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Electromyography Acquisition and Intervention in Healthcare for Older Adults: A HCI Scoping Review

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Abstract. As age advances, the decline in bodily functions and the rise in age-related diseases pose various challenges to the daily lives of the older population. This scoping review discusses the potential of Electromyography and Electrical Stimulation technologies in addressing aging health issues. This review aims to discover potential design opportunities for EMG and ES technologies in promoting healthy aging by searching for answers from the diverse research purposes, target groups and human-computer interactions involved in the 42 selected articles. Through the thematic analysis, we discovered six categories of applications and four core design themes. Based on our findings, a map has been illustrated to provide visual guidelines for future research and design practice. To enhance the overall health and quality of life for older adults, it would be beneficial to concentrate on three interdependent aspects: independent at home, active outdoors, and mental well-being.

Keywords. Electromyography, electrical stimulation, healthcare, older adults

1. Introduction

1.1. Older Adults and Healthy Aging

"Healthy Aging" describes a process of fostering and maintaining functional abilities to achieve well-being in old age [1]. It emphasizes ensuring that all older people enjoy healthy, active and productive lives. This means focusing on their physical health, mental health, social activities, and quality of life [2]. However, as one ages, there is a natural decline in bodily functions that can result in an increased incidence of age-related diseases. For instance, impairments in motor function can manifest in a variety of ways, including muscle atrophy, neurological decline, and other related diseases. These circumstances can pose different challenges in daily living for older adults, such as difficulty walking, loss of balance, and muscle weakness. It may further cause them to lose their ability to live independently. Therefore, our goal is to promote healthy aging among older adults, enabling them to maintain independence at home, stay active in communities and experience emotional fulfillment in their later years. From the perspective of human-computer interaction, we focus on Electromyography and

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Electrical Stimulation as practical solutions to aid older adults in managing their various health concerns.

1.2. Electromyography and Electrical Stimulation

Electromyography, as a method for muscle information acquisition, is utilized to measure, process, and identify muscle activity [3]. To be more specific, EMG is a diagnostic procedure that evaluates the health condition of muscles and the nerve cells controlling them. Its relevance in the context of aging is manifold. Recent studies highlight EMG's potential in interactive applications [4], [5]. Through non-invasive biometric techniques, EMG offers older adults an intuitive and natural interactive experience. One significant application is Electromyography biofeedback (EMG-BF) [6]. Typically integrated with virtual reality training, it allows users to receive real-time feedback on muscle activity, contributing to assisted therapy and muscle training [7]. Moreover, EMG has been employed for gesture and facial expression recognition [8], [9]. It detects subtle muscle changes associated with gestures or emotional states, providing a novel perspective and depth to user experience design and interface control.

Electrical stimulation (ES) represents a technique that employs electrical pulses to evoke muscular contractions. Its versatility and effectiveness render it an invaluable asset in clinical settings, especially for the aging population addressing the challenges of age-related muscular and neurological decline [10]. This scoping review emphasizes two prominent ES-based methods: Electrical Muscle Stimulation (EMS) and Functional Electrical Stimulation (FES).

The purposes and application scenarios of EMS and FES differ significantly. EMS primarily focuses on training muscle endurance, while FES aims to restore bodily functions lost due to neural injuries or degeneration, assisting elderly individuals in performing specific functional movements [11]. EMS is a technique that employs electrical impulses to activate muscles. By transmitting electrical pulses to the muscles, EMS stimulates nerves, inducing muscle contractions, thereby aiding the elderly in maintaining and amplifying muscle functionality [12]. Within the Human-Computer Interaction communities, the applications of EMG and ES in the health management of older adults are continually expanding. This article aims to summarize the research purpose, application scenarios, challenges and design opportunities of electromyographic acquisition and intervention within healthy aging, and the role of HCI, according to a scoping review of the existing literature.

1.3. Research Questions and Objectives

This article provides a scoping review of utilizing EMG and ES for Healthy Aging. Through this review, we aim to discern diverse perspectives on designing EMG or ES driven solutions. The main research question is: “What are the potential design opportunities for EMG acquisition and intervention for well-being in older age?”

To answer this question, the following sub-questions were constructed:

1) What are the current EMG, EMS, and FES applications for older adults? (Refer to 3.2, 3.3 & 3.4)

2) What design potential do EMG and ES technologies hold in interdisciplinary applications? (Refer to 3.5)

2. Methodology

The selection process of our scoping review was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.

2.1. Data Sources and Search Strategies

In this scoping review, we focus on articles published between 2013 and 2023, a decade that has witnessed significant advances in myoelectric technology and its multidisciplinary applications. Two databases were selected for the search: the Association for Computing Machinery (ACM) and Scopus. These databases were chosen for their rich collection of HCI-related research and the potential interdisciplinarity they offer, ensuring comprehensive coverage of the topic. Our search strategy was meticulously designed to capture the essence of our research questions. EMG and ES interventions were the first part of the search terms to provide a clear technical framework. The concept of "Healthy Ageing" was refined and split in our search strategy into two aspects: "the Elderly" and "Healthcare", making sure our search results were target group and problem-oriented.

Electromyography and Electrical Stimulation (“Electromyography*” OR “EMG*” OR “myoelectric*” OR “Electrical Stimulation” OR “EMS*” OR “FES*”)

AND the Elderly (“older adults” OR “elder*” OR “aging*” OR “Patient”)

AND Healthcare (“Physical Health” OR “Mental Health” OR “rehabilitation” OR “accessibility” OR “mobility” OR “therapy*” OR “assist*” OR “prevent*”)

It's noteworthy that, within the "the Elderly" category, we found that solely relying on keywords such as ("older adults" OR "elder*" OR "aging*") might result in a limited number of search outcomes. Consequently, we incorporated the term "Patient" to capture studies on age-related medical conditions and ailments, such as muscle weakness, paralysis, and stroke...

2.2. Data Sources and Search Strategies

Non-research, case studies and review articles, non-English publications and inaccessible materials are excluded in our study. We further narrowed our disciplinary scope to disciplines that are highly relevant to elderly health and human-computer interaction, encompassing “Engineering”, “Health Professions”, “Computer Science”, “Nursing”, “Social Sciences” and “Environmental Science”.

2.3. Evaluation Procedures

The identified articles were screened by two reviewers. Both reviewers screened the titles and abstracts of the papers independently. During the first step, the results were compared and discussed, and we reached a mutual agreement on the selected studies. Duplicate articles were removed. In the subsequent assessment phase, the full-text articles were scrutinized independently by the two reviewers. If there were any disagreement about the inclusion or exclusion criteria between both, a third reviewer made the final decision. The ultimately chosen articles were amalgamated and cataloged in the Zotero tool, where the thematic analysis was undertaken.

3. Results

3.1. Search Results

The systematic search procedure is illustrated in the PRISMA flow diagram (Figure 1). Our literature search from 2013 to 2023, initially yielded 2215 articles. We identified 412 papers after screening the titles and abstracts and removing duplicates (N=27). A total of 42 articles met the inclusion criteria. Of these, 30 articles pertained to EMG technology, 8 studies focused on Electrical Stimulation, and 4 papers involved both technological approaches. 370 studies were excluded, primarily due to not focusing on EMG or ES for aging individuals or no HCI/design and healthcare involved. Zotero tool has been used to further code and analyze to answer our research questions.

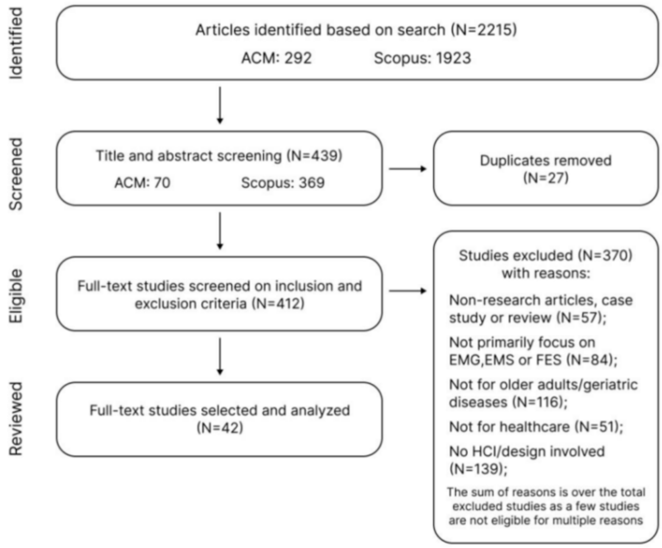

Figure 1. Flow diagram of the results of study selection.

To answer our first sub-question, we summarize five research purposes for acquiring EMG and providing electrical stimulation in the range of elderly individuals' health, which is indicated in Table 1. Specific analyses will be presented in separate paragraphs 3.2, 3.3, and 3.4.

Table 1. Thematic analysis results of main research purposes

the purpose of research	Number of Studies	Detailed aspects
Electromyography for daily assistance	11	- EMG controlled aids [13], [14] - Researching muscle status during daily activities for design [15], [16] - Communication tool based on sEMG signals [17]

Electromyography for motor training and rehabilitation	14	- Virtual reality, Augmented reality or video game training [18] - Motor Imagery [19] - Limb rehabilitation devices or systems [20]
Electromyography for affective identification and expression	6	- Identify facial expressions through sEMG signal [21], [22]
Electrical Stimulation for motor training and rehabilitation	8	- Gait guidance and restoration [23], [24] - Standing balance enhancement [25] - Providing therapeutic stimulation for upper limb [26], [27]
Integration of EMG and ES in rehabilitation	4	- EMG controlled FES [28], [29]

3.2. Electromyography for Older Adults

We observed that, in recent studies, Electromyography recognition, control, and biofeedback have been presented both separately and collaboratively in interdisciplinary areas to satisfy diverse aging challenges and purposes of research (Table 1) involving Daily assistance (N=11), Motor training and Rehabilitation (N=14) and affective identification and expression (N=6).

3.2.1. Daily assistance

11 papers contributed various types of design interventions for healthy aging in daily assistance sessions. In particular, 6 studies proposed EMG controlled wheelchairs or robotic aids. 4 articles analyzed and evaluated muscle status during daily activities to validate the feasibility of the design or provide recommendations for future designs, and only one study focused on communication assistance.

Providing EMG technical assistance to older individuals and those with motor disorders has been a crucial research focus spanning over a decade. EMG signals have been harnessed to control wheelchairs [13], [30]–[32], and other assistive devices for routine tasks [14], [33]. Considering smart wheelchairs, traditional joystick interfaces might pose challenges for the intended audience due to potential motor skill limitations. To better aid their daily activities, the Myo armband has been designed [30]. It controls the wheelchair by capturing EMG signals from the user's forearm. Another study processed EMG data from both upper and lower limb muscles to discern wheelchair movements in six directions: forward, backward, left, right, start, and stop [13]. In terms of aiding in hand tasks of daily living, a study by Polygerinos et al. introduced an assistive soft robotic glove [14]. It integrates soft robotics and surface EMG to perceive when the user wants to open or close their hand and provide appropriate support. Similar research has targeted chronic stroke or Parkinson's patients, such as "Soft-SixthFinger" [33].

Four studies investigated innovative methods, such as electromyography and other technologies, to evaluate and enhance mobility in various aging scenarios. These include an analysis of the effectiveness of wearable devices such as knee braces [34] and soft exoskeleton suits [35], and future design ideations according to the toolbox for fitness assessment [15] and muscle fatigue during stair climbing [16] in the elderly population. In addition, A seminal study [17] offered a promising non-invasive technique for communication. By capturing surface EMG signals generated when a user winks, the tool displays letters of the alphabet sequentially, allowing the user to select.

3.2.2. Motor training and rehabilitation

We found 14 papers discussing Electromyography for motor training and rehabilitation, including Virtual reality, Augmented reality or video game training (N=8), and other limb rehabilitation devices or systems (N=6).

Motor training through digital games were designed to provide a more immersive training experience for older patients. Numerous studies concluded that gamified treatments provide high-quality training through realistic and virtual interaction. It has the potential to reduce rejection rates, engage participants and improve their abilities to control their limbs [19], [36]. And patients also responded positively (N=5). Four articles integrated electromyographic biofeedback in Virtual reality training to acquire muscle activity in real-time to capture information about a patient's progress in rehabilitation and adjust the training program to achieve optimal results. Three other articles discussed the integration of machine learning and algorithms to parse EMG data for personalized feedback [37]. To exemplify, an emotion-adaptive VR experience for eldercare that uses EMG to measure emotional valence and stress in real-time has been created [38]. It mentioned machine learning and multi-modal physiological sensing techniques to create more balanced and personal VR environments. Additionally, by evaluating different virtual reality training applications, an study identified game elements that may better activate and train users' muscles such as more dynamic and varied movements (e.g., jumping, squatting and one-legged standing), and adding additional weight or steps to increase muscle activation [18].

3.2.3. Affective identification and expression

Several papers (N=6) have identified and classified facial expressions using sEMG signals obtained from the face muscles. For example, Lima and the other two researchers concluded that four features extracted from EMG signals, namely RMS, MAV, IEMG, and VAR, showed better variations in the emotions studied (anger, joy, happiness, and sadness) [21]. Another study emphasized the contribution of affective identification to provide individuals with medical conditions like stroke or facial nerve damage the opportunity to express emotions [39]. However, this research has not directly linked to mental health management or therapy for older adults.

3.3. Electrical Interventions for Seniors

Eight studies examined the effectiveness of EMS and FES in geriatric care, particularly in improving walking, balance, and rehabilitating the upper extremities and hand. Among them, Four studies delved into the applications of electrical stimulation in maintaining aging mobility, focusing on intervention for lower limbs, which involves gait guidance and restoration (N=3) and standing balance enhancement (N=2).

Meanwhile, four articles covered robotic systems and electrical stimulation functions. Providing therapeutic stimulation, hand joints and upper limb movements are assisted to improve motor control in older patients. For example, one study examined a robotic device for patients with upper extremity hemiplegia after a stroke. The study's results indicated that ES improves motor control and aids in rehabilitation [27].

3.4. Integration of EMG and Electrical Stimulation Techniques in Rehabilitation

Four articles referred to the combination of EMG and ES techniques. To illustrate, EMG controlled FES techniques have been demonstrated to improve balance, gait function, and symmetry immediately [28]. In addition, combining gamified rehabilitation with EMG-controlled FES can increase patient engagement and motivation, making them more willing to participate and benefit [29]. Other researchers have assessed and refined the FES wearable from both user and clinician perspectives [41]. It was discovered that both patients and physicians conveyed positive feedback regarding the technology, albeit with safety and comfort concerns. To facilitate a multimodal approach, the NeuroSuitUp platform [42] utilized various technologies like wearable robots, serious games, and more. This integration offers a comprehensive rehabilitation pathway and a richer therapeutic experience for patients.

3.5. Core Design Themes at the Intersection of Electromyographic Interventions and Human-Computer Interaction

Through 93 codes generated in 42 articles, Our analysis observes four core themes that encapsulate the prevailing trends and focus areas in electromyography and electrical stimulation relative to interaction design in Table 2. In this table, the sum of the "Number of studies" is larger than the actual number of literature articles since some papers involve more than one design theme.

Table 2. Thematic analysis results of core design themes

Human-computer Interaction / Design involved	**Number of Studies**	**Detailed aspects**
Assistive technology and Tool design	18	- Smart wheelchairs [13] - Robot for daily hand tasks and rehabilitation [14], [26] - Toolbox for the muscle data analysis [15]
Gamified therapy	11	- Virtual reality training and Electromyographic biofeedback [43] - VR or AR motor imagery [44] - Serious game [29]
Wearable	12	- Electromyographic sensor placement [45] - Electrical stimulation patches [28], [42]
Interface design	14	- Facial expression classified [21] - Hand gesture controlling [37] - Brain computer interface [46]

Due to the necessity of wearing electromyographic sensors and electrical stimulation devices, a total of 7, 6, and 4 articles respectively discussed the interdisciplinary applications of wearable technology in Assistive Technology and Tool Design, Gamified Therapy, and Interface design. Furthermore, among the papers reviewed, four of them shared a common theme of Assistive Technology and Tool Design, along with Interface Design. Three studies involved both Gamified Therapy and Interface Design.

4. Discussion

We presented our research findings on a map (Figure 2) to more directly and systematically express the relationships and interactions between these EMG and ES applications, limitations, and core design themes. This mapping not only not only serves as a guide for future research and practice, but also highlights potential design opportunities. Meanwhile, It clearly points out which areas need to be further explored, which have particular constraints, and which areas have the potential for collaborating or combining.

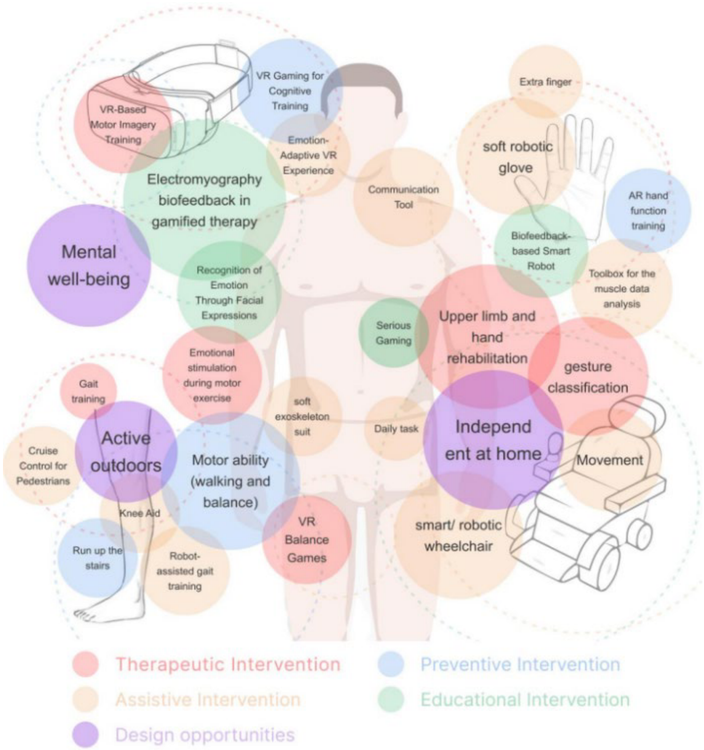

Figure 2. Mapping for review findings and design opportunities

Through our analysis and mapping, we identified four design intervention methods, Therapeutic Intervention (e.g. upper limb and hand rehabilitation; VR games), Assistive Intervention (e.g. robotic wheelchair and glove), Preventive Intervention (e.g. functional training for motor and cognitive) and Educational Intervention (e.g. serious game; EMG biofeedback).

4.1. Independent at Home

The focus of medical care has gradually shifted from the hospital setting to home assistance, training, and rehabilitation for the elderly. Aids such as gloves, wheelchairs, and rehabilitation robots have come to mediate the interaction between people and their living environments. In response to the independence of older adults at home, we propose a design recommendation that explores the potential of smart home technologies with EMG control interfaces.

We hypothesize that by using IoT technologies as the backbone of environmental interactions and integrating physicalized multimodal feedback through smart furniture, older adults can perceive real-time rehabilitation feedback in a real physical environment. Explore whether this approach can enhance the realism and engagement of training. In this, the older adult's EMG signals are captured and recognized by sensors for controlling the physicalized feedback, while an electrical stimulation kit is applied to provide the necessary muscle stimulation. Specifically, when the system detects that the activity of a muscle group has reached a predetermined target, the smart lights in the home may change color, or the music player may generate music with a different melody, a dynamic response of digital art, etc. In addition, the system will provide customized training and feedback content based on the individual's rehabilitation needs and progress. By integrating myoelectricity with IoT technology into smart home systems, we can better integrate rehabilitation into an ongoing living environment rather than viewing it as a daily task that needs to be done in isolation. Perhaps EMG information can also trigger adaptive changes within the home environment to help older adults better understand their physical condition while enriching their perception.

4.2. Active Outdoors

Recent studies have pointed out that the acquisition of EMG data is limited by the application scenario and the physical condition of the signal collector, such as different body shapes, movements, and sensor placement. Therefore, an essential research question at this stage is how to optimize the acquisition of EMG to adapt to different dynamic scenarios and differences in the human body. Perhaps the design of modular or flexible material EMG sensors that can adjust to different body shapes and movements or the use of machine learning algorithms to recognize an individual's physiological and dynamic characteristics... More efficient and sophisticated assistive devices and therapeutic systems can be developed with accurate and stable EMG signals to help older adults safely and energetically participate in outdoor activities, e.g., to prevent falls and train standing and balance.

Furthermore, Electrical Stimulation provides a non-visual feedback mechanism that can be used to convey specific information. For example, in outdoor environments, electrical stimulation can be used as a navigational aid for walking, providing immediate physical feedback to signal direction or obstacles. Timely postural adjustments can be made to prevent falls and other accidents in older adults.

4.3. Mental Well-Being

According to the concept of Healthy Ageing, the mental and social health of older people is an essential aspect that cannot be ignored. However, very few scoping studies have focused on participants' experiences during the intervention. Besides, there has been little involvement of older adult-related social relationships, such as patients' families and friends. This raises an important question: is there a need to pay more attention to the social relationships of older people, and would these communities contribute to therapeutic and social connectedness? Will these communities contribute to therapeutic and social relations? Will they enhance the psychological well-being of older adults?

To alleviate the helplessness and anxiety that older people may experience, How might we build a multiplayer digital platform that allows older people's family members and friends to provide support and encouragement by participating in shared virtual training and activities? By capturing and analyzing EMG data, we can provide each participant with a personalized training plan and real-time biofeedback to ensure that they receive appropriate guidance and support during training. The digital platform also supports participants in sharing their experiences and seeking professional advice and guidance from rehabilitators and doctors via telemedicine technology. This enables each participant to train in an open and safe environment. This multi-party assistance promotes the psychological well-being and social health of older adults.

5. Conclusion

This paper provides an overview of EMG and ES technologies' applications, shortcomings, design, and research objectives in aging-related health concerns. Through analyzing 42 selected articles, we identified six categories of applications and four core design themes of Electromyography and Electrical Stimulation technologies. We have articulated these insights into a map to better interpret our research questions. By emphasizing three interconnected aspects - ensuring home independence, fostering active outdoors, and nurturing mental well-being - EMG and ES technologies could potentially reshape the landscape of aging wellness.

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