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LITERATURE REVIEW

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INVESTIGATION OF THE EFFECTS OF PASSIVE EXOSKELETONS ON WEIGHTLIFTING*

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ABSTRACT

Exoskeletons are technologies that are constantly developed to be used in different areas to reduce pain and periodic deformation felt under heavy loads. A great number of researchers and technology companies have been working on developing exoskeleton systems that augment human mobility to achieve several benefits in human life. This study includes current studies of passive exoskeletons which are specifically tested. The effects of passive exoskeleton systems reducing the load on the spine have been investigated for various lifting positions. In addition, reducing the biomechanical loads affecting the user's joints, muscles and soft tissues have been mentioned. In the conclusions section, the importance of researchers from the different branches to work on exoskeleton technology is emphasized.

Keywords: *Passive Exoskeleton, Wearable Systems, Assistive Devices, Lifting Devices.*

PASİF DIŞ İSKELETLERİN AĞIRLIK KALDIRMAYA ETKİLERİNİN ARAŞTIRILMASI

ÖZ

Dış iskeletler, ağır yükler altında hissedilen ağrı ve periyodik deformasyonu azaltmak için farklı alanlarda kullanılmak üzere sürekli geliştirilen teknolojilerdir. İnsan yaşamında çeşitli faydalar elde etmek amacıyla, insan hareketliliğini artıran dış iskelet sistemleri geliştirmek için çok sayıda araştırmacı ve teknoloji firması bu konuda çalışmaktadır. Bu çalışma, pasif dış iskeletler üzerine yapılan güncel çalışmaları içermektedir. Pasif dış iskelet sistemlerinin omurga üzerindeki yükü azaltmasının etkileri, çeşitli kaldırma pozisyonları için araştırılmıştır. Ayrıca kullanıcının eklem, kas ve yumuşak dokularına etki eden biyomekanik yüklerin azaltılmasından bahsedilmiştir. Sonuçlar kısmında, farklı branşlardan araştırmacıların dış iskelet teknolojisi üzerinde çalışmasının önemi vurgulanmıştır.

Anahtar Kelimeler: *Pasif Dış İskelet, Giyilebilir Sistemler, Yardımcı Cihazlar, Kaldırma Cihazları.*

1. INTRODUCTION

Bionics and exoskeletons have become more study in the last decade instead of prosthetics and orthotics. Exoskeletons, spread from the medical sector to military platforms, will be more common concepts in the near future. Researchers point to the approaching of the days when people moved around in their communities with the help of wearable exoskeletons (Sawicki et al., 2020). When designing an industrial exoskeleton, the aim is to ensure the worker with additional strength that is also comfortable to use to decrease the possibility of injury while performing their duties (Karfidova et al., 2020).

There are some points in exoskeletons that are considered negative and are still considered as disadvantages in current studies. Issues such as difficulty in donning and taking off, the discomfort of length and short settings, limitation of range of motion, or the weight of the device are still the most cited disadvantages of exoskeleton designs. However, the support these systems provide to the user during lifting is the mainstay behind most academic studies and the success story of commercially available products. Studies examining the effect of exoskeletons to decrease the load on the spine during lifting are available in the literature. In this study, findings emerging from different opinions and test results were compiled.

The development of exoskeletons also brought along branching. For example, with the increasing developments in the military field, the Super Warrior-2019 Exoskeleton Competition was organized in Beijing in October 2019. The competition contained munitions loading, light shunting, material handling, tapped walking, hurdle climbing, ditch crossing, and weapon operation, which are meticulous tests of current exoskeleton designs (Jia-Yong et al., 2020). As it is useful for soldiers to carry the necessary equipment and weapons with less effort (Lowe et al., 2019), it will be beneficial to use the exoskeleton system in sectors where repetitive work is done, such as the construction sector (Kim et al., 2019). Mass manufacturing companies also measure their performance to achieve the same quality every time in repetitive tasks. (Maurice et al., 2020) argued in their study that an exoskeleton should increase user performance and capacity while performing the task, as productivity decline brings additional cost and quality drop to companies.

Exoskeleton is not only decreasing metabolic cost of energy, may also reduce muscle pain for works under the same conditions. It is stated that wearing exoskeleton reduces energy consumption as much as 17% during repetitive lifting that fulfilled by 11 healthy men in 5 minutes (Baltrusch et al., 2019a). In another study, wearing exoskeleton were reduced muscle activities during repetitive lifting and that causes to decrease lower metabolic cost of energy by 22% (Wei et al., 2019). Reduction of energy consumption has been observed that kinematic movements do not affect significantly (Baltrusch et al., 2019b).

As a result of modeling human mobility and neuroscience inspiring electromechanical systems, exoskeletons reached a level that can perform some tasks. If the functions underlying human balance and movement are understood, it can be adapted to legged robots, motor learning models, and prosthetic and orthotic devices (Fasola et al., 2019).

2. PASSIVE EXOSKELETON RESEARCH

Passive exoskeletons can continue to work for a long time since no external power supply is needed. The use of such devices in active life can unite the advantage of flexible human operate with a constant reduction in workers' postural load (Luger et al., 2019a). Most of the exoskeletons designed for industrial use were produced to reduce the load on the spine. Passive wearable exoskeletons aim to store and recycle energy from the lower limbs to help the wearer perform a specific movement (Pardoel & Doumit, 2019).

Passive exoskeletons are devices that increase human movement through the specific use of mechanical elements such as springs, hoists, hoops, and clutches. At the same time, semi-passive exoskeletons counties on exterior power to merely modify the passive behavior of the exoskeleton, such as the modification of spring stiffness at the joint or control the position of clutches, while still counting on only mechanical elements for actuation (Lovrenovic & Doumit, 2019). As the wearer leans forward, their potential energy is stored in the spring and then returns as they stand up again (Alemi et al., 2019). One of the reasons why springs are used in passive exoskeletons is to stabilize the weight of user limbs or the user body (Zhou et al., 2020).

Exoskeletons can provide users with the following advantages: more durable by dispensing mechanical energy to avoid damage during activities that may cause serious problems such as quick cutting maneuvers or falling from excessive heights, more decisive by modulating the sensory-motor reaction of neuromuscular systems to disturbances, more nimble and faster by rising the relative strength capacity of their muscles (Sawicki et al., 2020).

2.1. Improvement of Lifting with Passive Exoskeletons

In this section, the contributions of recent studies on the removal task are reviewed.

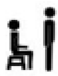
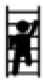
A person needs lower limb movements to perform daily activities such as sitting, walking, running, and to use body functions (He et al., 2007). During lifting, kinematic factors such as moment and power generation from the hip, ankle, knee, and waist joints contribute (Hwang et al., 2009). Failure to maintain strong coordination of upper and lower limbs during lifting causes chronic back pain (Pranata et al., 2018). For this reason, various methods have been adopted to prevent back pain, such as weight restriction and lifting instructions (Bush-Joseph et al., 1988). Because the lifting technique can affect the occurrence of the low back pain (Kingma et al., 2006).

The spine is a structure that achieves its balance from the lower limb (particularly the hip joint) and supports the weight of the upper limb (McGregor & Hukins, 2009). The spine load is more effective in people with low back pain, depending on the starting position and weight of the object to be lifted (Marras et al., 2004).

A group of researchers conducted trials on users with and without back pain, in which they tested the maximum number of lifts per 2 minutes with a weight of 20 kg and evaluated their results as shown in Figure 1 (Baltrusch et al., 2020c).

Test		Procedure	Objective outcome measure
1. Lifting		Lifting a box of 20 kilos for 2 minutes from ankle height as often as possible. Lifting technique and lifting speed is chosen by the participant.	Number of lifts in 2 mins.
2. Carrying		Carrying 20 kilos in a box for 10 meters. Time recording stopped when the participant passed the 10-meter mark.	Performance time (s)
3. Static forward bending		Standing with flexed trunk between 30 and 60 degrees. Trunk angle is chosen by the participant. Performing a simple manual task on a table at knee height, max 5 mins.	Maximal holding time (s)

Figure 1. Physiological performance tests to report the responses of healthy and low back pain groups to weightlifting (Baltrusch et al., 2020c).

4. 3 point kneeling position		Holding 3-point kneeling position with one hand on the floor. Performing a simple task on the floor, max 5 mins.	Maximal holding time (s)
5. 6 Minutes Walk Test		Walking as far as possible in 6 minutes.	Distance (m)
6. Sit to stand		Sitting down on a chair and getting up 5 times. Participant started in sitting position and time recording stopped when participant sat down the 5th time.	Performance time (s)
7. Stair Climbing		Climbing up- and downstairs as fast as possible for 20 steps. No use of handrails. Time recording stopped when both feet were on the floor again.	Performance time (s)
8. Ladder Climbing		Climbing up and down a ladder twice. Time recording stopped when both feet were on the floor again.	Performance time (s)
9. Bending the trunk		Bending forward as much as possible, knees extended.	Distance fingertip to floor (cm)
10. Wide Stance		Standing with feet 20 cm apart, gradually increasing distance by 20 cm.	Maximal distance (cm)
11. Rotation of the trunk		Rotating the trunk 5 times to both sides.	None
12. Squatting		Squatting down to the floor 3 times, leaving the heels on the ground.	None

Continuation of the Figure 1.

According to research, the healthy group and the low-back pain group did not differ in age (44 years vs. 43 years), weight (87kg vs. 78 kg) and height (180 cm vs. 175cm). Figure 2 shows a remarkable increase in performance when users wear the exoskeleton. (The maximum number of lifts in 2 minutes: 18 lifts ± 6 vs. 20 lifts ± 6)

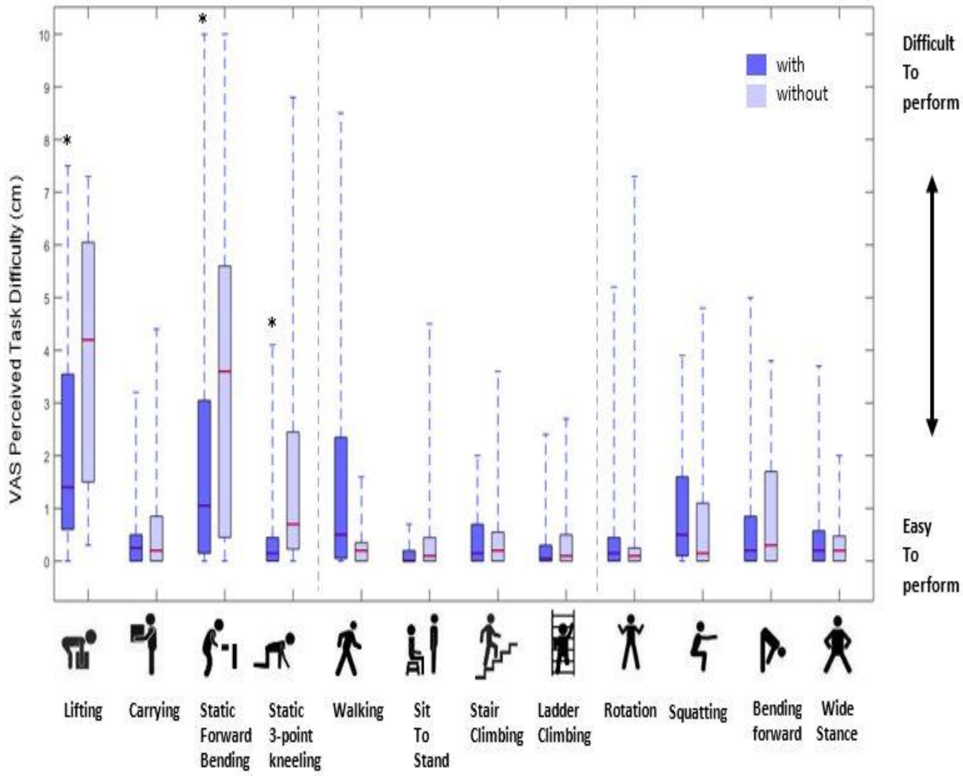


Figure 2. A series of changes in perceived task difficulty for diverse tasks. Such a rise indicates a negative effect and a reduction indicates a positive effect (Baltrusch et al., 2020c).

Baltrusch, Koopman, et al., (2019b) conducted a study where they measured metabolic cost, kinematics, mechanical joint work, and muscle activity during a 5-minute repetitive lifting task. In the study, participants underwent a 10 kg box lifting at ankle joint height with and without an exoskeleton. The implantation of the exoskeleton they recommended reduced the net cost of metabolic removal by 18%. [Average (SD): 5.63 W / kg (1.26) - 4.64 W / kg (1.38); p = 0.000]. The researchers explained that the average muscle activity in the back muscles decreased significantly when wearing the exoskeleton in one lifting cycle. It was stated that the muscle movement in the abdominal muscles remained the same.

According to Xiong et al., (2019), aimed at lowering metabolic cost, the researchers showed that the metabolic cost of walking at 1.38 m / s with optimal assistance decreased by 7.6% compared to usual walking. They designed an assistive system emphasize hip joint. The total process of their assistance systems is controlled by the mechanical clutch. It also includes springs on the knee joint to assist flexors during the late swing phase.

In study of Zhou et al., (2020), it was proposed that a spring with high hardness and small bias stress or lower hardness and large bias stress can be chosen to stabilize the gravity of the human exoskeleton system. The study results explain that the extra torque necessary in the knee and hip joints will be smaller if springs with lower hardness and greater preload are used.

Koopman et al., (2019d) mentioned about exoskeletons have been shown to decrease back muscle activity by 10% to 40% during static forward bending in their study.

An exoskeleton not only may reduce the feeling of fatigue during the task, but is also safe during accidents. However, users may prejudice that the exoskeleton will be useless and uncomfortable (Hensel & Keil, 2019). On the other hand, Luger et al., (2019b) examined the effects of exoskeletons on user comfort in their study and calculated that the user comfort score was 7.9 out of 10 as a result of the survey. They also observed that sitting low was more comfortable than sitting high.

3. CONCLUSION

Studies have shown the potential of the exoskeleton to reduce the metabolic costs of lifting, thereby decreasing the risk of fatigue in the course of repetitive lifts. There are promising designs to decrease the load on the spine, especially low back pain caused by repetitive work.

The way exoskeletons protect the wearer could be summarized as reducing the biomechanical loads affecting the user's joints, muscles, and soft tissues. In the design of exoskeletons, certain test methods and standards will need to be established to provide capabilities that the user does not have.

In order to develop exoskeleton technology, deep research and experiments will be required in different branches such as physiology, psychology, engineering, and design. In this way, human and machine will be able to gain power and time in harmony.

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