Recep Tayyip Erdoğan Üniversitesi Fen ve Mühendislik Bilimleri Dergisi, 6(1) 1-13 2025
Recep Tayyip Erdogan University Journal of Science and Engineering, 6(1) 1-13 2025
ISSN: 2687-2315 / E-ISSN: 2757-7686

A Systematic Literature and Market Analysis for Wearable Exoskeleton

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Araştırma Makalesi/Research Article
Geliş Tarihi/Received: 10.12.2023
Kabul Tarihi/Accepted: 07.12.2024

Abstract

Exoskeleton systems are generally designed to have a structure suitable for human anatomy and are wearable structures that interact with people. They can be used to contribute to the basic functions of users such as walking, running, sitting, standing and carrying heavy loads, as well as in the rehabilitation and treatment process such as restoring the ability of the user's lower and/or upper limbs. Another area of use is to increase the strength of healthy limbs above normal. The primary goal is to increase performance and, in this sense, they have a wide range of uses. Designed exoskeleton structures make people's lives easier and provide individuals with a better quality of life in the areas where they are used. The aim of the study is to present academic studies and current products in the market in the field of wearable exoskeletons, to determine which class these products belong to, to determine which area the studies are focused on and to determine potential study areas for new research. Systematic literature analysis was used in the study and studies and products were analyzed according to inclusion and exclusion criteria. This study systematizes studies in the field of exoskeletons, determines their interrelationships, introduces basic applications for researchers who are new to this field and aims to create an interdisciplinary study area.

Keywords: Exoskeleton structures, lower extremity, upper extremity, wwearable technology, biomechatronics

Giyilebilir Dış İskeletlere Yönelik Sistematik Bir Literatür Taraması ve Pazar Analizi

Öz

Dış iskelet sistemleri genel anlamda insan anatomisine uygun yapıya sahip olacak şekilde tasarlanmış, insanlarla etkileşim halinde çalışan giyilebilir yapılardır. Kullanıcıların yürüme, koşma, oturma, ayakta durma ve ağır yük taşıma gibi temel işlevlerine katkıda bulunmak için kullanılabileceği gibi, kullanıcının alt ve/veya üst uzuvlarının yeteneğinin geri kazanılması gibi rehabilitasyon ve tedavi sürecinde de kullanılabilir. Bir diğer kullanım alanı sağlıklı uzuvların gücünü normalin üzerine çıkarmak amacıyladır. Öncelikli amaç performans artırmak olup bu anlamda da geniş bir kullanım alanı bulmaktadır. Tasarlanan dış iskelet yapıları insanların hayatını kolaylaştırmakta ve kullanıldıkları alanlarda bireylere daha kaliteli bir yaşam sunmaktadır. Çalışmanın amacı, giyilebilir dış iskeletler alanında yapılan akademik çalışmaları ve pazardaki mevcut ürünleri ortaya koymak, bu ürünlerin hangi sınıfa ait olduğunu belirlemek, çalışmaların hangi alanda yoğunlaştığını saptamak ve yeni araştırmalar için potansiyel çalışma alanlarını belirlemektir. Çalışmada sistematik literatür analizi kullanılmış olup dahil etme ve hariç tutma kriterlerine göre çalışmalar ve ürünler analiz edilmiştir. Bu çalışma ile dış iskelet alanındaki çalışmaları analiz edilerek birbirleri arasındaki bağıntılar belirlenmiş, bu alana yeni giren araştırmacılar için temel uygulamaları tanıtılmış ve disiplinlerarası çalışma alanı oluşturulması hedeflenmiştir.

Anahtar Kelimeler: Dış iskelet yapıları, alt ekstremite, üst ekstremite, giyilebilir teknoloji, biyomekatronik

Cite as;
Pala Ercan, İ. and Türksoy, H.G. (2025). A systematic literature and market analysis for wearable exoskeleton. *Recep Tayyip Erdogan University Journal of Science and Engineering,* 6(1), 1-13. Doi: 10.53501/rteufemud.1385754

1. Introduction

Biomechatronics is a new field in the world, the scope of which has begun to be determined in recent years and studies have been carried out intensively especially textile engineering, mechatronic engineering etc. One of the systems that has come to the fore in this field, which is in constant development and progress, is the exoskeleton systems. Exoskeleton systems are systems that try to communicate between the human and the mechatronic system, and to perform human movements as similar as possible. Exoskeleton structures are energy efficient, safe, stable and wearable electromechanical elements that can work in harmony with the human body. As in the definition of this electromechanical element, exoskeleton systems can be used as actuators such as servos, motors, hydraulic cylinders, pneumatic cylinders, etc. It can contain many active actuators such as springs and dampers (Ercan Pala, 2019). Exoskeleton robots can be seen as advanced versions of orthotic and prosthetic applications in order to work as closely as possible with the human body. The biomechanical imitation of joint movements or a high level of compatibility with the dynamics of these movements is the main purpose of use of exoskeleton robots (Ekkelenkamp et al., 2005).

Exoskeleton systems are used to support different parts of the body according to their intended use. These structures can support the arms and waist region, as well as the structures used for load-bearing purposes can support the waist and legs. Exoskeleton systems are divided into three according to the regions supported in the human body (Şahin, 2014).

- Upper - Extremity: Exoskeletons designed to support the human upper region.
- Lower - Extremity: Exoskeletons designed to support the human lower region (Şahin, 2014).
- As a result of recent studies, exoskeleton systems are divided into three. In addition to the lower and upper extremities, the whole-body exoskeleton is also considered as an exoskeleton classification according to recent studies.

Another type of classification is the classification according to the way these structures are used. According to the use of exoskeleton systems; It is divided into two classes as therapeutic systems and motion support systems. The field of use of therapeutic systems is physical therapy and rehabilitation. Since the use of the upper limbs is very common in daily life, disturbances in this region have a great impact on the quality of human life. For this reason, studies on rehabilitation robots are mostly progressing as upper limb support (Jau, 1988).

Therapeutic systems are divided into three as passive, active and interactive systems. Passive systems do not have an actuator. While active systems contain electrical, hydraulic or pneumatic actuators to provide movement, interactive systems additionally enable the patient to actively participate in the treatment process by using different control techniques (Riener et al., 2005).

Movement support systems, on the other hand, are designed to facilitate the daily life of the patient and to enable them to perform the necessary activities (Leifer, 1981). Servo motors, hydraulic cylinders, pneumatic cylinders etc. are used as actuators in the exoskeleton system. Many active actuators can be used as well as springs, dampers, etc. passive actuators can also be used (Şahin et al., 2015).

Exoskeletons can be used to contribute to the wearer's basic functions such as walking, running, sitting, standing, and carrying heavy loads, as well as in rehabilitation and treatment procedures such as restoring the ability of the wearer's lower and/or upper limbs, or to increase the strength of healthy limbs beyond normal. can be developed (Önen, 2011). With the developing actuator and sensor technologies, these systems have a more dynamic, powerful and ergonomic structure, and thus they find a wide area of use for themselves. They provide significant benefits to people by being used in many rehabilitation, military, industrial and recreational applications (Şahin, 2014). The designed exoskeleton structures facilitate the lives of people in the areas where they are used and offer a better quality of life (Bau, 1988). Its use in areas such as rehabilitation treatment of paralyzed people, increasing strength in healthy people, and application as an auxiliary limb in elderly or physically disabled people is increasing day by day. In order to meet expectations and get better results, researches on the improvement of exoskeleton robots continue in depth (Ekkelenkamp et al., 2005).

In this study, the features of wearable exoskeletons were explained, and the prominent studies in the literature and the market were examined due to the fact that there are many studies in the field. The aim of the study is to reveal the data on the use and classification of studies in the field of biomechatronics and wearable exoskeleton applications, to determine in which areas the wearable exoskeleton studies are concentrated, to reveal which areas are missing and what needs to be done. In addition, it is one of the sub-objectives of this research to create interdisciplinary study areas by introducing basic applications for researchers who will enter this field.

2. Method

In this study, systematic literature analysis was used to find answers to the research questions. Conducting research using existing information and establishing a relationship with this information constitutes the basis of academic research. (Snyder, 2019). Considering that the number of academic studies is increasing day by day and their contents are constantly being developed and changed, it has become important to systematically and transparently synthesize these studies in a way that will create new information. (Torraco, 2016). Systematic literature review is a research method that determines how this synthesis process should be carried out. The aim of this methodology is to systematically examine all studies by taking into account the criteria determined to find an answer to the research question determined for the study. (Kraus et al., 2020).

Kitchenham (2007) divided the methodology for systematic review of the relevant literature that is the subject of the research into three steps;

- Determining the research questions and steps to be followed
- Conducting a review that includes the selection and accuracy of articles as well as the extraction and synthesis of data,
- Preparing a report containing the results obtained and providing information about the study.

As the first step for this analysis, the purpose and subject of the research were revealed. The aim of the study is to reveal the academic studies in the field of wearable exoskeletons and the existing products in the market, to determine which class these products belong to, to determine in which area the studies are concentrated, and to identify potential study areas for new researches. As second step of the study, the keywords of the study were determined. Keywords; exoskeleton structures, lower extremity, upper extremity, wearable, biomechatronics. For the literature review, studies registered in the Google Academy database were examined. National and international studies were scanned with the determined keywords. Although the existence of studies conducted especially as literature on exoskeleton expanded the scope, our inclusion criteria for the analysis were the development of a physical exoskeleton in the studies. The areas of use and classification of the developed exoskeletons in our study were among our inclusion criteria. In the fourth step, a re-analysis was conducted considering the inclusion criteria and the studies to be used were determined. In addition, no date restriction was made in order to conduct the literature review comprehensively. Studies that did not directly fall into the exoskeleton field and for which a physical exoskeleton was not developed were excluded from the research. In the last step, the findings obtained were compared and interpreted in terms of results and suggestions, and evaluations were presented. The studies examined as a result of the literature review and their details are given in Table 1.

In addition, it is important to support the literature research in the study, not only in the field of academia, but also to examine the commercialized products in the market in terms of revealing the product diversity in this field. In this context, the products available in the market in the field of wearable exoskeletons were examined**.** The market research on exoskeleton systems was carried out on the internet with the keywords 'Exoskeleton Structures', 'Exoskeleton', 'exoskeleton', and information and images were taken from the internet [URL-1]. The inclusion criterion in the screening for products in the market is that the products are commercialized and delivered to users through sales channels. As a result of the research, the exoskeleton structures commercialized by the companies appeared in four areas. The first of these areas is the exoskeletons used in the sports field, and the second is the exoskeletons used in the military field (Table 2). When the market research results are examined, another area where exoskeleton structures are seen most is the industry area (Table 3). As a result of the market research, the last area where exoskeleton structures are used the most is the health field (Table 4).

3. Results

As a result of the systematic literature analysis, considering the criteria, research question and the purpose of the study, a total of 42 studies were included in this study. 0,16 (f:7) of these studies were presented in internationally refereed scientific journals, 0,5 (f:21) of them were presented in scientific conferences and published in proceedings. 0,33 (f:14) studies included in the analysis were theses.

When the results obtained from the literature review are examined, it is seen that the studies on exoskeleton structures that started at the end of the 80s mostly focused on exoskeletons for treatment and rehabilitation in the field of health. Various lower, upper extremity and whole trunk skeletal structures, control algorithms developed for these exoskeletons, shortening the treatment time of exoskeletons, reducing weight, being adjustable, and their relationship with the body have been the main subjects of studies in the field of academia. Apart from this, the issue of load bearing is one of the frequently encountered topics in the literature.

Out of the 42 studies examined in total, 0.143 (f:6) whole body exoskeleton, 0.738 (f:31)

Table 1. Result of the literature review (Ercan Pala, 2019)

Exoskeleton	Purpose Of Usage	Classıfıcatıon	Exoskeleton	Purpose Of Usage	Classıfıcatıon
HARDIMAN	Load Lifting (Önen, 2011)	Whole Body	Gordon and Ferris (2007)	Supporting the human walk (Gordon and Ferris, 2007)	Lower-Extremity
BELGRAD	Rehabilitation of Paralyzed Patients (Önen, 2011)	ower-Extremity	Costa and Caldwell (2006)	Rehabilitation (Costa and Caldwell, 2006)	Lower-Extremity
PİTMAN	Power Support (Önen, 2011)	Whole Body	Ghan (2006)	System description of exoskeleton named BLEEX (Ghan and Kazerooni, 2006)	Lower-Extremity
Electric power Booster	Measuring human-to-device forces (Önen, 2011)	Whole Body	ELEBOT	Measurement of ground reaction forces (Cao et al., 2006)	Lower-Extremity
Power Dress	Load Lifting (Önen, 2011)	Whole Body	G.K. Borovin et al., (2006)	10 degrees, whole body supportive (Borowin et al. 2006)	Whole Body
DARPA / project	Strength Increase (Şahin, 2014)	Whole Body	Kazerooni et al., (2006)	Mechanical design of the BLEEX exoskeleton (Kazerooni et al., 2006)	Lower-Extremity
DARPA / project	Load Lifting (Şahin, 2014)	Lower-Extremity	EXPOS	Supporting the movements of sick and elderly people (Kong and Jeon, 2006)	Lower-Extremity
HME	Muscle Strengthening (Misuraca and Mavroidis, 2001)	Lower-Extremity	LEE	Endoskeleton; measuring user's movements, exoskeleton; load carrying (Low et al., 2004)	Lower-Extremity
Van den Bogert (2003)	Improve existing structures, reduce joint torque and forces (Van den Bogert, 2003)	Lower-Extremity	Steger (2006),	The called Sensitivity Amplification Control for BLEEX algorithm (Steger, 2006)	Lower-Extremity
Moromugi (2003)	Increase human endurance and strength (Marogumi, 2003)	Lower-Extremity	Walsh et al., (2006),	Load Lifting (Walsh et al., 2006)	Lower-Extremity
BLEEX	Portable power unit that assists in Load Carrying (Racine, 2003)	Lower-Extremity	Wheeler et al., (2006)	A new contact pressure distribution sensor for BLEEX (Wheeler et al., 2006)	Lower-Extremity
Racine (2003)	Racine (2003)	Lower-Extremity	Zoss (2006)	Actuator system design of the BLEEX exoskeleton (Zoss, 2006)	Lower-Extremity
NTU	An exoskeleton using Encoders to control the device (Liu et al., 2004)	Lower-Extremity	ALEX	Gait Rehabilitation (Banala, et. al. 2007)	Lower-Extremity

Table 1 continiue. Result of the literature review (Ercan Pala, 2019)

Exoskeleton	Purpose Of Usage	Classıfıcatıon	Exoskeleton	Purpose Of Usage	Classıfıcatıon
LOPES	Gait rehabilitation (Ekkelenkamp et al., 2005)	Lower-Extremity	NAEIES	Load Lifting (Gui et al., 2007)	Lower-Extremity
Gordon (2005)	Strengthening foot muscles (Gordon, 2005)	Lower-Extremity	He and Kiguchi (2007)	Supporting leg movements of people with muscle weakness (He&Kiguchi,2007)	Lower-Extremity
Hollander (2005)	Reducing the energy requirement for actuators (Low et al., 2005)	-	Mankala et al., (2007)	Walking support for patients with spinal cord disorders (Mankala et al., 2007)	-
Moreno et al., (2005)	Lightweight exoskeleton for outdoor usage (Moreno et al., 2005)	Lower-Extremity	Sun et al., (2007)	Sensor system for exoskeleton named WPAL (Sun, et. al 2007)	-
Reinicke et al., (2005)	Control algorithm development for exoskeletons (Moreno et al., 2005)	-	Veneman et al., (2007)	Gait rehabilitation device called "LOPES" design and control (Veneman et al., 2007)	Lower-Extremity
Suzuki et al., (2005),	Development of controllers for exoskeletons (HAL-3) (Suzuki et al., 2005)	Lower-Extremity	Dollar and Herr (2008)	Reviewed the historical development of lower extremity exoskeletons and active orthopedic devices (Dollar and Herr, 2008)	Lower-Extremity
Valiente (2005),	Load Lifting (Valiente, 2005)	Upper Extremity	Cao et al.,	Supporting walking (Cao et al., 2009)	Lower-Extremity
Yang et al., (2005)	Supporting the human walk (Yang et al., 2005)	Lower-Extremity	YÜDİS	Supporting walking (Önen, 2011)	Lower-Extremity

lower-extremity exoskeleton, 0.023 (f:1) upper extremity, 0.095 (f:4) exoskeleton supporting structures were observed. These supporting structures include studies such as sensor and control algorithm development. For this reason, they could not be included in any group in the classification of exoskeleton structures found in the literature.

When the usage areas of the exoskeleton structures examined as a result of the literature review are examined, load bearing and walking support have been the most researched and studied areas in the literature. Out of the 42 studies examined in total, 0.190 (f:8) load lifting, 0.190 (f:8) walking support, 0.119 (f:5) rehabilitation, 0.119 (f:5) endurance and strength increase, 0.048 (f:2) strength measurement were determined. Other studies examined in the literature review are in the areas of developing and supporting exoskeleton structures such as control algorithm design, sensor distribution, controller development, actuator system design. When the exoskeleton studies for load bearing were examined, it was seen in all classes of the trunk, lower extremities and upper extremities. Exoskeletons seen in the walking support area are only included in the lower-limb area. Exoskeletons, which are stated to be used for endurance and strength increase, were found in all trunk and lower extremity classes in the literature research.

Table 2. Exoskeleton structures used in sports and military (Ercan Pala, 2019)

Exoskeletons Used in Sports Area			Exoskeletons Used in Sports Area		
Exoskeleton	**Purpose of Usage**	**Classification**	**Exoskeleton**	**Purpose of Usage**	**Classification**
Againer	Shock absorbing feature that provides support to the knees	Lower-Extremity	Marine Mojo	Increase walking performance by absorbing shocks and vibrations	Lower-Extremity
RoboGolfPro®	Creating muscle memory	Upper extremity	PowerWalk	An energy-consuming exoskeleton for military use	Lower-Extremity
Ski ~ Mojo,	Shock absorbing	Lower-Extremity	ASYA (Military Walking Assistant)	Walking, running, climbing, jumping and carrying loads	Whole body

Table 3. Exoskeleton structures used in healthcare (Ercan Pala, 2019)

Exoskeleton Structures Used in Healthcare					
Exoskeleton	**Purpose of Usage**	**Classification**	**Exoskeleton**	**Purpose of Usage**	**Classification**
BalanceTutor	Eliminating balance losses	Lower-Extremity	Walking Assist	Gait rehabilitation exoskeleton	Lower-Extremity
G-EO	Gait rehabilitation exoskeleton	Lower-Extremity	ARKE ™,	Gait rehabilitation exoskeleton	Lower-Extremity
KineAssist MX	Catchig patients in case they fall	Lower-Extremity	ATLAS 2030	Medical exoskeleton specially designed for children	Lower-Extremity
Lokomat	Gait rehabilitation exoskeleton	Lower-Extremity	Axosuit	Gait rehabilitation exoskeleton	Lower-Extremity
NX-A3	Gait rehabilitation exoskeleton	Lower-Extremity	Bionic Leg	Increasing mobility	Lower-Extremity
ReoAmbulator	Gait rehabilitation exoskeleton	Lower-Extremity	Ekso GT	Gait rehabilitation exoskeleton	Lower-Extremity
RoboGait	Gait rehabilitation exoskeleton	Lower-Extremity	ExoAtlet	Rehabilitation and personal use	Lower-Extremity
Walkbot	Gait rehabilitation exoskeleton	Lower-Extremity	HUMA	Walking aid for those with limited muscle strength	Lower-Extremity
Atlante	Simulating natural motion	Lower-Extremity	PhoeniX	To assist people with mobility restrictions	Lower-Extremity
C-Brace	A medical orthotic device	Lower-Extremity	Roki	Gait rehabilitation exoskeleton	Lower-Extremity
ExoAtlet	Rehabilitation and personal usage	Lower-Extremity	Darwing	Arm support	Upper extremity
H-MEX	Low spinal cord injury support	Lower-Extremity	ExoArm	Arm support	Upper extremity
HAL®	Providing extra strength to the knee or ankle	Lower-Extremity	ALEx	Rehabilitation of the whole arm	Upper extremity
GOGOA HANK	Gait rehabilitation exoskeleton	Lower-Extremity	AMADEO	Hand and finger robotic rehabilitation device	Upper extremity
Indego®	Walking training	Lower-Extremity	ArmeoPower	Combined arm and hand rehabilitation	Upper extremity
Keeogo ™	Support for using stairs and walking	Lower-Extremity	ArmeoSpring	Early movement rehabilitation in the limitation of arm mobility	Upper extremity
ReWalk	Gait rehabilitation exoskeleton	Lower-Extremity	ArmeoSpring Pediatri	Rehabilitation of the whole arm	Upper extremity
REX	Ability to move individuals with spinal cord paralysis	Lower-Extremity	Hand of Hope	Hand rehabilitation	Upper extremity

Table 3 continue. Exoskeleton structures used in healthcare

Exoskeleton	Purpose of Usage	Classification	Exoskeleton	Purpose of Usage	Classification
InMotion ARM	Hand rehabilitation	Upper-extremity	NX-A2	Rehabilitation of the whole arm	Upper-extremity
InMotion WRIST	Hand rehabilitation	Upper-extremity	ReoGo	Rehabilitation of the whole arm	Upper-extremity
Daiya	Better grasping of objects	Upper-extremity	MyoPro®	Hand and elbow rehabilitation	Upper-extremity
Paule	Vibration suppression and stabilization	Upper-extremity	SEM Glove	Struggling with insufficient grip	Upper-extremity

Table 4. Exoskeleton structures used in industry (Ercan Pala, 2019)

Exoskeleton Structures Used in Industry					
Exoskeleton	**Purpose of Usage**	**Classification**	**Exoskeleton**	**Purpose of Usage**	**Classification**
Airframe	passive shoulder support	Upper-extremity	Chairless Chair	Exoskeleton converted into sitting unit	Lower-Extremity
Armor-Man 2	second generation steadicam device for passive shoulder support	Upper-extremity	Hercule	Exoskeleton converted into sitting unit	Lower-Extremity
Ekso Works Vest,	passive shoulder support	Upper-extremity	LegX	Reducing stress on the knees during prolonged standing	Lower-Extremity
Exhauss	Auxiliary structure for loads that must be carried on the waist	Upper-extremity	Muscle Suit	Load Lifting	Lower-Extremity
ShoulderX	Auxiliary apparatus for long-term work at the upper level of the waist with various tools	Upper-extremity	V22	Facilitating load handling and preventing site injuries	Lower-Extremity
Wieldy Exoskeleton	second generation steadicam device for passive shoulder support	Upper-extremity	Laevo	Protecting the spine during load lifting	Lower-Extremity
AWN-03	Reducing stress on the spine during load bearing	Lower-Extremity	Daiya	Grasping objects better	Upper-extremity
BackX	Reducing stress on the spine during load bearing	Lower-Extremity	SEM Glove	Grasping objects better	Upper-extremity
FLx ErgoSkeleton	Reminder of correct posture and lifting techniques	Lower-Extremity	Ekso Works	Passive device holding the exoskeleton	-
HWEX	Load Lifting	Lower-Extremity	FORTIS	Passive device holding the exoskeleton	-
HAL (Lomber),	Identifying strains during load handling	Lower-Extremity			

When the market research findings were examined, four areas where exoskeleton structures were used intensively were identified. The first of these areas is the exoskeleton structures used in the sports field. Three commercialized products have been identified in the field of sports. Of these products, they belong to the lower extremity class of 0.67 (f:2) and the upper extremity class of 0.33 (f:1). When the usage areas and properties of the exoskeleton structures in the sports field are examined, 0.67 (f:2) is related to areas requiring shock absorbing properties and 0.33 (f:1) is related to muscle memory formation. It has been observed that exoskeletons with shock absorbing properties belong to the lower extremity group, while the exoskeleton designed to create muscle memory is included in the upper extremity group.

Another area where exoskeletons are used is the military. In the market research, three commercialized exoskeleton structures used in the military were identified. Out of these exoskeleton structures, 0.67 (f:2) lower extremities and 0.33 (f:1) whole body exoskeletons appear. When the usage areas of exoskeleton structures, which have been commercialized in the military field, are examined, they are energy-consuming structures to increase user performance by absorbing shocks and vibrations, to carry loads and for military use.

The field of health (medical) is one of the most preferred areas of exoskeleton structures. Of the 44 exoskeleton structures examined, 0.636 (f:28) lower extremities and 0.363 (f:16) upper extremities were included. In the exoskeletons used in the health field, common areas of use were not found in the structures belonging to the lower extremity and upper extremity classes. When the classifications are examined within themselves, when we look at the usage areas of the exoskeleton structures in the lower extremity group; 0.535 (f:15) gait rehabilitation-support walking, 0.178 (f:5) are used to increase mobility and 0.071 (f:2) are used to prevent balance losses. Apart from these areas, there are also specialized exoskeleton structures for children to provide extra strength to the knee and ankle. When the upper extremity group was examined, 0.5 (f:8) arm rehabilitation and support, 0.31 (f:5) hand rehabilitation, 0.125 (f:2) grip ability.

The last area where exoskeleton structures are used the most is industry. Of these exoskeleton structures, 0.38 (f:8) upper extremity and 0.52 lower extremity classes are encountered. When the upper extremity class is examined, 0.5 (f:4) passive shoulder support of the exoskeleton structures in this area has been developed to better grasp objects 0.25 (f:2). The remaining exoskeletons, on the other hand, have features such as load bearing and allowing long-term work with tools that work above the waist. Considering the exoskeletons in the lower extremity class, which are among the exoskeleton structures developed in the industry, they are designed to be 0.63 (f:7) load-bearing and 0.18 (f:2) sitting units. Other upper extremity exoskeletons have effects such as reminding correct posture techniques and facilitating long-term standing. When the exoskeleton structures used in the industry are examined, auxiliary structures outside the classification have also been observed. These auxiliary structures are passive tools that hold the 0.09 (f:2) exoskeleton.

4. Conclusion and Recommendations

Exoskeleton systems are wearable structures designed to have a structure suitable for human anatomy, working in interaction with humans, in general terms. Exoskeletons can be used to contribute to the wearer's basic functions such as walking, running, sitting, standing, and carrying heavy loads, as well as in rehabilitation and treatment procedures such as restoring the ability of the wearer's lower and/or upper limbs, or to increase the strength of healthy limbs beyond normal can be developed (Önen, 2011). In the study, when the results of the literature review are examined, it is seen that the majority of the exoskeleton structures in the literature are included in the lower extremity group. A similar situation was encountered in the results of market research. It has been revealed that the exoskeleton structures in the four areas examined in the market are also included in the lower extremity group, as in the structures in the literature. In both studies, exoskeleton structures included in the upper extremity group followed the lower extremity group. Unlike the others, the whole body exoskeleton group was encountered only in exoskeleton studies in the literature. There are no full body exoskeleton studies available in the market area. Another result of the research is that there are structures that are not included in all three groups (lower-extremities, upper-extremities and whole trunk exoskeletons) in the classification of exoskeleton structures. This group, which supports exoskeletons in various ways, is found in literature studies and exoskeleton structures in the industry. These supporting structures examined in the literature review include control algorithm design, sensor distribution, controller development, actuator system design; Exoskeleton-supporting structures used and studied in the industry are passive structures that hold the exoskeleton. It has been determined that the usage areas of the exoskeletons examined in the obtained data are load-bearing and walking-supporting structures in the literature studies. Market research, on the other hand, did not focus on a specific area of use in the field of sports and military. However, when the health area is examined, it has been observed that the exoskeleton structures in this area are mostly used in areas such as supporting walking, hand-arm-gait rehabilitation and increasing mobility. In the studies carried out in the field of industry, the usage areas are focused on load bearing, shoulder support and sitting units. It can be clearly seen from here that the studies on exoskeleton structures in the literature are inclusive of the studies in the market area.

Considering the general results of the study, it is necessary to expand the scope of the classification of exoskeleton structures in the literature and to include the structures supporting the exoskeleton in this classification. Another result of our study is the observation that the developments in certain areas of use are at a more advanced level and that there is a need for development and progress in other areas of use.

In future studies, it is recommended to establish interdisciplinary teams, create different areas of use, and develop exoskeleton structures in the literature and bring them to the market. It is foreseen that the use of exoskeleton structures will become more widespread and their usage areas will increase, especially with the joint studies of engineering and design disciplines in this field.

Author contribution

Tasks involved in this project include idea and concept development, concept and design, supervision and consultancy, data collection, data processing, literature review, writing and critical review.

The tasks included in this project included both authors contributing to the idea and concept development phase,

Pala Ercan, İ. contributed to concept and design, data collection, data processing, literature review and writing

Türksoy, H.G. contributed to supervision and consultancy, critical review.

Financing Statement

This research has not received any specific grant from any funding organization, commercial or non-profit sector.

Conflict of Interest Statement

The authors declare that they have no conflict of interest.

Ethical Standards:

'No Ethics Committee Approval is required for this study'.

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