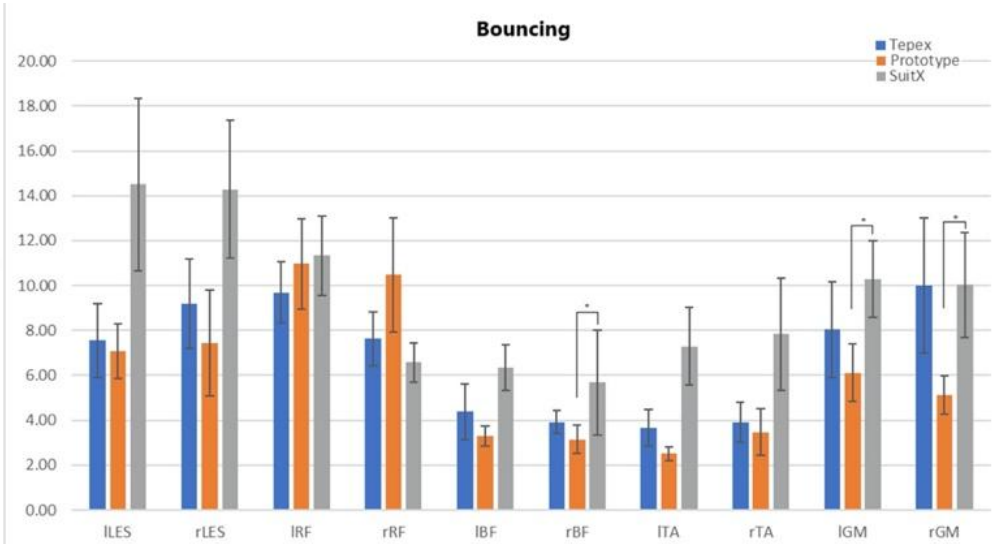

Fig. 12 Muscle activity of 2 erector spinae and 8 lower extremities muscles during bouncing task. *significant at $p < 0.05$

TABLE I
DEMOGRAPHIC CHARACTERISTICS OF THE TEN EXPERIENCED PERFORMERS

		Mean	SD	Min	Max	Frequency
Age		35.00	5.48	28	45	
Height (m)		1.78	0.02	1.75	1.84	
Weight (kg)		74.50	10.05	64	97	
Body Mass Index (kg/m²)		23.41	2.63	20.9	28.65	
Year of performing experience	Theme park actor	7.40	5.64	2	15	
	Freelance actor	11.90	5.70	6	25	
Sport specialty	Volleyball					1
	Football					4
	Basketball					5
	Badminton					1
	Climbing					2
	Swimming					3
	Baseball					1
	Skiing					1
	Gym					2
	Running					2
Dominant leg	Right					10
	Left					0

TABLE II
MEAN WWL SCORES OF THE SIX DOMAINS

	Mental demands	Physical demand	Temporal demands	Effort	Performance	Frustration
Tepex	6.15	12.56	2.30	5.11	8.19	1.00
Prototype	10.26	12.07	2.44	6.00	8.04	3.26
SuitX	13.30	15.63	2.74	8.44	6.48	7.04
Tepex_SD Error	1.3	2.69	0.73	1.26	1.91	0.35
Prototype_SD Error	2.2	2.83	1.65	0.96	1.79	1.06
SuitX_SD Error	3.1	2.78	1.82	1.87	1.68	2.23

TABLE III
CORRELATION BETWEEN AFFORDABLE OPERATING TIME AND MEAN OF SUB-SCORE OF 6 MEASURES

	Mental	Physical	Temporal	Effort	Performance	Frustration	WWL
Tepex	-0.25	-0.42	-0.27	-0.23	-0.25	-0.27	-0.55
Prototype	0.29	-0.78	-0.35	-0.33	0.45	-0.57	-0.50
SuitX	-0.03	-0.16	-0.42	-0.06	0.19	-0.13	-0.24

TABLE IV
CORRELATION CHART OF TOTAL SCORE AND AFFORDABLE PERFORMING TIME WITH PAIRWISE COMPARISONS BETWEEN MOUNTINGS OF 1, TEPEX; 2, PROTOTYPE AND 3, SUITX

	Pairwise Comparisons		Mean	Std. Error	P value
NASA_TLX Total Score	1	2	-6.778	3.822	0.305
		3	-18.334*	4.809	0.015*
	2	1	6.778	3.822	0.305
		3	-11.557*	3.82	0.048*
	3	1	18.334*	4.809	0.015*
		2	11.557*	3.82	0.048*

*. The mean difference is significant at the .05 level.

B. Difference in Muscle Activity between Three Different Mountings during Bouncing Task

The bouncing movement was selected to imitate giggling effect by shaking the puppet body and it required moving the body up and down in quick succession. The degree of freedom (DOF) on knee joint of prototype functioned with assistance by exhibiting lower EMG activation among nine out of ten selected muscles. Knee Joint protection of the SuitX facilitated the participants to squat repeatedly by reducing the knee joint and quadricep muscle forces. However, the frequent repeated bouncing postures which required the timely flexibility on

DOF of knee joints were not be benefited. Smaller scale of adjustment control might need to be enhanced.

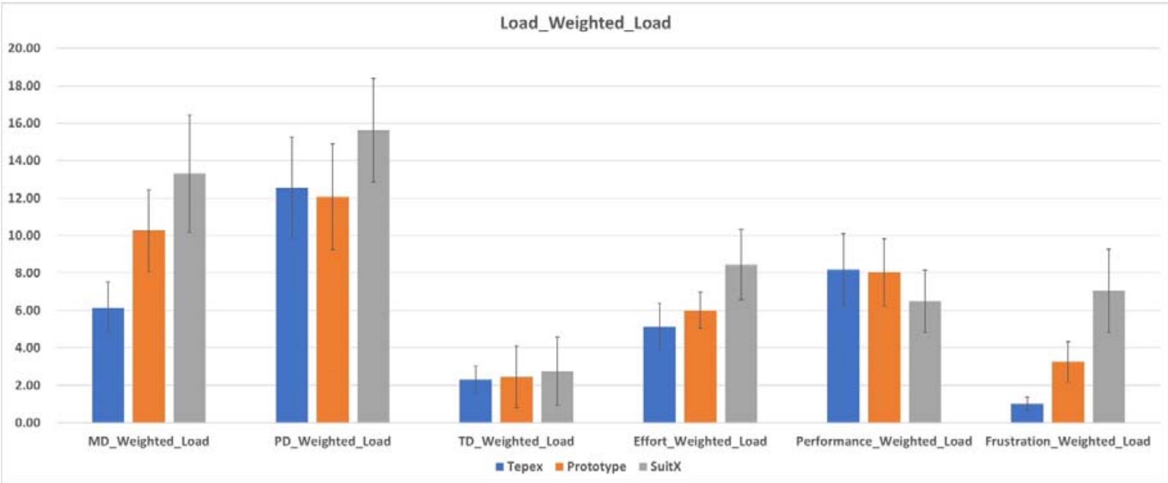

Fig. 13 The mean WWL Scores of the six domains

C. NASA_TLX

The Mean WWL Scores reflected (Table III) in task-related measures reflected significantly high in mental demand and physical demand, while apparently lowest in temporal demand. This reflected that physical output is the most concerned by the participants on using both exoskeletal models. Following concern is mental demand on adopting and practicing with the models. Participants have consistently goodwill on affordable longer operating durations by using prototype but still with mental demand concerns reflected that an Existing exoskeleton system require a period of adaptation by the end user. Highlighting this point by NIOSH [15], the federal government agency for preventing work-related health and safety problems presented in the symposium 2019 that for a new user, task performance is not likely to reach a steady state immediately that acceptable test is needed to establish. Measure of frustration in WWL of prototype and SuitX exoskeleton models are higher than Tepex harness model with 226% and 604% respectively. Participants also reflected that the sensitivity of hydraulic system in SuitX requires more stability. The DOF in LegX region requires a smaller scale from existing one to three levels. Furthermore, the added weight of some devices with increase of energy expenditure/metabolic workload may also contribute to the frustration rate [15].

Table IV shows the results for 9 subjects (1 excluded due to personal reasons) evaluated using the different 3 mountings with load in the task with different workload levels. Significant differences of different mountings between Tepex and SuitX tasks, or between Prototype and SuitX are apparent ($p < 0.05$). The results exhibited noticeable correlation with subjective evaluation using NASA-TLX.

D. Correlation of Total Score and Affordable Performing Time

According to the correlation computation, physical demand and frustration of the prototype are higher correlated to the affordable time, which indicated with more pre-test practice on balancing the wheeled prototype, the affordable time could be increased effectively. The participants reported sense of insecurity during bending tasks with SuitX exoskeleton on the lower back of the thoracic region. The feeling increased during the forward moving task. Extra attachment on the region may be required to connect stably between the human and device to avoid load being swayed with body movement. Participants also expressed a need for more sturdy shoulder straps which could hold firmly on their shoulders.

E. Limitations

There are several limitations that need to be addressed regarding this study. First, all the data were collected under laboratory conditions in which the subjects performed forward moving and bouncing tasks indoors. In real, live puppet performance is operated with variable dynamics and on unstable terrain, hence, it is unclear whether the same findings could be produced.

Secondly, the effect of time on the performance of back muscles with the use of exoskeletons remains unknown. In this study, subjects were asked to perform only two tasks in total, but the average duration of live performance could be lasting 45 mins. It remains unclear whether low activations in the 5 bilateral muscle areas of Tepex operation could still be consistently reflected when using the exoskeleton with a longer duration of use.

Thirdly, the number of participants may need to increase onto the existing test as extension in order to gain higher statistical significance. Demographic data of puppet performer sector, such as age, height, BMI and physical fitness, are with wide ranges and high standard deviation, which affect probability of the test result. Further study is suggested to analyze the co-relation with muscle activation and metabolic cost including heart rate, for a better understanding of physical output.

V. Conclusions

The exoskeleton improved related muscle activity in bouncing task significantly, implying good potential use of passive exoskeletons in reducing back loading in major lumbar and lower extremity regions. Further studies are suggested in order to examine on different tasks, such as goods delivery and patrol with loads which consist higher mobilities and rough terrain adaptation, so that exoskeleton could be incorporated more comprehensively into different work sectors.

Funding

The authors would like to acknowledge the funding from the Institute of Textiles and Clothing, The Hong Kong Polytechnic University.

Declaration of Competing Interest

We wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work could have influenced its outcome.

Acknowledgments

The authors would like to acknowledge the support of Mr. Jacky Ma in providing technical support for the wireless surface electromyography system, the knowledgeable puppet-operating advices from Mr. Lik Sang Chan and the technical operational support from Mr. Jo Yan Kwong and Kin Lun Fong.

References

[1] S. G. Hart, "Nasa-Task Load Index (NASA-TLX); 20 Years Later," *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, vol. 50, no. 9, pp. 904–908, 2006, doi: 10.1177/154193120605000909.

[2] M. P. de Looze, T. Bosch, F. Krause, K. S. Stadler and L. W. O'Sullivan. "Exoskeletons for industrial application and their potential effects on physical work load," *Ergonomics*, vol. 59, no. 5, pp. 671-681, 2016. doi:10.1080/00140139.2015.1081988.

[3] T. Bosch, J. van Eck, K. Knitel, and M. de Looze, "The effects of a passive exoskeleton on muscle activity, discomfort and endurance time in forward bending work," *Applied Ergonomics*, vol. 54, pp. 212–217, 2016, doi: 10.1016/j.apergo.2015.12.003.

[4] M. Lima, A. S. Ferreira, F. J. J. Reis, V. Paes, and N. Meziat-Filho, "Chronic low back pain and back muscle activity during functional tasks," *Gait & Posture*, vol. 61, pp. 250–256, 2018, doi: 10.1016/j.gaitpost.2018.01.021.

[5] M. M. Alemi, J. Geissinger, A. A. Simon, S. E. Chang, and A. T. Asbeck, "A passive exoskeleton reduces peak and mean EMG during symmetric and asymmetric lifting," *Journal of Electromyography and Kinesiology*, vol. 47, pp. 25–34, 2019, doi: 10.1016/j.jelekin.2019.05.003.

[6] X. Yong, Z. Yan, C. Wang, C. Wang, N. Li and X. Wu. "Ergonomic Mechanical Design and Assessment of a Waist Assist Exoskeleton for Reducing Lumbar Loads During Lifting Task," *Micromachines*, vol. 10, no. 7, pp. 463, 2019.

[7] H. Kim, Y. J. Shin and J. Kim, "Design and locomotion control of a hydraulic lower extremity exoskeleton for mobility augmentation," *Mechatronics*, vol. 46, pp. 32–45, 2017, doi: 10.1016/j.mechatronics.2017.06.009.

[8] US Bionics, Inc, *BackX*. Access on: 20 May 2020. [Online]. Available: http://www.suitx.com/backx

[9] H. J. Hermens, B. Freriks, C. Disselhorst-Klug, and G. Rau, "Development of recommendations for SEMG sensors and sensor placement procedures," *Journal of Electromyography and Kinesiology*, vol. 10, no. 5, pp. 361–374, 2000, doi: 10.1016/S1050-6411(00)00027-4.

[10] P. Konrad, "The ABC of EMG: A Practical Introduction to Kinesiological Electromyography," Noraxon USA, Inc. Version 1.4, 2006.

[11] H. Park, D. Branson, S. Kim, A. Warren, B. Jaconson, A. Petrova, S. Peksoz and P. Kamenidis, "Effect of armor and carrying load on body balance and leg muscle function," *Gait & Posture*, vol. 39, no. 1, pp. 430–435, 2014, doi: 10.1016/j.gaitpost.2013.08.018.

[12] K. M. Simpson, B. J. Munro, and J. R. Steele, "Backpack load affects lower limb muscle activity patterns of female hikers during prolonged load carriage," *Journal of Electromyography and Kinesiology*, vol. 21, no. 5, pp. 782–788, 2011, doi: 10.1016/j.jelekin.2011.05.012.

[13] A. Silder, S. L. Delp, and T. Besier, "Men and women adopt similar walking mechanics and muscle activation patterns during load carriage," *Journal of Biomechanics*, vol. 46, no. 14, pp. 2522–2528, 2013, doi: 10.1016/j.jbiomech.2013.06.020.

[14] G. Chu, J. Hong, D. H. Jeong, D. Kim, S. Kim, S. Jeong and J. Choo, "The experiments of wearable robot for carrying heavy-weight objects of shipbuilding works," *2014 IEEE International Conference on Automation Science and Engineering (CASE)*, 2014, vol. 2014, pp. 978–983, doi: 10.1109/CoASE.2014.6899445.

[15] NIOSH. *Proceedings of the 2018 Ergo-X Symposium: Exoskeletons in the Workplace — Assessing Safety, Usability, and Productivity.* Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 2020-102, 2019, https://doi.org/10.26616/NIOSHPUB2020102.