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Metabolic Cost Reduction and Analysis of Assisted Walking Gait: A Review

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Abstract

With the occurrence of pathological disorders in some people or aging, metabolic energy consumption begins significantly due to the weakness of the peripheral muscles and the increase in body fat with time, which aggravates the issues for this type of people, causing the rest hours extremely lengthy and consequently may produce heart or arterial diseases and elevate the mortality rate. Regarding the significance of the matter, this study examines a number of previous researches that featured several approaches to energy calculation and strategies for lowering energy consumption through the use of various external assistance devices, such as exosuits or exoskeletons, to assist people in carrying out their everyday tasks. And additionally discussed musculoskeletal simulation employs a variety of programs, especially OpenSim, which enables users to build models of musculoskeletal structures and produce dynamic movement simulations. According to the research findings, exoskeletons and other assistive technology can successfully lower the cost of metabolic energy to varying extents, depending on the device's weight, placement within the body, and whether it is active, semi-active, or inactive. In the future, the work to design and simulate a semi-active torsional ankle-foot exoskeleton with a specialized mechanism aimed to minimize metabolic energy.

Keywords: Walking, Metabolic Cost, Assistive Device, Exoskeleton, Model, Analysis, Simulation, Opensim.

دراسة مراجعة لخفض التمثيل الغذائي والتحليل لمساعد المشي

نور عبد الكريم، محمود رشيد إسماعيل

الخلاصة:

مع حدوث الاضطرابات المرضية لدى بعض الأشخاص أو الشيخوخة يبدأ استهلاك الطاقة الأيضية بشكل كبير بسبب ضعف العضلات الطرفية وزيادة الدهون في الجسم مع مرور الوقت مما يؤدي إلى تفاقم المشكلات بالنسبة لهذا النوع من الأشخاص مما يتسبب في طول ساعات الراحة وبالتالي قد ينتج عنه أمراض القلب أو الشرايين ويرفع معدل الوفيات. وفيما يتعلق بأهمية الأمر، تتناول هذه الدراسة عددا من الأبحاث السابقة التي تضمنت عدة مناهج لحساب الطاقة واستراتيجيات لخفض استهلاك الطاقة من خلال استخدام أجهزة المساعدة الخارجية المختلفة، مثل البدلات الخارجية أو الهياكل الخارجية، لمساعدة الناس في القيام بمهامهم اليومية. بالإضافة إلى ذلك ناقشت محاكاة العضلات والعظام باستخدام مجموعة متنوعة من البرامج، وخاصة OpenSIM، والتي تمكن المستخدمين من بناء نماذج للهياكل العضلية الهيكلية وإنتاج محاكاة الحركة الديناميكية. وفقا لنتائج البحث، يمكن للهياكل الخارجية والتقنيات المساعدة الأخرى أن تخفض بنجاح تكلفة الطاقة الأيضية بدرجات متفاوتة، اعتمادا على وزن الجهاز، وموضعه على الجسم، وما إذا كان نشطا أو شبه نشط أو غير نشط. في المستقبل، العمل على تصميم هيكل خارجي للقدم والكاحل مزود بنابض دائري وميكانيكية خاصة يهدف الى تقليل تكلفة الطاقة الايضية.

1. Introduction

The quantity and kind of movement that people engage in different situations are frequently measured using physical activity measuring techniques. It is common practice to anticipate energy expenditure (EE) using objective physical activity (PA) monitoring techniques. The capacity to calculate PA and evaluate EE in people who live freely is crucial given the rising prevalence of obesity, type 2 diabetes, and other non-communicable diseases (NCDs) worldwide [1]. Physical activity refers to any skeletal muscular action that causes energy expenditure [2]. Physical activity and energy expenditure are not the same thing. Simply put, physical activity is a behavior that causes an increase in energy expenditure above resting values [3]. entire energy expenditure (TEE) is the entire amount of energy used over a 24-hour period and includes three components: resting energy expenditure (REE), thermic effect of food (TEF), and active energy expenditure (AEE) as shown in (Figure 1), accounts for 70% of (TDE E) in inactive individuals [4-5]. Sleep metabolic rate (SMR) and wakefulness without physical activity are the two halves of (RMR). With slight variations by race, gender, and obesity, the latter makes up 5% of (RMR) [6,7,8]. (RMR) and (SMR) are words used synonymously to describe energy expenditure, regardless of physical activity or (TEF). (RMR) is mostly determined by fat-free mass, which accounts for 70% of the variance. Other important determinants include gender, age, and familial characteristics [9, 10].

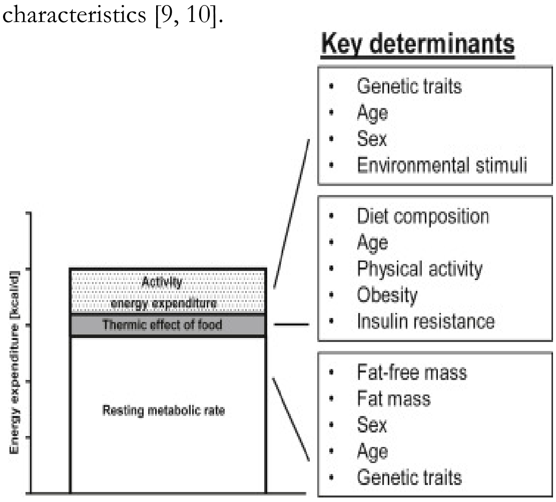

Figure (1): Factors of the daily energy consumption

2. Methodologies for Evaluating Energy Expenditure

2.1: Direct observation and self-reporting

Early in the 20th century, measuring energy expenditure—especially physical activity—became popular as a means of increasing worker efficiency and production [11]. Information regarding the kind, frequency, duration, and intensity of physical exercise was often gathered by subjective reports, such as questionnaires and diary entries [12,13]. Prior to assessing physiological responses, energy expenditure could only be measured by directly seeing physical activity patterns or analyzing film footage [11].

2.2. Direct Calorimetry

The direct calorimetry approach uses a calorimeter to assess the subject's rate of losing heat. It is an extremely reliable method to measure the rate of metabolic activity [14]. although their application is limited by the expensive cost. Additionally, there are Four forms of direct calorimeters, specifically the “isothermal direct calorimeters” (also referred as “heat-flow or heat-conduction calorimeters” [15].

2.3 Indirect Calorimetry

Indirect calorimetry involves measuring inspired and expired gas volumes, as well as O2 and CO2 dosages. Gas is collected employing a variety of ways, including the Douglas Bag, canopy, and face mask. Indirect calorimetry is a non-invasive and accurate approach for assessing energy consumption in the field using ambulatory metabolic mechanisms [16]. Energy expenditure is determined using Weir's formula which is as follow:

Energy expenditure (kcal) = 3.941 × VO_2 (L) + 1.106 × VCO_2 (L) [81]

3. Modeling For Analysis Gait Pattern

Developing powered or unpowered exoskeletons for human augmentation requires an understanding of human gait patterns. Applications for human motion simulation, such as motion analysis, robotic control, motion prediction, and product prototype design, frequently include lower extremity modeling.

A- COG (center of gravity) Model

The inverted pendulum model (IPM) is the most conventional COG model for walking simulation. It expresses abstract gait information by focusing on the COG's trajectories and modeling legs as an elastic link with varying length and stiffness. It can be applied to walking to forecast GRF (ground reaction force) and energy usage.[17]

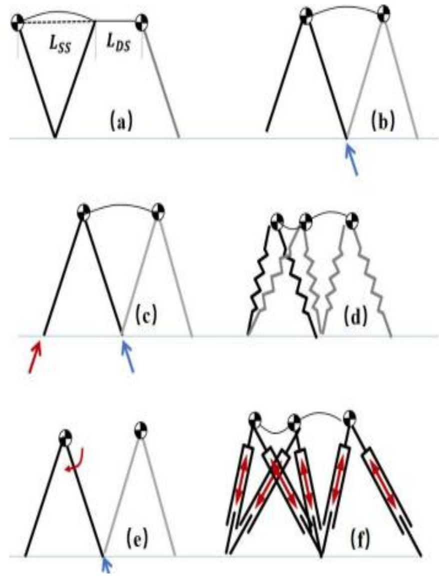

Figure (2): inverted pendulum model (a)to(c) are passive models, (d)to(e) are motivated by effect, and (f) is an active model [17]

B- Musculoskeletal model

Musculoskeletal models have emerged as the preferred technique for comprehending the underlying workings of human (and other animal) movement, initially spurred by a therapeutic interest in disorders of gait They are derived from the dynamic evaluations of linked rigid-segment models. The body is shown in rigid-segment models as a collection of separate, tough body elements joined at joints. Rigid-segment models are expanded upon by musculoskeletal modeling, which incorporates intricate simulations of individual muscles and neurological control. Musculoskeletal modeling extends the dynamic technique by using muscle parameters to solve the muscle redundancy problem under a given minimization criterion. [17]. Musculoskeletal modeling uses three models: static, dynamic, and contact. A contact model of the muscle skeleton, a static model of the muscle tendon, and a dynamics model of the muscle tendon are all included in musculoskeletal modeling, as shown in Figure (3).

The most popular simulation program, OpenSim, solves forward dynamics by combining data filters with inverse dynamics, thus implementing inverse dynamics. The distribution of muscles and bones is clearly shown by musculoskeletal modeling, which informs the design of the exoskeleton's distribution [18]. Many studies have discussed this topic; Using a unilateral knee orthosis,

Tomislav Bacek et al. (2022) [19] investigated the relationship between the musculoskeletal system of humans and energy adaption mechanisms during treadmill walking. They discovered that orthotic assistance had washout effects on joint kinematics and muscle activation, and that its kinematic effects were exclusive to the supported leg and joint. Bianco et al. (2022) [20] investigated metabolic savings from multi-joint support and discovered optimal joint combinations using musculoskeletal modeling. They improved the control algorithms for lower-limb exoskeleton assistive devices and created 2D muscle-driven walking simulators. They discovered that multi-joint devices provided 50% more metabolic savings than single-joint devices, with connected multiple-joint devices accounting for the majority of savings.

Manuel Cardona et al. (2019) [21] created an open-source musculoskeletal model for biomechanical investigation of the human lower limb that simulates both healthy and pathological gait. Six lower-limb joints, 10 knee ligament segments, 88 Hill-type muscle-tendon segments, and 14 bones make up the model. It imitates functional electrical stimulation effects, enabling for simulations of a variety of lower limb disorders. The model was validated with actual data from their gait recording device and CODA motion software.

Wang et al. (2018) [22] developed a gait analysis technique using musculoskeletal modeling and OpenSim. They created a walking model of human lower extremities, analyzing muscle force and joint kinematics and revealing a link between force and gait phase.

Wellington C. Pinheiro et al. (2024) [23] used OpenSim two-degree-of-freedom musculoskeletal modeling to create a biomechanical model of pathological tremors in Parkinson's patients. Their findings showed the model accurately represented individual tremor statistical features rather than essential tremor.

Amirhossein Majidi Rad et al. (2019) [24] developed OpenSIM 4.0 models and simulations of the human musculoskeletal system, which included artificial knee joint deformities and a single hinge joint exoskeleton. The vastus lateralis muscle produces only 4.3% more force when knee joint motion is restricted, according to the results.

In order to overcome the shortcomings of earlier models, Junyan Li et al. (2019) [25] created a finite element muscular and skeletal model to forecast 3D muscle contractions. Realistic three-dimensional muscles, spatial muscle fiber alignment, interactions between muscles and bones, and strains and pressures on muscles were all taken into account in the model. The overall contact force of the knee was accurately predicted by the model.

Yi Ting Yap et al. (2023) [26] used OpenSim to study the biomechanical effect of knee joints braces on walk data. The study found that knee braces limited knee range of motion and altered stance-to-swing ratio, walking speed, and step length. The study suggests that musculoskeletal modeling and simulation tools can be used for practical and less invasive analysis of human motion.

Manuel Cardona et al. (2019) [27] developed a 3D model of the musculoskeletal system for multiple sclerosis using the Musculoskeletal Modeling Software (MS MS). The model can be exported to Simulink for Functional Electrical Stimulation and injury assessment, aiding biomechanical analysis and rehabilitation robot design.

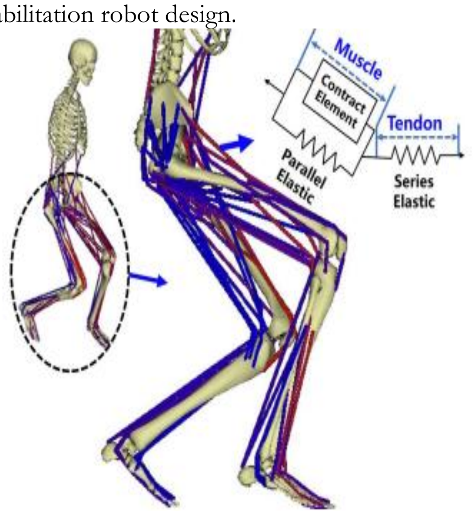

Figure (3): Musculoskeletal model of lower extremity in OpenSim [17].

4. Assistive Devices

Assisted devices for the human body are tools and technology designed to support, enhance, or raise physical capacities and standard of living. Among the several assistance technologies available are walking aids, orthoses, and exoskeletons.

4.1 Exoskeleton

A human exoskeleton is a particular kind of mechanical device that an operator wears to help with limb movement and motor job performance. These exoskeletons are extensively utilized in rehabilitation facilities, for military purposes, for a range of orthopedic conditions, and varying degrees of paralysis. This technology's primary goal is to improve the capabilities of the human body. Running and heavy walking both have the potential to have lower metabolic energy costs when exoskeletons are used.[28]. Wearable robotic exoskeletons that lower the metabolic cost of walking have the potential to help military personnel, and firefighters carry large loads and increase mobility for many people, including those with neurological or musculoskeletal problems.

Assistance options that reduce metabolic expenses using both powered and without power apparatus have only lately been discovered. Although exoskeletons have improved walking by reducing metabolic expenditures, further development may be necessary before exoskeleton products are widely adopted. It has been demonstrated that assisting one or two joints using both mobile and tethered exoskeletons lower metabolic spending [29].

Many robotic lower limb exoskeletons designed to improve human performance rely on locomotion activities such as walking uphill, carrying a load while walking, and navigating varied terrains. Firefighters and military personnel may encounter a variety of natural terrain, including steep inclines, and are often required to lift weights exceeding 30 kg. Because the metabolic cost of walking with a weight increases linearly with load, walking uphill has a higher metabolism cost than walking flat. Walking's metabolic cost can typically more than double when combined with an incline and a heavy backpack load, as opposed to walking at the same speed on flat terrain with no burden. Another aspect influencing metabolic cost is the kind of terrain Compared to walking on unstable ground like sand, gravel, or dirt, walking on flat surfaces like pavement or gravel uses more energy. Depending on the locomotor demand, an exoskeleton capable of supporting one lower limb joint but not another should have a different energetic cost [30].

4.2 Types of Lower Exoskeletons

For many different of reasons, lower exoskeleton types are preferred, including as enhancing human endurance by reducing the metabolic demands of a particular activity or boosting human capabilities like load capacity or walking speed. Devices that use exoskeletons are frequently categorized in the following manner:

A. part of human body
B. activity

4.2.A.1: Hip Exoskeleton

At the hips, the upper and lower limbs are connected. The human hip has three degrees of freedom (DoF): medial/lateral rotation, abduction /adduction, and flexion /extension.

It takes these movements for a body to run or walk. A hip exoskeleton is a wearable robotic device intended to help with movement, especially for people who require assistance when walking or have lower limb problems. These devices can help increase stability, enhance gait, and minimize stress on the hip joints. Different designs of exoskeletons are illustrated in figure (4) [31].

4.2.a.2: Knee Exoskeleton

The human knee joint is an essential portion of the body since it produces a lot of torque when one walks, runs, or moves from a squat to a standing position and vice versa. Furthermore, when engaging in certain activities, the knees also limit impact. In addition, the knee is situated between the ankle and the hip.

The knee offers simpler flexion/extension and rotational movements in comparison to the hip and ankle. Knee exoskeletons improve mobility and offer support to help people with a variety of tasks. Knee exoskeletons aid with balance and lower the chance of falls, especially in the case of older people or those recuperating from injuries. Different knee exoskeleton designs are developed based on the needs, as shown in Figure (5).[31]

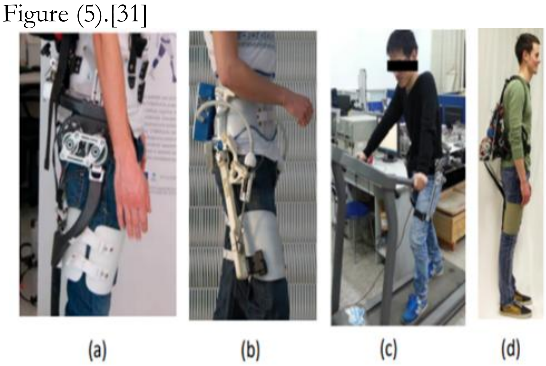

Figure (4): Hip exoskeletons (a)[32]; (b)[33]; (c)[34]; (d) body Exosuit [35]

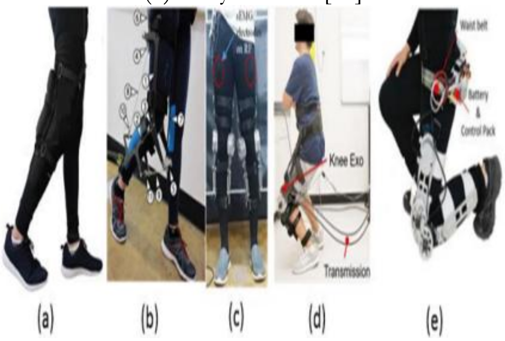

Figure (5): Knee exoskeletons (a)[36], (b)[37], (c)[38], (d) [39], (e) [40]

4.2.A.3: Ankle Exoskeleton

The ankle is the joint that is been exposed to the most torque during a walking motion. This joint includes four bones in three planes of motion (three DoF). But dorsiflexion, or plantar movement, is the most prevalent action that takes place during the stride cycle. Ankle exoskeletons are practical tools that help a range of individuals become more physically proficient, enhance their quality of life, and recover quickly. Figure (6) demonstrates the variety of ankle exoskeletons that have been created.[31]

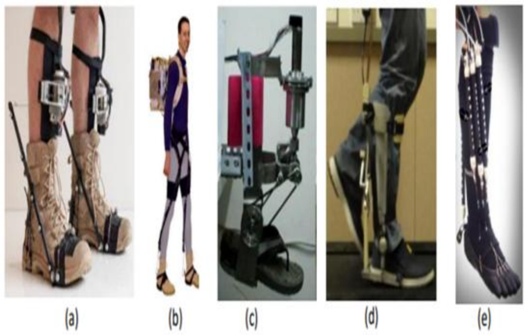

Figure (6): One-DoF ankle exoskeleton (a) [41]; (b) 42]; (c) 43]; (d) [44]; and (e [45]

4.2.A.4: Multiple Joints Exoskeleton

To stimulate a joint, many muscles may be required, each of which travels through multiple joints. Several actuators are used in some exoskeletons to actuate the ankle, knee, and hip joints. Multiple exoskeletons can help people with lower limb disabilities move more efficiently by supporting and stabilizing them. They can also increase a soldier's strength and endurance when they are carrying big burdens over long distances. Figure (7) shows several types of multiple joint exoskeletons. [31]

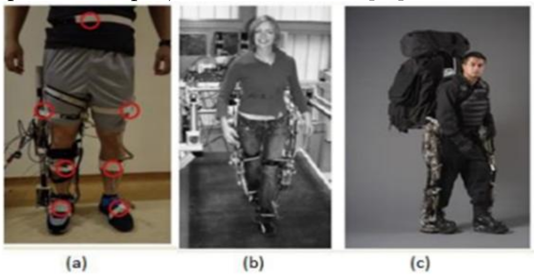

Figure (7): Multiple joints exoskeletons: (a) [46]; (b) [47]; and (c) [48].

4.2. B.1: Active assist device:

An active exoskeleton, which was powered by one or more actuators (such as an electrical motor, a pneumatic artificial muscle, or a hydraulic cylinder), was able to provide a higher support force. With the powered support that active exoskeletons offer, a user's movements can be amplified, or the effort involved in walking and lifting can be decreased.[49]

Figure (8): Active assist device [50]

4.2.B.2: Passive assist device:

As represented in figure (9), a passive (unpowered) system stores and releases human movement energy as needed by the use of materials, springs , or dampers instead of an external power source. Although non-powered exoskeletons are frequently lightweight, their controllability is restricted since they lack electronics and a power source. These exoskeletons are typically used to enhance joint mobility and support, align, prevent, or treat abnormalities in a human body link or joint. In order to generate very slow-motion speeds, passive exoskeletons need a lot of physical activity and a strong the top part of body to supply all the power required for movement .[51]

Figure (9): Passive assist device [52]

4.2.B.3: Semi-passive device:

Devices classified as semi-active are in the middle; they can't add energy to the gait cycle, but they still need a sources of power to run Systems for electrical control, clutches, or variable dampers, for example. A quasi-passive device's power need is typically, though only sometimes, minimal.[53]

Figure (11) Semi passive devices [54]

5. Metabolic energy reduction using different assist devices

Using various assistive technologies such as exoskeletons, exosuits, or expands can help people save energy throughout their regular activities.

5. A: exoskeletons devices

Wearable exoskeletons have grown in popularity in the aided mobility, medical rehabilitation, and military sectors in recent years. These technologies are widely used in everyday life, industry, and research. [55-57]. Exoskeletons fall into one of two different groups: either they augment human endurance through decreased the metabolic demands of a particular activity, or they increase human capacities like walking speed or load capacity. The exoskeleton's ultimate objective is to improve running endurance and decrease muscle activation. Nonetheless, the two kinds of devices are frequently confused. For instance, a device that lowers the metabolic cost of exercise may also increase the rate at which the same metabolic cost is incurred. Exoskeletons may also include certain orthopedic devices intended to restore lost function.[58] [59].

Many studies have focused on metabolic reduction since lowering energy expenditure can help reduce stress reactions and increase general well-being while also allowing the body to focus resources on healing and immunological responses,

Ali Reza Manzoori et al. (2024) evaluated two hip exoskeleton controllers: the Simple Reflex Controller (SRC) and the Hip Phase-Based Torque Profile Controller (HPT). They tested these controllers on 23 novice, healthy adults walking at 4 km/h without substantial familiarization .

The results revealed that both controllers considerably minimized metabolic rate by 18.0% and 11.6% when compared to walking with the exoskeleton in non-powered mode [60].

Ava Lakmazaheri et al. (2024) studied the effectiveness of human -in-the-loop ankle exoskeleton optimization in older adults. Ten fit individuals over 65 years old engaged in 240 minutes of treadmill training and optimization using tethered ankle exoskeletons. The study found that assistive ankle plantarflexion torque patterns increased metabolic rate and self-selected walking pace, leading to a 25% reduction in transport energy cost [61].

Livols et al. (2024) found that using a powered, portable hip exoskeleton can decrease The energy requirement of walking in four people with above - knee joint amputations. The reduction ranged from 10% to 17%, with a 2-24% reduction for three out of four participants. The study suggests that energy injections at the hip level could be a viable treatment option, increasing mobility and improving locomotor training, potentially improving quality of life [62].

Luís Quinto et al. (2023) conducted a study on a dual-purpose passive ankle exoskeleton designed to lower metabolic expenses during walking. The study involved 29 participants using three force elements, the outcomes indicated that the exoskeleton able to reduce metabolic consumption, give comfort, and offer a range of motion, making it suitable for uneven terrain and prolonged use [63].

Ohhyun Kang et al. (2023) have invented an un-powered wearable exoskeleton that can reduce a wearer's perceived weight during walking. The exoskeleton can reduce weight transmitted by 7 kg, increase the human trunk extension angle by 1.8°, and decrease the wearer's net metabolic rate by up to 47.41%. This energy-efficient device can improve a person's ability to carry loads and address structural issues associated with upper extremity devices [64].

Di Hu et al. (2022) found that a powered exoskeleton can lowered walking metabolic costs by modifying power within the foot- ankle complex. The exoskeleton stores negative mechanical energy from the foot, recycling it before mid-stance and transferring it to the ankle joint for push- off. This increases energy efficiency in the foot-ankle complex and reduces quadriceps muscle contraction during heel strikes [65].

Cunjin Wang et al. (2022) created a quasi-passive ankle exoskeleton using a heel-strike energy-storage mechanism and a lightweight, energy-saving clutch. The device recycles energy lost during heel strikes into propulsion, improving aid and reducing metabolic costs. The device was tested on Six people in good health on both level and incline surfaces, with less assistance torque and lower total metabolic expenditure when walking uphill [66]. The study by

Panizzolo et al. (2021) examined how an autonomous exoskeleton might lower metabolic expenses in elderly people.. The findings suggest that a steady, low torque can significantly reduce metabolic costs, making it a promising option for enhancing the functionality of hip assistive devices, particularly for those who require greater independence [67].

Wendy M Bryan et al. (2021) assessed how three volunteers were affected by a hip -knee-ankle exoskeleton. When compared to walking alone in the device, they found that walking with an exoskeleton reduced metabolic utilization by 47% at no load, 35% at low load, and 43% at high load [68].

Wang et al. (2021) conducted three experiments to measure the effects of an exoskeleton on muscle function. They found that the exoskeleton reduced surface electromyography signal amplitude and plantar pressure while also reducing the percentage of weight through the feet. The exoskeleton also reduced metabolic cost, with an average extra expenditure of 2.85% and 2.52% [69].

Michael Shepertycky et al. (2021) discovered that wearing an exoskeleton that eliminates kinetic energy during the walking may lower the metabolic cost of walk by (2.5 ± 0.8%) for healthy male users, emphasizing the importance of energy removal time and amount [70].

Tiancheng Zhou et al. (2021) discovered that a multiarticular un-powered exoskeleton can more effectively modulate the metabolic energy of hip and knee joint musculature . The exoskeleton's biarticular spring-clutch mechanism transfers and recycles energy, lowering target muscle activity and resulting in an (8.6 ± 1.5%) drop in metabolic rate in comparison to walking without an exoskeleton [71].

Franks et al. (2021revealed that single-joint, two-joint, and whole-leg support greatly decreased walking metabolic expenditure utilizing a hip-knee-ankle exoskeleton simulator and human-in-the-loop refinement. Walking metabolic expense declined by 50% when all three joints were supported, indicating that exoskeleton support can reduce walking energy use by half. [72].

Ettore Etenzi et al. (2020) created an un-powered passive-elastic exoskeleton that stores elastic energy during knee extension and facilitates ankle plantarflexion . The results demonstrated a 23% increase in average net metabolic power once utilizing the exoskeleton but an (11%) drop when disengaged [73].

Kirby A Witte et al. (2020) improved the motorized and spring-like exoskeleton features for treadmill use. Powered assistance augmented energy efficiency by 24.7 ± 6.9% compared to zero torque and 14.6 ± 7.7% when jogging in conventional shoes. However, spring -like help had little effect, simply increasing energy efficiency and metabolic rate [74].

Caihua Xiong et al. developed a hip-knee passive exoskeleton using springs for knee-flexion and hip extension, reducing metabolic using by (7.6%) during walking, with springs extending to store knee joint negative mechanical power [75].

5. B: exosuit devices

Jinsoo Kim et al. (2022) found that walking in a tethered hip flexion exosuit can reduce energy costs by 50% with about 50% less mechanical power, demonstrating the importance of tailored support for hip flexion. This reduction is 14.8% lower than without assistance [76]. Lingxing Chen et al. (2021) discovered that a novel lightweight soft exosuit, which is currently the lightest powered exoskeleton, considerably reduces energy consumption by 11.52% when walking on a treadmill at five kilometers per hour. This lightweight exosuit significantly reduces muscle fatigue in the rectus femoris, vastus lateralis, and gastrocnemius muscles by 10.7%, 40.5%, and

5.9%, respectively, when compared to non-exosuit locomotion [77].

Hamid Barazesh and Maziar Ahmad Sharbaf developed a non-power lower limb exosuit using bi-articular variable stiffness(k) components. The exosuit uses an updated (FMCH) control system with height feedback , aiming to create a passive-exosuit based on a neuromuscular model of human gait. The study found that this approach can lower walking metabolic expenditure by 10%, with passive biarticular elasticity leading to a 14.7 ± 4.27% reduction in metabolic expenditure and a 4.68 ± 4.24% reduction in walking metabolic cost [78].

Fausto A. Panizzolo et al. (2019) studied how moving with a soft-exosuit supporting the hip joint caused energy changes during training sessions. Over 20 days, participants attended five sessions, walking with a weight of (20.4 kg) for (20) minutes while the exosuit was powered and 5 minutes without it. The study found that training had a significant impact on metabolic cost percentage changes [79]. Zhou et al. (2021) found that a multiarticular unpowered exoskeleton can regulate metabolic energy of hip and knee musculature more efficiently. The exoskeleton's biarticular spring-clutch mechanism transfers and recycles energy, reducing target muscle activities and resulting in an 8.6 ± 1.5% reduction in metabolic rate compared to walking without the exoskeleton [80].

6. Discussion

Some of the assistive devices that aim to reduce the effort expended and enhance human physical activity have been reviewed. The usage of exoskeletons to enhancing various human activities types was the main topic of this review. There are two primary types of exoskeletons: powered and unpowered. The exoskeletons can be applied to different segments of the human body. The exoskeletons used on the lower limbs of humans are the main subject of this review. Numerous domains, such as biology, neuroscience, mechanics, and robotics, benefit from and are enhanced by the study of movement. Two essential jobs are made possible by OpenSim, which combines techniques from these domains to produce quick and precise movement simulations. The approach may first compute factors such as muscle forces and tendons' stretch and recoil during movement, which are difficult to observe empirically. Second, OpenSim can predict unique movements, such as kinematic changes in the human gait during loaded or inclined walking, utilizing motor control models. **Table (1)** below indicates the most significant types of assistive devices, their position on the human body, and the rate of metabolic energy reduction.

Table (1): The type, location and energy reduction of assistive devices

Type of Assistive Device	Location	Metabolic Reduction
Two hip exoskeleton controllers: Simple Reflex Controller (SRC) and hip phase-based torque profile controller (HPT) [60]	Waist and thigh	18.0% (SRC) 11.6% (HPT)
ankle exoskeleton [61]	Leg and foot	19%
quasi-passive ankle exoskeleton [66]	leg and foot	6.4 ± 1.3%
hip-knee-ankle exoskeleton [68]	Waist, thigh, leg and foot	47% at no load, 35% at light load, and 43% at heavy load.
passive lower limb exosuit [78]	Waist, thigh and leg	14.7 ± 4.27%
tethered hip flexion exosuit [76]	Waist and thigh	15.2 ± 2.6%
soft exosuit [77]	Waist and thigh	−10.1±3.2%
multiarticular unpowered exoskeleton [80]	Waist and thigh	8.6 ± 1.5%

7. Challenge and Limitation

From reviews of many previous research investigations, the following points can be identified:

1-Metabolic energy monitoring has limitations, such as:

a. The complexity of metabolic processes that make it impossible to accurately capture all energy transfers.

b. Individual Variability: Determinants comprise age , gender, composition of the body, and fitness level can all influence standardized metabolic rate measurements.

c. Methods of Measurement: Standard procedures, such as indirect calorimetry, may be sensitive to their surroundings and require precise calibration. Although more accurate, direct calorimetry is not practical for everyday use.

d. Short-Term vs. Long-Term Measurement: Depending on the intensity and duration of an activity, energy expenditure might fluctuate significantly, making it difficult to obtain a representative average across time.

2. There are certain restrictions and concerns when employing exoskeletons as assistive technology to measure metabolic energy reduction.

a. Calibration and Individualization: Because each user has unique biomechanics and needs, a thorough calibration process is required to ensure that the exoskeleton aids users to the proper degree while maintaining measurement accuracy.

b. Environmental Factors: External factors such as surface type and geography can affect the exoskeleton's function and thus the quantity of metabolic energy expended.

c. Device Weight and Design: The weight and design of the exoskeleton can influence the overall amount of energy consumed. Measurement problems might result from equipment that is too heavy or awkward, requiring more energy to operate than expected.

8. Conclusion

Due to the relevance of metabolic energy consumption and how it directly affects individuals' activity during daily actions, as well as the extent to which it reflects on health, a review study was conducted for many assistive devices, including exoskeletons and exosuits, which contribute in certain proportions to reducing the energy consumed during any daily activity carried out by theindividual. This study used a survey gathered through the previous 10 years to investigate how assistive technologies effect activity. These devices were tested both experimentally and conceptually using various modeling techniques, such as OPENSIM software MATLAB, numerical or biomechanical simulation. After reviewing the prior literature, the researchers focused on the following:

1- Research suggests that active exoskeletons reduce metabolic costs more effectively than non-powered exoskeletons., which rely on mechanical elements like springs or elastic bands to absorb and give off energy. They can shift the load and provide support, but they cannot generate force.

2- The exoskeleton minimized muscle fatigue while maintaining mobility of movement

3- Exoskeletons have energy-recycling systems that gather wasted energy during negative power phases and use it to help walk

4- Exosuits can reduce metabolic costs and improve walking performance.

5- The results of previous studies suggested that the metabolic energy reduced with assisted device about (6 -18%). This differences according to the types (passive, semi-active or active), location and the weight of the devices

6- Musculoskeletal models are an important tool for biomechanical research. Simulation and modeling of the musculoskeletal system techniques offer a less invasive and more practical approach to analyzing human motions. It also provides a means to Look into the influence of medical. gadgets.

7- OpenSIM is one of the forms of biomechanical analysis of bodies used in many applications due to its multiple benefits, including analyzing the movement of bodies, developing muscular and skeletal structural models and active motion simulations, and knowing the extent of metabolic energy consumption, whether the individual is without an assisted device or with a supporting device, and despite its great importance, previous studies are very limited in their application.

8- In the future, the work to design and simulation light weight and low-cost semi-active ankle-foot exoskeleton with torsional ankle spring, hydraulic damper to assist in shock absorption during the gait and adjustable dorsiflexion mechanism to control the walking and prevent any excessive unwarranted movement, manufactured by 3d printing. technology (FDM), which aim to minimize the metabolic cost of patients with weakness of lower limb muscles and study the impact of an assistive devices. on metabolic. cost will be examined and analyzed using an OpenSim simulator and compared with experiments on the force platform and video capture of motion analysis.

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